DIGITAL’s home office and main manufacturing facilities are located in this former woolen mill complex in Maynard, Massachusetts. We have 900,000 square feet here, about 100 times more than when the company started producing digital modules eleven years ago. We also manufacture at three other locations.

Cover photograph courtesy of MACHINERY July 1968 issue.
### PART I
K SERIES SOLID STATE CONTROL MODULES

- **LOGIC MODULES**
  - K0XX to K3XX
- **INTERFACE MODULES**
  - K5XX and K6XX
- **ACCESSORIES AND HARDWARE**
- **ANALOG/DIGITAL MODULES**
- **BASIC APPLICATIONS**
- **ADVANCED APPLICATIONS**

### PART II
CONTROL AND DATA ACQUISITION SYSTEMS

- **SYSTEM DESIGN**
- **DIGITAL SYSTEMS**
- **SYSTEM COMPONENTS**
- **DEC PRODUCT SUMMARY**
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FOREWORD

This second edition of the DIGITAL Control Handbook is for anyone who specifies, designs, manufactures or uses electronic or mechanical logic for instrumentation and control. Here you will find a wealth of useful information on the latest techniques and products available for implementing faster, cheaper, more reliable solid state electronic control systems.

Featured in this edition is the greatly expanded K Series line of low cost logic and interfacing modules, designed especially to operate in the electrically noisy surroundings that are unavoidable around electrical machinery. Over thirty K Series applications notes are included to help you easily design custom systems from these easy-to-use modules. Here are presented designs for four kinds of sequencers, digital comparators, thumbwheel switch multiplexers, annunciators, shaft angle pickup logic, memories for preset codes or limits, and many more. In addition to the Applications section, there are also dozens of useful design notes to be found in product descriptions scattered through the book. They are accessible from the regular index at the back or by using the thumb index on page 1.

Also described in this edition are compatible analog/digital conversion modules, standard analog/digital conversion subsystems, and complete systems for data acquisition (INDAC), N/C tape preparation (Quickpoint) and gas chromatography (Gaschrome-8). This edition also contains information on a broad selection of the latest PDP computers and other equipment for control and data acquisition systems. The DIGITAL Control Handbook will let you take advantage of the latest advances in solid-state control equipment.

DIGITAL sales engineers in over forty offices around the world and our home office applications engineering staff are ready to help you put your control designs into action. They are all listed on the inside back cover. After you have scanned the book, give us a call.
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1. TRADEMARK, Superior Electric Company
2. TRADEMARK, United Shoe Machinery Corp.
INTRODUCTION

Control system complexity and demands on reliability are rising with ever-increasing automation. More and more, control system designers are looking to solid state electronics for new answers to the old problems of reliability, complexity, and economy. Some of the answers are provided by solid-state digital logic designed for the industrial environment, and solid state analog-digital conversion to link analog sensors and actuators to digital control.

Why Solid State?
The time-honored way to do control logic is with the deceptively simple-looking relay. The metal-to-metal contact area sees physical and chemical actions of remarkable complexity. Even the mechanical-magnetic interactions are involved enough to cause problems now and then. Still, relays sometimes respond beautifully to simple maintenance. If the contacts stick, force them apart; if they are dirty, clean them.

Railway signaling relays, operating perhaps a hundred times a day, accumulate 25 years and a million operations without failure. And modern sealed-contact relays can do 10 billion operations under the right conditions without wearing out. So why abandon well-proven, reliable components? Only because it is necessary. And it is necessary in a growing number of applications.

Reliability
As profit margins grow tighter, and maximum process efficiency becomes a necessity rather than an ideal, control system reliability assumes greater importance. Faulty operation and machine downtime can swiftly and disastrously cut into the profit picture. With a highly complex control system, check-out can easily become a very costly and time consuming operation. Many factors affect the reliability of a control system. A major consideration is the speed at which the logic control elements must operate. At 1KHz, near the maximum rate for dry reed delays, 100 million operations accumulate in about 30 hours. Longer-lived mercury-wetted contacts, operating 100 times per second, accumulate 10 billion operations in about four years. Even if a four year component life is enough, there are applications where 100 operations per second are not. Solid state logic, with nothing to wear out, stick, or corrode, can operate almost indefinitely at 100,000 operations per second.

Complexity is another factor. Demands for more automation, more efficiency, more safety, more accuracy all result in increased control system complexity. As a result, the sheer numbers of logical decisions demand component reliability far greater than that acceptable in a small system. Solid state logic provides the degree of reliability needed in a large system, at reasonable cost.

Size
Even the tiniest-contact reed relay coil is enormous alongside a transistor, or a complete integrated circuit. And most small control systems are not built with reed relays: to get the advantage of ruggedness or standardization, usually all the relays used are built to 300 volt or even 600 volt specifications whether they drive external loads or just relay coils. But a single small printed circuit board can easily accommodate a half dozen or more relay equivalents in logic capability, in a small fraction of the space of one 300 volt relay.
Computer Tie-In

There are several levels of computer involvement possible, extending from incorporation of a computer as a part of an individual control system to the use of a central computer to monitor the performance of many independent control systems. Regardless of the level at which the computer interacts, its presence demands an interface between solid-state circuitry and the controlled machine or process. If such an interface is forced into existence by the present or projected future use of a computer, why not put solid state control logic behind it and gain the benefits of solid state speed, compactness, and reliability through the entire system?

Also solid-state logic can communicate with existing analog sensors and actuators through solid-state analog-to-digital (A/D) and digital-to-analog (D/A) converters.

All of these factors tend to make solid state control systems increasingly attractive, particularly as their costs come down.

Who Should Be Designing For Solid State Controls?

Broadly speaking, the decision between conventional relay controls and the new solid state controls, like most engineering decisions, hinges on comparative overall costs. Where three or four or a half dozen relays can do the whole job, the cost of a solid-state interface will seldom be justified unless high speeds are required. Very large or computer-oriented systems leave little justification for the use of relays.

For intermediate systems, the comparison is more complicated. The tabulation below can serve as a framework for a systematic review of factors you should consider before you specify your next control system.

<table>
<thead>
<tr>
<th>Considerations</th>
<th>Factors Suggesting Relays</th>
<th>Factors Suggesting Solid State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>Control system failure causes no panic. Temporary manual control acceptable. Simple system, easy to troubleshoot.</td>
<td>Downtime cuts quickly into process profitability. Quick check-out of entire system in case of trouble desirable, instead of on-the-spot checking. Lives and property might be endangered by failure.</td>
</tr>
<tr>
<td>Cost</td>
<td>Low cost relays acceptable. Maintenance costs need not be considered. Personnel training costs important. System failures will not cause significant secondary costs.</td>
<td>High quality relays used for comparison. Costs of failure high. Installation space costly. Cost of future modifications must be considered. Maintenance costs over life could be important.</td>
</tr>
<tr>
<td>Complexity</td>
<td>Small systems, perhaps a half dozen relays or fewer.</td>
<td>Complicated systems, which would require fifteen or more relays to implement.</td>
</tr>
<tr>
<td>Sophistication</td>
<td>Traditional performance still acceptable.</td>
<td>New levels of performance are needed, calling for increased control system complexity to remain competitive.</td>
</tr>
</tbody>
</table>

2
<table>
<thead>
<tr>
<th>Considerations</th>
<th>Factors Suggesting Relays</th>
<th>Factors Suggesting Solid State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiarity</td>
<td>Controls that must be serviced by electricians who can not be retrained.</td>
<td>Environments already include other solid-state components or they will soon be added. Also, multi-system installations where a few controls technicians will cover a lot of equipment.</td>
</tr>
<tr>
<td>Growth</td>
<td>No foreseeable use of computers. Little likelihood of important modifications.</td>
<td>Added performance or safety features may be wanted later without tearing the system down. Computer tie-in might become desirable or is planned already.</td>
</tr>
<tr>
<td>Size</td>
<td>Plenty of space available.</td>
<td>Relay equipment might require separate balconies, restrict maintenance of machinery, or block aisles. Features added later must fit original enclosure.</td>
</tr>
<tr>
<td>Speed</td>
<td>Control system delays of tens of milliseconds acceptable. Operating rate is low, relay wearout no problem.</td>
<td>Compatibility with pulse tachometers, photoelectric pickups, electronic instruments required. Closed-loop stability demands quick response. High repetition rate that would cause wearout of moving parts.</td>
</tr>
</tbody>
</table>

**Why Digital?**

Relays, solenoids, switches, fuses, locks, counters, annunciators, panel lights and panic buttons all have one thing in common: they are digital. All these devices (when working properly) are up, down, on, off, in, out; but never in-between. Strictly speaking, of course, you cannot get from on to off without passing through in-between. But digital devices pass through in-between at maximum speed, and without waiting around for doubt to creep in.

Non-digital devices like panel meters, potentiometers, and slide rules work in the “in-between” area, producing outputs that are proportional to the input. The angular position of a panel meter pointer is the analog of the magnitude of the electrical input. A potentiometer’s voltage output is the analog of mechanical shaft position. In a slide rule, position is the analog of magnitude.

In a slide rule, accuracy is limited by the thickness of the calibrating marks and the difficulty of estimating values between them. Each space is an area of uncertainty. The same kind of uncertainty exists in every proportional electrical system, in the form of noise. In all but the most expensive analog equipment, the amount of noise, like slide rule error, limits accuracy to two or three significant figures.
Noise taken in this broad sense affects every proportional device. Noise is a major reason for the dominance of digital computers over analog computers where complex calculations are required. Small amounts of noise contributed by each analog input or computing element add up to degrade the accuracy of the answer. In digital circuits, the noise can be disregarded as long as it is below an “off” or “on” threshold level.

Analog controllers and servo systems, chart recorders, panel meters, and small analog computers are often simpler and cheaper than their digital equivalents, and should be used wherever they can do the job. But since so many commonly used control devices (from relays to panic buttons) are digital anyway, all-digital control is convenient. For complex control situations, digital methods can deliver accuracy and perform types of control beyond the ability of an analog system at any cost. And using solid state digital control, analog and digital devices can work together through A/D and D/A conversion. Better still, noise-free direct digital sensors and actuators can be used in the design of new process equipment.

**Noise Immune Control Modules**

Because of their high sensitivity and speed, solid state components can respond to noise that relays would safely ignore. To use solid state logic with freedom from noise problems in the neighborhood of arcing contacts, brushes, welders, etc. requires special design considerations.

Unlike analog devices, digital circuits have a noise “threshold” above which a noise or signal must rise to cause any change in the output of the circuit. It is this threshold that accounts for the superiority of digital circuits in processing information through complex manipulations without loss of accuracy.

In the design of solid state logic for industrial use, this basic threshold feature of digital circuits can be exploited. By adding external capacitance, the speed, and thus the sensitivity, of the circuit can be lowered.

**Noise**

Suppose that on the basis of the above, you find you should be using solid-state digital logic. But will the system “drop bits,” or otherwise go haywire in your environment? How well can noise trouble be anticipated, and what measures should be taken? How can you compare the noise immunity of competing manufacturers’ circuits? These questions need some kind of answer before you can feel confidence in taking the step.

A logical starting point is the noise itself. What is its amplitude? Its frequency distribution? How does it vary with time? With temperature? How many picofarads of coupling capacitance between the noise sources and the logic wiring? How many nanohenries of shared inductance in the logic and noise ground return paths?
Right away you suspect these questions are going to be difficult to answer. You may be able to say that typical noise source voltages are "measured in kilovolts" and are "strongest in the Megahertz frequencies." But going beyond such hazy estimates will require detailed knowledge of the physical conditions that interact to produce electrical noise. You'll need to know the materials used in all metal-to-metal contacts, and the condition of the contact surfaces. You'll need the inductance and capacitance of the wires connecting them. And the inductance and capacitance of the loads they drive. And the gases in the atmosphere surrounding the contacts. Even the exact routing of the wires will have to be examined.

Is solid-state out of the question after all, because analysing the noise environment is impractical? No, solid-state is not impractical: provided you use circuits designed specifically for noisy environments, where the focus is on qualitative rather than quantitative factors.

Engineering For the Unknown
Engineers prefer to deal in quantities: "how big," "how many," and "how much." Success in dealing with noise requires a different approach because very few if any accurate numbers about noise will be forthcoming. Qualitative considerations, those that affect the overall character of circuit behavior rather than specific numerical details, are central to this approach.

We can group the qualitative tools available for dealing with electrical noise into two groups: those that keep noise out of the solid-state logic, and those that minimize the influence of noise that gets in. Keeping noise out is cheaper than electrically rejecting it, since primarily mechanical and packaging considerations rather than electronic aspects are involved. Here are some of the ways you can keep noise out:

1. Segregate logic wiring from field wiring. Don't design input converters and output drivers so field wiring goes through the same connectors used to carry logic signals. Arrange to use opposite ends of printed boards for logic and field wiring connections, and never allow the two kinds of wiring to lie side-by-side or be bundled together.

2. Don't mix logic ground with field ground. This doesn't mean logic ground should float; on the contrary. But heavy currents should not pass through the logic ground system on their way back to a power supply. An excellent scheme is to switch the AC line with isolated triacs. DC solenoid drivers might seem difficult to isolate, but judicious use of ground isolating resistors and auxiliary chassis tiepoints can force most of the load current outside of the logic ground system.

3. Use high-density packaging. Computer type modular construction minimizes lead lengths in the logic, minimizing the capacitive coupling between logic wiring and nearby field wiring. Dense packing also cuts resistance and inductance in the logic grounding system, minimizing interference from any residual noise currents that may flow there.

4. Where logic and power circuits must be adjacent, use shielding. For example, a group of printed boards carrying field circuits can be shielded from general purpose logic modules simply by inserting un-etched copper clad boards in the sockets that separate the two groups. (Logic power must skip these sockets to avoid shorting the supply). A single ground connection to the shield board is perfectly adequate, since the noise currents it carries will be limited by the small capacitance involved.
5. Filter the line voltage where it enters the logic power supply, or at supply output terminals. Supplies for panel lamps should also be filtered, if their wiring approaches logic wiring. Do not use logic power for any other function or carry supply output wires into the field for any reason.

The above five measures may suffice to allow even fast, computer-speed logic to be used in the vicinity of severe noise. Often, however, some forgotten loophole in the noise exclusion plan will spoil the dependability of an otherwise noise-tight system. All it takes is one such leak to cause real headaches if the logic itself is sensitive to noise. A good belt-and-braces approach will include not only these noise isolation qualities, but several noise desensitizing qualities as well:

1. Slow speed of response. Noise is usually most intense at high frequencies (in the Megahertz). Metal-to-metal contacts are nearly ideal step generators, and wiring resonances often dictate high-frequency noise peaks. A circuit that can’t be switched for five microseconds is deaf to all but the biggest and slowest of noises, and usually will be entirely undisturbed. But be careful to use discrete capacitors, not sluggish semiconductors to obtain circuit slowdown. Semiconductor manufacturers “improve” their products regularly, often by increasing their speed.

2. Good current threshold and voltage thresholds. By “good” is meant “measured in milliamperes and volts.” The bigger the better, but guard against falling in love with numbers. A factor of two in voltage threshold means little if you can’t predict noise amplitudes to the nearest order of magnitude.

3. Risetime independence. Circuits that don’t care what risetime you feed them give you an important insurance policy. If all else fails, you can hang a capacitor to ground at any troublesome point, without worrying about the effect this has on risetime. Even more than the other qualities, risetime independence is a prime example of engineering for the unknown.

4. Special care in timer and flip-flop design. These are the circuits that stretch a noise spike to damaging length. A system that has noise-immune, risetime-independent flip-flops and timers will for most purposes be as noise immune with ultra-fast gates as with slow gates.

Looking Ahead
Many of the factors listed above cost nothing more than forethought. All are applicable regardless of choices between discrete components, integrated circuits, or a combination. As the qualitative approach to noise avoidance is more widely understood and applied, solid-state logic will become more accepted, more universal. Fears will disappear. Should your next control system be solid-state?
K SERIES
CONTROL MODULES

Computer-oriented logic, by its very nature, is high speed (1 MHz and above), and provides noise immunity far below that required in a process control environment. The upper frequency range of the K-Series modules is 100 KHz, with provision for reduction to 5 KHz for maximum noise immunity. These modules incorporate all silicon diodes, transistors, and integrated circuits, deliberately slowed.

Either English (non-inverting) logic or NAND/NOR logic is compatible with K Series. The hardware for this series is specifically designed for standard NEMA enclosures. FLIP CHIP™ mounting hardware can likewise be used for rack-mounting, inasmuch as K-Series modules fit standard DEC sockets.

Proven FLIP CHIP™ connectors, used for years in applications from steel mills to lathe controls, provide modularity. Even the connection between terminal strips and electronics can be plugged for installing the logic after field wiring is complete, and removing it quickly for modifications or additions.

Checkout and trouble shooting is easy with K-Series logic. Every system input and output has an indicator light at its screw terminal. A special test probe provides its own local illumination and built-in indication of transients, as well as steady states. Every point in the system is a test point, and consistent pin assignments reduce the need to consult prints.

Construction materials and methods are the same as for other high-production FLIP CHIP™ modules, including a computer-controlled operating test of each complete module. K-Series modules further offer the size reduction, reliability, flexibility, and low cost of solid state logic, with an added bonus of easy interconnection. FLIP CHIP™ industrial modules are ideal for interfacing high-speed M-series or computer-systems to machinery and processes. Sensing and output circuits operate at 120 vac for full electromechanical capability. Inputs from contact devices see a moderate reactive load to assure normal contact life. Solid state ac swiches are fully protected against false triggering. Voltages from the external environment are excluded from the wire-wrap connections within the logic.

K SERIES SPECIFICATIONS

SUMMARY

Frequency range: DC to 100 KHz. Control points on each module allow reduction to 5 KHz for maximum noise immunity for critical functions.

Signal levels: Ov and +5v, regardless of fanout used.

Fan-out: 15 ma available from all outputs; typical inputs 1-3 ma.

Waveforms: Trapezoidal. No fast transients to cause cross talk. External capacitive loading affects speed only; no risetime dependence.

Temperature range: −20°C to +65°C, using all-silicon diodes, transistors, and monolithic integrated circuits (0° to 150°F). (Limited to 0°C on four module types).
Noise immunity: False "1": 20 ma at 1.6v for 1.5 μsec typical. False "0": 3 ma at 3v for 1.5 μsec typical. Time thresholds can be increased by a factor of 20 for critical points by wiring the slowdown control pins.

Simple power requirements: Single voltage supply, +5v ±10%. Dissipation typically 120 mw per counting or shifting flip-flop, 30 mw per control flip-flop, 25 mw per two-stage diode gate.

Control system voltage: 120 VAC, 50 or 60 hertz.

Mounting provisions: Standard NEMA industrial enclosures. May also be used in 19" electronics cabinets.

**GENERAL SPECIFICATIONS**

**Construction Features**

K-Series modules include the quality features of older lines of FLIP CHIP modules: flame-resistant epoxy-glass laminates, all-silicon semiconductors, gold plated fingers and solid gold connector contacts. Thorough testing of each module is by computer operated automatic tester for most modules, or by specialized equipment for those which are not amenable to automatic test. A test specification sheet or data sheet is packaged with each module, including a circuit schematic for that type. Monolithic or hybrid integrated circuits are included wherever they can improve the performance-cost ratio. Versatile mounting hardware imposes as few physical constraints as practicable. Outline drawings below show nominal module dimensions.

**STANDARD MODULE SIZES**

**SINGLE-WIDTH FLIP CHIP MODULE**

**SINGLE-HEIGHT FLIP CHIP MODULE**
Logic Signals
There are no ultra-fast transients at any K Series output. Logic signal "1" and "0" levels are essentially independent of fanout. Rise and fall transitions have controlled slopes which are not strongly influenced by normal changes in fanout, lead length, temperature, or repetition rate. The fastest K Series trapezoidal logic signal can be fully analyzed with a 500KC oscilloscope. Logic "1" or "true" is +5 volts and logic "0" or "false" is zero volts except where redefined by logic designer. Counters and shift registers advance at the "1" to "0" transition and are cleared by a "0" level. Any unused input may be left open.

M Series Compatibility
M Series outputs can drive K Series logic gates and output converters K604 and K644 directly, and any K Series input after passing through a K Series gate, provided they meet timing requirements. See Applications Notes.
Fanout and Fanin

K Series fanout capabilities are sufficient to relegate fanout calculations to the final checking phases of logic design. Logic outputs from any module type can drive up to 15 milliamperes. Logic gate inputs consume 1 milliamper per input. Other loadings range from 1 to 4 milliamperes as indicated by the loading numbers enclosed in squares on each specification diagram.

Expandable gates give K Series a fanin capability well beyond typical logic requirements. The most restrictive fanin limitation in K Series logic concerns the wired AND configuration, for which several logic outputs are simply wired in common: the wired AND fanout capability is reduced to three milliamperes when the maximum of 5 outputs are tied together. The second level of logic (the OR node) within K113 and K123 gates is limited to less than 10 OR inputs to preserve output false time control. The input AND gates of K113 or K123 modules may be extended with K003 expanders up to a maximum of 100 inputs, well beyond any practical requirement.

Operating Temperature

K-Series modules are designed for operation in free-air ambient temperatures between \(-20^\circ C\) and \(+65^\circ C\) (\(0^\circ F\) to \(150^\circ F\)) except the following types which are restricted to \(0^\circ C\) (\(32^\circ F\)) minimum: K202, K210, K220, K230.

Speed

Many applications for K Series modules involve operation at rates lower than relay speeds. Even at speeds many times faster than relay capabilities, timing need not be considered unless the logic includes a "loop". A flip-flop constructed of logic gates is such a loop, in which the output at a given point feeds back to influence itself, thus demanding input durations longer than total loop delay. Proper operation of such loops should be verified by calculation using the specifications below. For a complex loop an experiment should be made if possible to look for flaws in the calculations.

When anticipated repetition rates will be of the same order of magnitude as rated logic frequency, more care is required in timing design. K Series circuits are intentionally slowed to the maximum extent practicable for 100 KHz operation, and the resulting propagation delays can limit complex logic systems to 50 KHz or even 30 KHz repetition rates. In addition, timing loops must be examined just as carefully in fast logic as in slow. If K Series speed appears marginal or insufficient for the job at hand, use M Series high speed logic modules.
## K-Series Timing

<table>
<thead>
<tr>
<th>Description</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Gate Propagation Delay, Output Rise (0V to +5V)</td>
<td>0.5</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Output D only, when connected to pin B</td>
<td>7.5</td>
<td>40</td>
<td>180</td>
</tr>
<tr>
<td>Logic Gate Propagation Delay, Output Fall (+5V to 0V)</td>
<td>0.3</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Output D only, when connected to Pin B</td>
<td>4.5</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Count/Shift Input Propagation Delay, Output Rise</td>
<td>2.0</td>
<td>5.0</td>
<td>9.0</td>
</tr>
<tr>
<td>As above, but pin B grounded to pin C</td>
<td>10</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Count/Shift Input Propagation Delay, Output Fall</td>
<td>1.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>As above, but pin B grounded to Pin C</td>
<td>10</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Rise time, all unslowed outputs</td>
<td>2.0</td>
<td>5.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Pin D outputs only, when connected to pin B</td>
<td>30</td>
<td>100</td>
<td>240</td>
</tr>
<tr>
<td>Fall time, all unslowed outputs</td>
<td>0.5</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Pin D outputs only, when connected to pin B</td>
<td>7.5</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>Minimum time between successive input transitions on any module which has one or more Count/Shift inputs</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As above, but pin B grounded to pin C</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exceptions:
Input transitions at pins J and K may follow other input transitions with delays down to zero; For characteristics not listed above, see timing information on individual data pages.

**NOTE:** Count Shift inputs are included in types K202, K210, K220 and K230

### Noise Immunity

Two properties of electrical interference often overlooked in evaluating logic noise immunity are its source impedance and its frequency distribution. Unless the digital logic is spread over several feet or yards so that high potentials can be induced in the ground system, most noise will be injected via very small stray capacitances and hence will have a high source impedance. The voltages at the noise source itself are usually measured in thousands of volts. Consequently, voltage thresholds alone cannot provide adequate noise rejection. The noise appears to come from a current source, so that logic circuit current thresholds are also an important measure of noise immunity.

Capacitance-coupled interference is strongest at the highest frequencies. Logic circuits which respond slowly can reject high frequency interference peaks that exceed dc current and voltage thresholds. K Series modules get their outstanding noise immunity from a balanced combination of current, voltage, and time thresholds.

Important as good noise thresholds are, practical noise environments are only vaguely predictable, so that the following design features are probably still more important:
1. All field wiring is isolated from K Series logic wiring pins.

2. Logic power is not transmitted outside the logic environment for contact sensing, etc.

3. W994 electrostatic shields may be plugged in to further isolate pilot circuit noise: see Construction Recommendations (first Applications Note)

4. Plug-in module compactness keeps logic wiring short, to reduce noise injection capacitance, and confines the ground mesh for reduced ground noise.

5. Every third logic gate has optional slowdown control, ample for slowdown of all control flip-flops.

6. If all else fails, lack of risetime dependence permits any K Series output to be loaded with 0.01 mfd to ground to further reduce impedance and speed of response. Each K003 diode expander has such a capacitor available at pin B.

**K Series Typical Noise Thresholds**

To be falsely interpreted as a high level, a low (zero volts) K Series logic level would have to be raised 1.6 volts and held there for 1.5 microseconds; to do this would require 20 milliamperes to be supplied somehow from the noise source to the K Series output in question for this period of time. To be falsely interpreted as a low level, a high (+5V) K Series logic level would have to be reduced 3 volts and held there for 1.5 microseconds; to do this would require 3 milliamperes to be supplied somehow from the noise source to the K Series output in question for this period of time.

**Power Requirements**

A simple 5 volt supply operates any K Series system. Tolerance at room temperature: ±10%. K Series regulators K731 and K732 have a built-in temperature coefficient of approximately minus 1% for 3°C(5°F) to obtain full logic fanout over a wide temperature range and to minimize the temperature coefficient of K303 timers. Both regulators run from a nominal 12.6 volt center-tapped transformer secondary, with hash removed. See Construction Recommendations for information about alternate sources of logic power. Logic power is not used for contact sensing; 120 VAC is specified to provide full compatibility with silver contacts and noisy environments.
K SERIES LOGIC SYMBOLS

Symbols used in K Series diagrams are based on standard IC1-1965-15B for industrial controls issued by the National Electrical Manufacturers' Association ("NEMA"). For those not familiar with this standard, the basic symbols are defined below, along with equivalent symbols from U.S. Military Standard Mil STD-806B. K Series modules are designed to allow a logical "1" to be identified with the positive voltage level, and logical "0" with zero volts. The diagrams shown below follow this convention. Notice that except for timers, the two symbol standards are one-for-one interchangeable. For relay logic symbol conversion, see second Applications Note.

<table>
<thead>
<tr>
<th>K-SERIES SYMBOL</th>
<th>LOGIC FUNCTION</th>
<th>MIL SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AND</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="AND Symbol" /></td>
<td><img src="image" alt="AND Truth Table" /></td>
<td><img src="image" alt="AND MIL Symbol" /></td>
</tr>
<tr>
<td><strong>OR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="OR Symbol" /></td>
<td><img src="image" alt="OR Truth Table" /></td>
<td><img src="image" alt="OR MIL Symbol" /></td>
</tr>
<tr>
<td><strong>NOT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="NOT Symbol" /></td>
<td><img src="image" alt="NOT Truth Table" /></td>
<td><img src="image" alt="NOT MIL Symbol" /></td>
</tr>
</tbody>
</table>

**NOTE:** OVERBAR MEANS NEGATION IF A IS FALSE. \( \overline{A} \) IS TRUE AND VICE-VERSA.
These inexpensive gate expanders offer great logic flexibility and versatility without a proliferation of module types. Logic functions performed by expanders are illustrated in combination with the K113 and K123 gates in several pages that follow the data sheet for the gates themselves.

K003 — $4
K012 — $7
K026 — $6
Together with the K003, K012 or K026 expanders, these gates perform any desired logic function, including AND, OR, AND/OR, NAND, NOR, exclusive OR, and wired AND.

Logic gate type K123 is an AND/OR non-inverting gate subject to expansion at either the AND or the OR node. Logic symbols and equivalents schematics are compared in the following illustrations. Typical pin connections are shown.

The AND input can be expanded up to 100 inputs total. The OR input can be expanded by any of the expanders, up to 9 inputs total. More OR inputs can be added if faster fall times are acceptable.

Expansion of the K113 inverting gate is identical. The equivalent circuit is the same except for inversion in the output amplifier.

Both gate types include a slowdown capacitor that can be connected to the output of one circuit to increase its noise rejection when gates are interconnected to make control flip-flops. Use of this capacitor increases rise and fall time by approximately a factor of 20.

K113 — $11
K123 — $12
The basic types of logic function obtainable by expansion are shown below for the K123 non-inverting gate. Logic functions for the expanded K113 inverting gate are identical except for inversion of the output. Letters refer to logic signal names rather than module pin numbers.

**BASIC NON-INVERTING GATE**

**AND/OR EXPANSION COMBINATIONS**

**UP TO 9 AND GATES**

**AND EXPANSION**

**UP TO 100 INPUTS**

**UP TO 100 AND INPUTS**

**OR EXPANSION**

**LOGIC FUNCTIONS WITH GATE EXPANSION**
NAND, NOR, EXCLUSIVE OR

The K113 inverting gate performs the NAND function directly, and performs the NOR function when combined with a K003 expander.

With proper input connections and a K003 expander, the K123 non-inverting gate performs the exclusive OR function.

NAND FUNCTION OF BASIC INVERTING GATE

NOR FUNCTION OF BASIC INVERTING GATE WITH EXPANDER

EXCLUSIVE OR CONNECTION OF BASIC NON-INVERTING GATE WITH EXPANDER
WIRED AND

Wired AND functions can be obtained by connecting K123 outputs to other K123 or K113 outputs as shown below.

WIRED AND EXAMPLES

SUMMARY OF GATE-EXPANDER LOGIC COMBINATIONS

<table>
<thead>
<tr>
<th>FOR ZERO VOLTS DEFINED AS LOGIC ZERO standard definition</th>
<th>FOR ZERO VOLTS DEFINED AS LOGIC ONE (inverted definition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Function</td>
<td>No. of Inputs</td>
</tr>
<tr>
<td>AND</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6-8</td>
</tr>
<tr>
<td>OR</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6-9</td>
</tr>
<tr>
<td>NAND</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6-8</td>
</tr>
<tr>
<td>NOR</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6-9</td>
</tr>
</tbody>
</table>
CONTROL FLIP-FLOPS FROM GATES

Control flip-flops can be formed by interconnection of gates as shown below.

NON-INVERTING GATE CONTROL FLIP-FLOP

The output of the flip-flop above is set to a ONE when the two SET inputs are both ONES. A ZERO at the RESET input returns the output to ZERO, provided at least one of the SET inputs is also ZERO.

INVERTING GATE CONTROL FLIP-FLOP

The flip-flop above, made from two inverting gates, provides complementary 1 and 0 outputs. A truth table is shown below.

TRUTH TABLE

<table>
<thead>
<tr>
<th>SET</th>
<th>RESET</th>
<th>1 OUTPUT</th>
<th>0 OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>NO CHANGE</td>
<td></td>
</tr>
</tbody>
</table>
Four flip-flop functional modules such as K210, K220, K230 can conveniently be augmented by a K134 to get “0” as well as “1” outputs. The K134 is also provided with expansion and inhibit inputs for use as the readout element of read-only memories using K281 diode memories (See Applications Notes). A common input at pin K can force all four outputs high, a helpful feature for building large K281 memories or very large K161 decoders.

K134 inverters may also be AND expanded by K003 gate expanders, providing an efficient way to obtain 4-input NAND or inverted NOR gates.
Three-bit binary numbers input to the K161 will be decoded into eight one-at-a-time outputs. Both inputs and outputs are high for assertion. The inhibit input allows BCD to ten line decoders to be built up, or permits several decoders to be interconnected for sixteen, twenty four, thirty two outputs, etc. Inhibit input may be left open if unused, even though high is the inhibit state.

Standard K Series slowdown circuits on each output minimize and for most purposes nullify the splinter pulses that all decoders emit during input transitions. Additional slowdown available on the zero output can usually suppress the larger splinter that may occur there. But since splinter size is ultimately determined by input timing tolerances, it is cleanest to avoid logic designs in which a decoder output is used as a source of pulses.

The diagrams below show how to connect decoders for 8, 10, 16 and 32 outputs. Much larger decoders are possible, and in fact up to 256 outputs or even more can be obtained by inhibiting all but one of several decoders.
32 STATE DECODER
Numerical comparisons such as those required in digital positioning controls are facilitated by the K174. Performing the same function as the comparator in closed-loop analog systems, the K174 tells which of two quantities is larger.

Fundamentally, the K174 performs a subtraction to determine whether a "borrow" would be needed to obtain a positive result. The magnitude of the difference is not available; only the sign.

If more than four bits are to be compared, several comparators may be cascaded as shown below. Note use of K003 as if expanding an "OR" to control the state of the output for the case of equal input numbers.

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**K174 DIGITAL COMPARATOR**

**TWO DIGIT COMPARISON OF THUMBWHEELS AGAINST K210, ETC.**

---

K174 — $18
The K174 can also be used to obtain three independent outputs for full greater-than, equal-to, less-than capability. The application below takes advantage of the fact that if A is equal to B, K will go high if J goes high and K will go low if J goes low. By inverting the output at pin K and feeding it back into pin J, the K174 will oscillate if A = B. If the timers are adjusted for a delay longer than the period of oscillation, the three possible output states can be obtained. (High for assertion). With the values shown, the frequency will be approximately 50 KHz. Outputs respond to new conditions in 100 µsec.
If the four outputs of K210 counter are wired to K184 "F" inputs, and a four bit binary fraction presented in reverse order to the corresponding "G" inputs, a pulse train is emitted at an average rate equal to the product of the K210 input rate and the binary fraction. Each transition from "0" to "1" at an FF input produces a 5 μsec output pulse to ground, if the corresponding "G" input has been high for 5 microseconds or more. Inputs are not rise-time sensitive. Outputs from several rate multipliers may be combined to give any desired precision.

Rate multipliers are primarily useful in numerical control applications, such as those described in the following magazine articles:

"Linear Interpolation" Control Engineering, June '64, p. 79
"Curvilinear Interpolation" Control Engineering, April '68, p. 81
"Many Digital Functions Can Be Generated With A Rate Multiplier" Electronic Design, Feb. 1, '68, p. 82.

In addition, the K184 can provide several other useful functions that take advantage of its internal complexities, shown below. Examples of both classes of use can be found among the applications notes.
K202 flip-flops do shifting, complementing, counting, and other function beyond the capabilities of simple set-reset flip-flops built up from logic gates. They also may be used to extend K210 counters or K230 shift registers.

When the output of the STEP gate falls from high to low, the information at the OR input (pins D-J, L-P) is transferred into the flip-flop. Pin J (or P) is ORed with the pin D (or L) input. Like pins J and P of a logic gate, these pins can be driven only from a K003, K012 or K026 expander.

Time is required for flip-flops and delayed inputs to adjust to new signals. The STEP gate output must not fall to zero sooner than 4 µsec after its own rise, the end of a CLR signal, or a change on associated SET input pins.

A K202 flip-flop is cleared by grounding the CLR input pin. The flip-flop is held in the zero state as long as the clear input is zero volts, regardless of other inputs.

When using a K202 flip-flop to extend the length of a K230 shift register, pins B on both modules must be left open (unslowed). Pin B slows the step inputs of the K202 for complementing correctly at slow speeds in very noisy surroundings; but the data inputs are not affected by pin B.
Complementing: Below is shown a complementing application. Here the information stored at the SET input is the opposite of the flip-flop’s present state. Each time the STEP gate output changes from “1” to “0”, the opposite of the current state is read in.

K202 COMPLEMENTING

Shift Register: The diagram below shows two flip-flops connected as a two-stage shift register. At each step the incoming signal, whether high or low, is set into the first stage of the register, and the original content of the first stage is set into the second stage. The input to each flip-flop must be stable for at least 4 microseconds before another shift pulse occurs, for reliable shifting.

K202 2-STAGE SHIFT REGISTER

Note: In older systems of logic, most flip-flop functions had to be performed by general-purpose flip-flops like the K202. The K Series, however, includes functional types K210, K220, and K230 which are both less expensive and easier to use than the K202 for most applications. Think of the K202 primarily as a complementing control flip-flop and register extender.
The four set-reset flip-flops in the K206 are arranged for convenient addressing from the outputs of a K161 Binary to Octal Decoder. The flip-flop outputs can then be wired to control and maintain the state of corresponding output drivers, providing addressable output conditioning from teletypes, computers, or fixed-memory sequence controllers.

In addition, the same decoder may be used to address a particular K578 input sampler by grounding the K206 enable input when flip-flop changes are not desired. Pin E enable fanin on the K206 is reduced to 2 milliamperes when K161 addressing is used.

Since most control systems have about half as many digital outputs as inputs, it is convenient to use the least significant bit of the K161 address to determine which flip-flop state is wanted. Odd addresses allow for setting; even addresses, resetting. All flip-flops may be reset together by grounding the clear input, pin K.
Checking the appearance of board contacts being gold-plated. Our 100-micro-inch plating is verified by periodic checking on a radiation gauge.
The K210 is a binary or BCD counter that can be wired to return to zero after any number of input cycles from 2 to 16. Count-up occurs when the COUNT gate output steps to zero. Decimal counting logic is built in; when pin D is unused, the counter resets to zero on the next count after nine. When pin D is grounded, the counter overflows to zero, after a count of 15. (Pin D is not intended for dynamic switching between binary and BCD counting.)

The counter is reset by grounding the CLR input for 4 microseconds or more. A positive level at the J input from a K003 expander also resets the counter for counts other than 10 or 16.

Wire the K003 as a decoder to detect one count less than the desired modulus. (Detect 5 for a count-of-6 counter, etc.)

For counts above 10, ground pin D. Combine two K003 expanders as shown below, where three counter outputs must be sensed (to divide by 12, 14, or 15).
K210 CONNECTED FOR COUNT OF 15

Time is required for flip-flops and pin J reset logic to adjust to new inputs. The count gate output must not step to zero sooner than 4.0 μsec after its own rise, a change at pin J, or the end of a clearing signal at pin K.

Larger counters are obtained by cascading K210’s or adding K202 flip-flops. To cascade K210 modules, wire the most significant output of one counter to the input gate of the next. Inputs to the least significant stage can be either pulses or logic transitions to ground; risetime is not important.

Any transducer such as a switch, photocell, pulse tachometer, thermistor probe, or others compatible with K508 or K524 input converters can generate the signal which is to be counted. The lack of input risetime restrictions may allow transducer outputs to drive K210 counters directly if damaging transients can be avoided, as when the transducer shares the logic system environment.

For visual readout of binary-coded decimal counters, the four outputs from each K210 may be connected to corresponding input pins on a K671 decoding driver and display.

K210 AUGMENTED WITH K202 FOR COUNT OF 32
Four flip-flops and all the gates needed for binary-coded decimal up counting, down counting, presetting, and clearing are built into the K220. Up-down counters are useful for many digital position readout and feedback applications.

The direction of counting is established by the signal at pin L, high for up counting and low for down counting. Pin L count direction changes should finish no later than 4.0 μsec before next count input.

When K220 counters are cascaded, a single connection from the “8” output of one K220 to the count input gate of the next establishes both carry and borrow propagation.
Up-counts occur when input makes the transition from high to low (±5 v to 0 v), as in K210 and K230. Down-counts, however, take place on the transition from low to high (0 v to ±5 v). Thus both carry and borrow signals propagate via the simple connection from 8-weight output to 10-weight input.

ONES present at readin gate pins U,S,P, or M are read into the respective flip-flops when pin D makes the transitions from low to high. The transition at pin D should finish not later than 4.0 µsec before next count input. Transition from low to high at pin D should also begin no sooner than 4.0 µsec after any previous transition at pins D,M,P,S, or U. Ground any unused readin gate inputs to prevent readin of undesired ONEs.

Grounding pin J or K forces all flip-flops to zero for as long as either clear input remains low.

Time is required for flip-flops, counting logic, or readin gates to adjust to new inputs. Except clear inputs, no counter input may be changed within 4 µsec of a transition at any other input. (Refers to logical output of count gate). When pin B is grounded for slowdown, allow 50 µsec.

All connections are made on the upper connector, except two: binary Up/Down counting may be obtained by grounding pins D and E on lower connector.

Below is shown a means for accepting up and down pulse-trains from two separate sources. For this application input pulse spacing should be at least 20 µsec and input pulse width should be at least 10 µsec.
Information presented to pin L of this four stage flip-flop register is shifted toward pin V with each transition from “1” to “0” at the shift input gate.

ONES present at readin gate input pins M,P,S, or U are read into the respective flip-flops when pin D makes the transition from low to high. The pin D transition should finish no later than 4.0 \( \mu \)sec before the next count input. Transition from low to high at pin D should also begin no sooner than 4.0 \( \mu \)sec after any previous transition at pins D,M,P,S, or U. Ground any unused readin gate inputs to prevent readin of undesired ONES.

Grounding pin J or K forces all flip-flops to zero for as long as either clear input remains low.

Shift registers up to 20 bits long can be formed by tying pin V of one K230 to pin L of the next, and operating all shift gates together. Supply all shift pulses from the same device to maintain synchronism. The propagation delay of even one gate is too large a difference between two shift inputs on the same register. If more than 20 bits are required, duplicate the shift-generating logic and tie the outputs in parallel to all K230 shift gate inputs.

Time is required for flip-flops, shifting logic or readin gates to adjust to new inputs. Except clear inputs, no register input may be changed within 4 \( \mu \)sec after a transition at any other input. (Refers to logical output of shift gate). When pin B is grounded for slowdown, allow 50 \( \mu \)sec.

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K230 — $36
Three magnetically latched mercury wetted contact relays in the K273 follow logic-level input information at rates up to 100 Hz, when pin E is grounded. Normally the OK Level output from a K731 source module drives pin E. When a line voltage failure is detected, pin E rises and each relay mechanically stores the last valid input data until full power returns.

K273 — $72

The K281 is designed to be used with the K161 (Binary to Octal Decoder), the K681 (8-30 ma drivers) and the K134 (4 inverters), to build a read-only memory. Each K281 initially contains eight four bit words consisting of only “1’s”. The user selects the codes he desires by cutting out diodes in the bit positions that are to be “0’s”. Additional K281 and K134 modules may be added to the system to generate more words and longer words. See Applications Notes for diagram of memory configuration.

K281 — $8
K303 timers provide time delays from 10 microseconds to 30 seconds and can be interconnected to form clocks with periods covering the same intervals. Fixed or adjustable delays and frequencies are obtainable. Calibrated controls are available (K371 through K378) for mounting directly on the K303. Remote controls can be added, if desired. A simplified schematic of the K303 is shown below. Note that the comparator has hysteresis, increasing the rejection of false "1" noise peaks at the input.
When a K303 input gate steps to zero, the uninverted output falls after a controlled interval, while the inverted output rises. The interval can be as little as 10 μsec or as long as 30 seconds, depending on the size of the R and C connected to pin J,P, or V. Recovery begins when the input gate rises to 1. Allow recovery time of at least 0.3% of the maximum delay obtainable from the capacitor, in order to guarantee 95% repeat accuracy in the delay.

A positive step at the input gate resets the K303 timer outputs. If the step occurs before a timeout is complete, the timeout is terminated and no change appears at the outputs. This property is sometimes convenient for establishing a pulse repetition rate threshold (Frequency Setpoint).

A built-in 2.2 nanofarad timing capacitor assures adequate noise rejection when external capacitors are mounted several inches from the timer. Time threshold for resetting is always several percent of rated recovery time, so that noise rejection time increases in proportion to the size of the timing capacitor. Remote rheostats and timing capacitors may be used, but noise rejection will be degraded. If several timing capacitors will be switch selected, wire in the smallest near the module and switch the others in parallel with it.

Variable or fixed timing resistors used with K303 timers may be any carbon composition, film, or wirewound rheostat or potentiometer. Delay time is linearly proportioned to resistance from 250kΩ down to a few thousand ohms, falling to zero (reset inhibited) below a few hundred ohms. Momentary shorting to ground of control pins will not cause damage, but a padding resistor of at least 300Ω in series with variable controls is advisable both to prevent continuous grounding and to avoid confusion which may arise if resetting is inhibited.

Timing capacitors may be any ordinary mica, paper, ceramic, or low leakage electrolytic type. For delays above a few seconds, wet slug tantalum electrolytic capacitors are advisable to avoid leakage induced drift at high temperatures. Temperature coefficient of delay has been optimized for the carbon composition potentiometers and tantalum electrolytic capacitors used in the controls described below, and is typically less than ±1% in 5°C (9°F) using K731 and K732 regulators for power.

K303 — $27
Calibrated controls for timers and clocks are available in several ranges. They mount to the K303 module by two screws per circuit, providing both mechanical and electrical connections. Each control includes a logarithmic potentiometer for easy settling over the full 30:1 calibrated range. Calibrations are approximate, meant for quick setup and easy control identification. Accurate time settings require the use of an oscilloscope, stopwatch, or other reliable time standard. These controls are intended for use at the end of K941 mounting bars; see Construction Recommendations (first note in Applications Section).

Note: Time delay jitter is proportional to supply voltage ripple if times of the order of 1 msec are selected. For critical applications, use light loading on separate K731 or use H710 supply.
TIMER K303

Two K303 sections can be interconnected to make a free-running oscillator if one of the timing capacitors is about 100 times smaller than the other. The circuit with the larger capacitor will predominantly control the frequency. The diagram below shows the interconnections.

2/3 K303 AS CLOCK BELOW 1 KHz

The 100 to 1 ratio of timing capacitors required limits this method to frequencies to 1 KHz or less, due to the 2.2 nanofarad capacitor built into each circuit. Three K303 circuits may be connected together for higher frequencies, as shown on next page.
3/3 K303 AS CLOCK ABOVE 500 Hz

Longer delays than 30 seconds using large electrolytic capacitors would suffer from increased drift due to capacitor leakage. Moreover, there are some applications in which moisture and contamination cannot reliably be excluded from the electronics environment, making 250KΩ timing resistance impractical due to leakage along board surfaces. For either situation, two techniques are available: either cascade several timer circuits, or combine a clock-connected K303 with one or more K210 counters. The clock may be gated off at an unused input to avoid synchronizing errors. The diagram below shows both techniques combined, using one K210 and all three sections of a K303 to obtain a 22 minute delay.
TIMER FOR UP TO 22 MINUTES

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**ACCESSORIES CONTAINING ELECTRONICS**

On the following pages is a broad selection of interface modules. To help you get acquainted with the range of capabilities they offer, here is a summary table. Grouping by type of use to aid selection is not rigid. Maximum compatibility has been preserved to permit any combination of modules to be put together in the same system.

<table>
<thead>
<tr>
<th>Logic-to-Interface Connection and Type of Use</th>
<th>Module Type</th>
<th>Compatible Accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K716 Interface Block</td>
</tr>
<tr>
<td>Integral 30” Flat cable connector. For small controls with heavy-duty field wiring</td>
<td>120 VAC input: K508 120/240 VAC output: K604 Transducer input: K524 2.5 Ampere DC Driver: K644</td>
<td>X</td>
</tr>
<tr>
<td>Integral Terminals for larger systems</td>
<td>120 VAC input: K578 120/240 VAC output: K614. 250 Volt DC Driver: K656</td>
<td>X</td>
</tr>
<tr>
<td>Solder Lugs with strain relief. For indicators, control panels, and nearby transducers</td>
<td>Transducer Input: K522 Dry circuit switch filter: K580 Inverted switch filter: K581 Low power indicator driver: K681 Indicator/Relay driver: K683</td>
<td>X</td>
</tr>
<tr>
<td>Integral 12” flat cable with NIXIE® tubes</td>
<td>Decimal Display: K671</td>
<td></td>
</tr>
</tbody>
</table>

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K303 WITH K373 AND K378

SMALL K-SERIES CONTROL INSTALLED IN NEMA 12 ENCLOSURE.
The K508 AC input converter, operating through the K716 interface block, is designed for use with ordinary silver contacts in limit switches, pressure switches, pushbuttons and the like. Each input terminal presents a reactive load of 1 volt-ampere, which together with an external 120 volt AC pilot circuit voltage inhibits contamination buildup at the contact surface.

Electrical noise riding on pilot circuit wiring is attenuated in the input transformers and by hash filters at the K508 module. Contact bounce filtering is designed to respond to the first signal, and to leave the logic output in the "1" state in spite of skips lasting up to 100 milliseconds.

K508 output circuits have hysteresis, so that no intermediate output state can result from an ill-defined input condition. No separate Schmitt-triggers are required. Outputs are at ground for no input, at +5 volts when energized. All connections use upper connector.
The K522 Sensor Converter can take signals from photocells, thermistors, and other variable-resistance sensors and convert them to logic levels. Its built-in $\pm 2.2$ volt reference, programmable hysteresis, and noise cancelling ability make it simple to use. The K522 does not, however, provide the tolerance to high level noise or accidental application of line voltage which is obtainable from the K524. The table below should help in deciding between the two types.

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>K522</th>
<th>K524</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of circuits</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Module size</td>
<td>single</td>
<td>double</td>
</tr>
<tr>
<td>Input connections</td>
<td>solder lugs</td>
<td>cable connector</td>
</tr>
<tr>
<td>Inputs accessible at module connector</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>DC differential mode possible</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Provision for adding transducer biasing trimpots in predrilled holes on board</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Noise cancellation range (common mode)</td>
<td>$\pm 1$ volt</td>
<td>$\pm 7.5$ volts</td>
</tr>
<tr>
<td>Maximum $+$ input range for correct output</td>
<td>0 to $+5$V</td>
<td>$\pm 30$V</td>
</tr>
<tr>
<td>Tolerance to overvoltage (no damage)</td>
<td>$\pm 3$ volts</td>
<td>140 VAC</td>
</tr>
<tr>
<td>Minimum hysteresis (deadband)</td>
<td>10mv</td>
<td>10mv</td>
</tr>
<tr>
<td>Maximum hysteresis</td>
<td>160mv</td>
<td>10mv</td>
</tr>
<tr>
<td>Maximum switching rate</td>
<td>50KHz</td>
<td>25KHz</td>
</tr>
<tr>
<td>Minimum transducer resistance (at threshold)</td>
<td>400Ω</td>
<td>400Ω</td>
</tr>
<tr>
<td>Maximum transducer resistance (at threshold)</td>
<td>20KΩ</td>
<td>100KΩ</td>
</tr>
<tr>
<td>Noise Cancellation ratio at Line Frequency (CMR)</td>
<td>10:1</td>
<td>10:1</td>
</tr>
<tr>
<td>Noise Cancellation ratio at 1 KHz</td>
<td>20:1</td>
<td>20:1</td>
</tr>
<tr>
<td>Temperature Coefficient of Threshold (typical)</td>
<td>±1mv/°C (0.1%)</td>
<td>±1mv/°C (0.1%)</td>
</tr>
</tbody>
</table>

Note: Outputs are high when + input is high.

In general, the K522 is suited to laboratory and light machinery use where transducers are nearby and there is little danger of high voltage being applied to them accidentally. This is especially important when low resistance transducers are used with board mounted trimpots, since the trimpot provides a path from the transducer leads back to the logic supply. (If high voltage such as 120 VAC) were to get to the logic supply, all modules in the system would be destroyed.

Below is a table of pin connections for programming the hysteresis of each circuit. Applications diagrams may be found after the K524 data.

<table>
<thead>
<tr>
<th>Value when wired to converter output</th>
<th>10mv</th>
<th>20mv</th>
<th>40mv</th>
<th>80mv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit 1</td>
<td>E</td>
<td>F</td>
<td>H</td>
<td>J</td>
</tr>
<tr>
<td>Circuit 2</td>
<td>L</td>
<td>M</td>
<td>N</td>
<td>P</td>
</tr>
</tbody>
</table>

Table of Hysteresis Programming Pins

K522 — $22
Basically a noise-rejecting, threshold sensing differential voltage amplifier, the K524 is readily adapted to sensing threshold points in DC analog signals, AC signals, and pulses. It can also be biased to sense resistance thresholds. The differential amplifying technique permits flexible grounding and shielding methods to accommodate floating signal generators and minimize noise.

The K524 Sensor Converter senses voltage transitions or resistance thresholds by noise-rejecting differential amplification. A choice of AC or DC coupling is provided.

Output transitions occur when input voltage differentials are within 0.3 volts or less. When the "+" input is more positive, the output is a ONE. When the "+" input is more negative, the output is a ZERO.

K524 — $98
The diagram above shows how a sensor located a few feet from a K522 can be connected by a simple twisted pair of wires if the environmental noise is not too severe. Differences in potential between logic ground and chassis ground at the sensor are not likely to exceed ±1 volt in such a case, so the noise cancellation ability of the K522 circuit would be adequate to maintain a consistent threshold. As the built-in reference in the K522 is half the voltage on the trimpot, the switching threshold is half the voltage on the trimpot; the switching threshold will be near equality between sensor and trimming resistances.

If the sensor is ungrounded, a ground return must be provided at the module by tying pin T and/or pin V to ground. The simplified equivalent circuit below shows the AC coupling capacitor which makes this necessary.

The K522 can also be used with a self-generating sensor such as a tachometer pickup, just as the K524 can. (See below.)

**K524 APPLICATIONS**

Below is shown a K524 circuit used in the same application as the K522 above, but where longer sensor leads and hence more noise is expected.
Switching occurs at equality between sensor and biasing resistance when +5 volts is used for bias. Pin BB (pin B on lower connector) must be connected to an independent bias supply, such as a separate K731 operated from a separate transformer, to insure gain damage currents through the bias circuits to the logic in case of accidental high voltages at K524 inputs. This precaution is most essential in systems containing K604 or K644 output converters, since inadvertent use of the wrong K716 socket is possible. This problem does not arise with self-generating sensors or where bias is supplied externally to variable-resistance sensors.

Since low-frequency noise injected by the chassis ground connection goes directly to the − input but is attenuated by the bias network at the + input, some loss of noise rejection will result. One way to restore full rejection would be to return the bias supply itself to the same noise source. If a K731 is used, this means both its transformer winding center-tap and its pin C connections must be connected to ground only at the point where the cable is grounded.

Because of the more complex input network in the K524, allowing true DC differential operation if desired, one additional connection is required. The simplified schematic below shows that the inverting input to the internal comparator must be connected either to the DC-coupled or to the AC-coupled input attenuator via the module connector pins.
Below is shown another way to use the K524, this time with a self-generating transducer.

Here is a table showing the auxiliary pin connections on the lower module connector for the various applications of the K524.

<table>
<thead>
<tr>
<th>APPLICATIONS</th>
<th>COUPLING</th>
<th>PIN CONNECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>As low performance analog comparator, for comparing two photocells etc., or</td>
<td>DC (K524</td>
<td>BD to BE, BJ to BK, BN</td>
</tr>
<tr>
<td>wherever reference is supplied externally.</td>
<td>only)</td>
<td>to BP, BT to BV</td>
</tr>
<tr>
<td>Photocells, thermistors, pulse tachometers, pressure transducers or where-</td>
<td>AC (see</td>
<td>BD to BF, BJ to BL, BN</td>
</tr>
<tr>
<td>ver it is convenient to use the internal 2.5 volt reference.</td>
<td>also K522)</td>
<td>to BR, BT to BV</td>
</tr>
</tbody>
</table>

Signals up to 25 KHz, suitable for counting by K210 or K220 counters, can be obtained with symmetrical input signals having at least 1 volt excursions past the switching point. Maximum output rates can be limited to approximately 5KHz by tying together pins AM and AN, AP and AR, etc.
Quality of plated-thru holes is checked in our new electrochemical facility before boards go to the module assembly area.
The K578 input converter, when mounted in a K724 or K725 interface shell, provides logic levels from 120 VAC signals from limit switches, relays etc. The 1VA reactive load provided by the K578 isolation transformers insures sparking at pilot contacts. Together with the ample circuit voltage used, this reactive load assures maximum contact reliability.

Electrical noise riding on pilot circuit wiring is attenuated both by the input transformer and by RC filtering. Bounce filtering is designed to pick up by the end of the first full cycle of contact, and to drop out (return to “zero” output state) by the end of three full cycles after the input is removed. (About 50 milliseconds.) This speed of response is desirable in large sequential scanning-type control systems, even though occasionally a heavy contact may be observed to produce more than one output transition due to very long bounce duration. If necessary, response speed may be cut in half by tying 150 mfd from the offending logic output to ground. However since no Schmitt triggers are included in the K578 (unlike the K508), a K184 must be used as described in the applications notes if it is important to know exactly how many contact closures have occurred in a given period.

Gating circuits equivalent to four K026 sections are included for contact scanning applications using the K161, or to facilitate forming the logical OR of many inputs. Direct outputs are from circuits similar to the K580, and may not be wired together.

Clamp-type terminals on the K578 take two wires up to size 14. Neon indicators are replaceable.
DRY CONTACT FILTERS
K580, K581

K SERIES

SOLDER LUGS

K580

SOLDER LUGS

K581

K580 — $20
K581 — $20
These filters convert signals from dry circuit or wiping contacts to logic levels. Primarily they are used with gold contacts such as the new encapsulated reed limit switches, thumbwheel switches, and the like. Those push-buttons or slide switches that provide good wiping action will also operate reliably with these filters, but silver contacts designed for long life on heavy duty loads are likely to give trouble. For them, use interfaces designed for such application like K508-K716 or K578, or at least switch a high voltage. (see K580 voltage table.)

Access to K580 and K581 inputs is by solder lugs only. Strain-relief holes are provided in board (near handle) for a 9-wire cable. The avoidance of contact connections on the logic wiring panel combined with heavy filtering guarantees noise isolation and protects modules by preventing accidental short circuits. Below is a summary of other characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Contact Current</th>
<th>Contact Voltage</th>
<th>Output for Contact Closed</th>
<th>Time Delay on Closure</th>
<th>Time Delay on Opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>K580</td>
<td>22ma</td>
<td>See Table</td>
<td>high</td>
<td>10msec</td>
<td>30msec</td>
</tr>
<tr>
<td>K581</td>
<td>22ma</td>
<td>5V</td>
<td>low</td>
<td>20msec</td>
<td>20msec</td>
</tr>
</tbody>
</table>

(Time delay figures above are nominal, and assume connection to the input of a standard gate such as K113 or K123.)

The contact current for the K581 comes from the logic supply, making it very important to assure freedom from accidental high voltages on K581 inputs, which could damage many logic modules by getting through to the system power supply. This hazard is not present with the K580, which uses an external source of +10 volts or more. The table below shows how external dropping resistors may be added to provide higher voltage operation.

**TABLE OF K580 VOLTAGE DROPPING RESISTANCES**

<table>
<thead>
<tr>
<th>CONTACT SUPPLY VOLTAGE</th>
<th>10</th>
<th>12</th>
<th>15</th>
<th>24</th>
<th>28</th>
<th>48</th>
<th>90</th>
<th>100</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dripping Resistance</td>
<td>82Ω</td>
<td>220Ω</td>
<td>620Ω</td>
<td>820Ω</td>
<td>1.8KΩ</td>
<td>3.6KΩ</td>
<td>3.9KΩ</td>
<td>4.7KΩ</td>
<td></td>
</tr>
<tr>
<td>Dissipation</td>
<td>0.05W</td>
<td>0.11W</td>
<td>0.3W</td>
<td>0.4W</td>
<td>0.85W</td>
<td>1.8W</td>
<td>2.0W</td>
<td>2.5W</td>
<td></td>
</tr>
</tbody>
</table>

When using dropping resistors and higher voltage supplies, total tolerance of resistors and supply should be ±10% to insure high levels between +4V and +6V at the logic. Also observe that a handful of dropping resistors in 90V or 120V systems may dissipate more power than the entire logic system, and must be located so as not to cause excessive temperature rise in the K series environment.

Note that these circuits may not be paralleled to obtain the wired OR or wired AND function, and that fanout is limited to 2 milliamperes in order to maintain the low (zero) output voltage within normal K-Series specifications. Fanout to ordinary logic gates and diode expanders may be raised to 4 milliamperes if some noise and contact bounce rejection can be traded off; but hysteresis inputs such as those at counter inputs, rate multiplier, etc., may not switch properly if the logic zero is allowed to rise much above +0.5V.

See application note for thumbwheel register multiplexing using K581.
Operating in conjunction with the K716 Interface Block, the K604 permits AC operated valves, solenoids, small motors, motor starters and the like to be controlled directly from K Series logic. Each circuit can handle up to 250 volt-amperes continuously. Total for any module, however, should not exceed 500 volt-amperes averaged over one minute. Ratings below include maximum horsepower based on use of Allen-Bradley type K* motor starters. Less sensitive starters or relays may have significantly reduced capacity.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Continuous V.A.</th>
<th>Inrush V.A.</th>
<th>Motor Direct</th>
<th>Type K Starter</th>
<th>208/220 Max. H.P.</th>
<th>480/600 Max. H.P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Fuse</td>
<td>250</td>
<td>600</td>
<td>1/20 H.P.</td>
<td>Size 3</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>No Fuse</td>
<td>250</td>
<td>1800</td>
<td>1/10 H.P.</td>
<td>Size 4</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

Littelfuse® type 275005 fuses provide fault protection for the triac output circuits. The fuses are mounted by clips on the connector board for easy replacement. Without the fuses, short circuits will destroy the module. The no-fuse information above is for reference only, and operation without fuse protection cannot be recommended. Circuits cannot be paralleled to increase ratings.

AC switch turnon takes place within 500 microseconds after input logic gate goes high. Turnoff takes place at zero crossings of the current. Maximum “off” leakage: 10 ma RMS at 140 VAC. Line voltage rating: 100 to 140 VAC, 50 to 60 Hz. Each triac output circuit has 400-volt breakdown rating. Shunt capacitor and shunt clipping devices inhibit false triggering on line transients.

Where very small devices such as pilot lamps, light duty relays, or AC input converters constitute the sole load, an auxiliary load such as a 12KΩ 2 watt resistor may be required to absorb sufficient holding current for full voltage output.

Two special precautions are made necessary by the presence of AC line voltages on the K604 module. First, always disconnect the ribbon cable connector before inserting or removing a K604 or an adjacent module, to avoid shocks or component damage. Second, W993 copper-clad boards ($4 each) should be installed between K604 modules and all other types except K508 or K644. With the pin A connection cut away, on either the board or the socket, the W993 copper clad board acts as an electrostatic shield. If this added interface protection is later found to be unnecessary, the sockets reserved for shield boards can be used to add logic features, modifications, etc. Refer to Construction Recommendations.

If desired, a K782 terminal board instead of the K716 may be used to obtain connections to field wiring. No indicators are provided on the K782, however.

For 240 volt operation, refer to the application note on this topic.
K604 CIRCUIT IN USE

DEC Module assembly lines combine automated manufacturing steps with visual inspection and computer controlled testing.
This module uses the K604 circuit and behaves in most respects the same. However, the K614 is designed to fit a K724 or K725 interface shell. Accordingly the K614 has built-in clamp-type terminals for wires to size 14, interchangeable indicators, and output ratings boosted to 500VA per circuit by the larger heat sink area available in this configuration.

See Applications Notes for information on 240 volt operation
Operating through the K716 Interface Block, the K644 DC Driver permits stepping motors, dc solenoids, and similar devices rated up to 2.5 amperes at 48 volts to be driven directly from K series logic. Built-in clamping diodes protect switching transistors from transient over-voltage.

Total output circuit current for the K644 module must not exceed 4 amperes averaged over any 1 minute period. The ribbon connector should be unplugged before inserting or removing a K644 module.

Moving the parts of a magnetic device changes the winding inductance. To equalize magnetic field turnoff and turnon times, the ratio of inductance to total circuit resistance must be held constant. This demands more resistance in the circuit during turnoff, when the inductance is higher. Resistance may be inserted between K716 terminal 15 (or 16) and the load supply to achieve this, provided the K644 output voltage will not exceed 55 volts. Whether resistance is added or not, these clamp return terminals must be connected to the load supply to protect the module from overvoltage during turnoff.

The K644 may be used with a K782 instead of a K716 to obtain the screw terminals needed for connecting heavy duty field wiring.

See applications section for logic diagrams of several stepping-motor applications.
Each circuit of this versatile driver can deliver up to 1 ampere at up to 250 volts, making it ideal for driving heavy-duty brakes and clutches or for high speed operation of other inductive loads. Like the K578 and K614, this module has integral clamp-type terminals and replaceable indicator lamps. (Lamps are effective only at 90 volts and above.) This driver module is designed to be used with K724 or K725 interface shells. Positive side of load supply must be connected to protect output transistors from damage during turnoff transient.
This module has two parts separated by a 1-foot ribbon cable. One part plugs into any module socket, the other contains a side-viewing Burroughs type B-5440 long life NIXIE glow tube on a mounting board. Four connections to corresponding module socket pins of a K210 or K220 binary-coded decimal counter completes the input wiring. The display tube board attaches with two screws to a K771 supply for both mechanical mounting and power supply electrical connections. Displays up to 6 digits long can be stacked on each K771 supply. Stacked digits have 0.8” mounting centers. See Construction Recommendations before assigning module locations.

K671 — $43
These eight-circuit modules drive external loads through 9-conductor cable soldered to split lugs at handle end by user. Strain relief holes, prepunched in board. Ground input to turn off, +5V to turn on.

Pin connections via diodes to outputs facilitate production automatic module testing while isolating system wiring from high voltages. Circuits are not slowed, and these connections are not recommended as output tiepoints unless exceptional care is taken to prevent noise and damaging voltages from degrading system reliability. (See Fixed Memory application note.)

K681 — $15
K683 — $30
<table>
<thead>
<tr>
<th>MODULE TYPE</th>
<th>RESISTIVE</th>
<th>INDUCTIVE</th>
<th>INCANDESCENT LAMPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>K681</td>
<td>18V, 30ma</td>
<td>18V, 30ma when suppression diodes (K784)</td>
<td>Lamps rated 18V, 40ma operated at 12V to reduce current to 30 milliamperes.</td>
</tr>
<tr>
<td>K683</td>
<td>55V, 250ma</td>
<td>55V, 250ma with added suppression diodes (K784)</td>
<td>Lamps rated 40ma, to 48V; Lamps rated 60ma, to 28V; Lamps rated 80ma, to 18V; Lamps rated 100ma, to 12V</td>
</tr>
</tbody>
</table>

Note greatly reduced ratings on tungsten loads. Lamp filaments draw typically ten times more current at turnon than when hot, resulting in very high transistor dissipation if supply voltage is high. Series current limiting resistors or shunt preheat resistors could be used to limit surge in certain cases, but ratings above assume this would be awkward or impractical.
In addition to being a set of noise-immune logic, the DIGITAL K Series offers a versatile system of modular instrumentation and control hardware. On the following pages you will find a variety of equipment for mounting, wiring, powering, etc. The table below may help you get acquainted.

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessories for Interface Modules (K5XX, K6XX)</td>
<td></td>
</tr>
<tr>
<td>K716</td>
<td>Interface Block</td>
</tr>
<tr>
<td>K724</td>
<td>Interface Shell, Power wiring only</td>
</tr>
<tr>
<td>K725</td>
<td>Interface Shell, Prewired for scanning</td>
</tr>
<tr>
<td>K782</td>
<td>8 Terminals</td>
</tr>
<tr>
<td>K784</td>
<td>8 Terminals with Diodes</td>
</tr>
<tr>
<td>Power</td>
<td></td>
</tr>
<tr>
<td>K731</td>
<td>1 Amp Regulator</td>
</tr>
<tr>
<td>K732</td>
<td>2 Amp Slave Regulator</td>
</tr>
<tr>
<td>K741</td>
<td>2 Amp Transformer</td>
</tr>
<tr>
<td>K743</td>
<td>3 Amp Transformer with</td>
</tr>
<tr>
<td></td>
<td>Auxiliary Winding</td>
</tr>
<tr>
<td>H710</td>
<td>5 Amp Low Ripple Supply</td>
</tr>
<tr>
<td>K771</td>
<td>NIXIE Supply</td>
</tr>
<tr>
<td>Mounting Hardware and Connectors</td>
<td></td>
</tr>
<tr>
<td>K940</td>
<td>Mounting Foot for K941</td>
</tr>
<tr>
<td>K941</td>
<td>Mounting Bar</td>
</tr>
<tr>
<td>K943</td>
<td>64 Module 19” X 51¼”</td>
</tr>
<tr>
<td></td>
<td>Mounting Panel</td>
</tr>
<tr>
<td>K980</td>
<td>End Brackets</td>
</tr>
<tr>
<td>1907</td>
<td>Hold-Down and Cover</td>
</tr>
<tr>
<td>H001</td>
<td>Cover Supports</td>
</tr>
<tr>
<td>H920</td>
<td>Module Mounting Drawer</td>
</tr>
<tr>
<td>H800</td>
<td>8-Connector Block</td>
</tr>
<tr>
<td>H802</td>
<td>Single Connector</td>
</tr>
<tr>
<td>Wiring Aids</td>
<td></td>
</tr>
<tr>
<td>913</td>
<td>Grip Clip Logic Wiring Patchords</td>
</tr>
<tr>
<td>914</td>
<td>Power Wiring Jumpers</td>
</tr>
<tr>
<td>932</td>
<td>Bussing Strip</td>
</tr>
<tr>
<td>934</td>
<td>Wire for Wrapping</td>
</tr>
<tr>
<td>H810</td>
<td>Pistol Grip Hand Wire-Wrap Tool</td>
</tr>
<tr>
<td>H812</td>
<td>Unwrapping Tool</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>K791</td>
<td>Test Probe</td>
</tr>
<tr>
<td>W980</td>
<td>Module Extender</td>
</tr>
<tr>
<td>W992</td>
<td>Clad Board, Single Size</td>
</tr>
<tr>
<td>W993</td>
<td>Clad Board, Double Size</td>
</tr>
<tr>
<td>H830</td>
<td>Handle Riveting Tool for Clad Boards</td>
</tr>
<tr>
<td>W994</td>
<td>Perforated Board, Single Size</td>
</tr>
<tr>
<td>W995</td>
<td>Perforated Board, Double Size</td>
</tr>
<tr>
<td>W021</td>
<td>Cable Connector, Logic Only</td>
</tr>
<tr>
<td>W023</td>
<td>Cable Connector, Logic and Power</td>
</tr>
<tr>
<td>W028</td>
<td>Cable Connector, Component Lugs</td>
</tr>
</tbody>
</table>
K SERIES HARDWARE
INTERFACE BLOCK  
K716

An important hardware feature of the K Series system is the K716 Interface Block, which permits field wiring to be installed at ordinary screw terminals by electricians. The logic modules interconnect to the K716 by plug-in ribbon cables.

**Typical Control Applications for K Series Modules Interfaced by K716**

**Contacts:** Ordinary silver contacts of the kind found in limit switches, pressure switches, and pushbuttons work best when operated with healthy levels of both line voltage and load current. The sparking that results prevents buildup of contact surface contamination. To assure reliable switching, isolation transformers in the K716 provide a reactive load for switched 120 vac pilot voltages. The K508 AC Input Converter ignores contact bounce. Hash filters in the module, and attenuation in the isolation transformer built into the K716, reduce electrical noise. Built-in indicators permit quick maintenance checks.

The K716 Interface Block serves as an interconnection interface for those K Series modules that communicate with external equipment. External field wiring terminates at a 24-terminal screw connection block that accepts plain stripped wire up to 14 gauge. No separate crimped or soldered terminals are required.
K716 INTERFACE BLOCK
SCHEMATIC

Ribbon cables from the K Series interface modules connect to printed circuit board sockets on the K716. This allows the K716 terminal block to mount on the rear panel of a NEMA enclosure for the convenience of electricians, while the digital system itself mounts on the door for easy access to both modules and logic wiring. The ribbon cable makes neat, simple wiring layouts and easy flexing at the hinge.

The three sockets in the K716 terminal block contain the same module-connector system used for the modules themselves, permitting quick disconnect of the entire logic system without affecting reliability. This arrangement, together with the K940-K941 bolt-on mounting hardware, allows initial checkout of control systems away from the site, as well as minimizing downtime in case of failure. (See Construction Recommendations.) The cable sockets have the same reliable gold contacts as K Series module sockets.

Socket B, for use with the K508 AC input converter, is fed by eight isolation, stepdown and contact loading transformers contained within the aluminum shell of the K716. The transformer primaries receive 120-volt pilot signals from external contact closures. Each input is monitored by a neon indicator.

Sockets A and C are for use with K524, K604, and K644. Neon indicators are provided to monitor the outputs of the K604 Isolated AC Switch module.

K716 — $90
The drawing above shows approximate dimensions of the K716. Mounting slots clear no. 10 screws and allow compensation for mounting screw location tolerances. See first Application Note “Construction Recommendations.”
All neon indicators are located within the K716 shell, visible at the rear of associated screw terminals.

Socket D, normally terminated by a shorting plug, runs all return lines from connector C to a common point. If the shorting plug is removed, independent wiring of connector C return leads for K524 or K604 modules is possible. A W033-06F-W033 cable connector ($15) must be installed between socket D and socket A. An extra 2-inch clearance is required by this connector board. Independent wiring provides connections for four two-wire circuits instead of 8 circuits with bussed returns.

Below is a recommended mounting pattern for combining many interface blocks. This pattern can be extended provided the 30” reach of ribbon is not exceeded.

K716'S IN INDUSTRIAL ENCLOSURE

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Unlike the K716 interface block pictured on the next page, these shells do not contain any electronic components. Instead, they provide the connectors and the mechanical support for self-contained interface modules K578, K614, and K656. Up to four such modules may be installed, with eight module sockets remaining between them for simple logic functions. Convenient wiring channels are obtained between units if they are mounted on 12” centers vertically and 6” centers horizontally. This way a total of up to 32 input converters and 16 output converters fits in one square foot of panel space, along with up to 16 logic modules.

The K724 provides only logic power connections between sockets. It is primarily intended for very simple logic systems or for large systems where all input and output logic levels are connected to a separate logic unit by connector cables.

The K725 uses a printed backplane to make most of the connections required in a remotely scanned system. In this type of system, a few address lines transmitted to the interface shell on a single connector cable is decoded by a K161 decoder within the shell either to sample one particular K578 input, or else to set or clear a K206 flip-flop which in turn controls the state of one of the output converters. This type of system is convenient to use with a computer, and also lends itself to situations requiring remote contact sensing and switching at several scattered locations.
K716 INTERFACE BLOCK
The K731 supplies ±5 volt dc power to pin A of all K Series modules and provides several specialized once-per-system control functions. Any source of center-tapped 12.6 v (50 or 60 Hz) allows the K731 to deliver up to 1 amp dc, which is sufficient to operate most typical control systems of up to 32 modules. The K731 is short-circuit proof.

This module is normally plugged into one of the innermost sockets on a K941 mounting bar, where its large components occupy space otherwise unused.

The turn-on output goes to ground during the power-up transient, and remains at ground until after the supply voltage has fully reached its quiescent value. It may be used to initialize flip-flops to a known starting condition.

The OK level output goes to ground when the supply voltage reaches 90% of its final value, and returns positive when less than 90% of full voltage is available. It is normally used as an enabling input to the K273 Retentive Memory module.

The line sync output allows a K113 or K123 gate to switch in synchronism with ac supply zero-crossings. This permits the line frequency to drive a real-time clock, or serve as the standard in a phase-locked loop with K303 timers, where higher frequencies must be synchronized with the line. Line sync fan-out is limited to 1 ma (for high fanout, use K113 or K123 for distribution). None of the K731 logic outputs may be used to obtain the OR function, and they may not be wired to any other output.

K731 delivers up to 1 ampere when used with a 12.6 volt transformer rated for 105-130 volt line; calculate loading from module data below. For 5% input voltage reduction (12.0v transformer or 100 volt line) the output current capability decreases 10%. Output voltage temperature coefficient is typically minus 0.1%/°C. See summary of module current consumption following K732 data.

K731 — $24
This module is normally tied to corresponding pins A, C, S, U, and V of a K731 Source. For each unit of current emitted by the K731, the K732 emits two. Up to three K732 slaves can be controlled by a single K731 for a total system current of 7 amperes.

In high-current systems, use short heavy wires for transformer secondary connections. Loss of 5% of secondary voltage in either ground return or transformer output leads will reduce regulator current ratings more than 10%.

Tabs near the handle end of the 732 may be connected to K741 or K743 transformers by using convenient 914 Power Jumpers. Then by wiring pins U and V to corresponding pins on K731, AC connections are provided through the K732 to the source module. To avoid loss of regulation, do not connect a K732 until enough modules have been plugged in to draw a reasonable current (several hundred milliamperes). For a summary of module current consumptions,

K732 — $27
<table>
<thead>
<tr>
<th>Logic Modules</th>
<th>Other Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>K003 3 ma</td>
<td>K508 65 ma</td>
</tr>
<tr>
<td>K012 12 ma</td>
<td>K522 25 ma</td>
</tr>
<tr>
<td>K026 6 ma</td>
<td>K524 35 ma</td>
</tr>
<tr>
<td>K113 17 ma</td>
<td>K578 0</td>
</tr>
<tr>
<td>K123 18 ma</td>
<td>K580 (Uses separate supply)</td>
</tr>
<tr>
<td>K134 23 ma</td>
<td>K581 22 ma</td>
</tr>
<tr>
<td>K174 12 ma</td>
<td>K604 40 ma</td>
</tr>
<tr>
<td>K184 56 ma</td>
<td>K614 20 ma</td>
</tr>
<tr>
<td>K202 120 ma</td>
<td>K644 20 ma</td>
</tr>
<tr>
<td>K206 50 ma</td>
<td>K656 100 ma</td>
</tr>
<tr>
<td>K210 150 ma</td>
<td>K671 13 ma</td>
</tr>
<tr>
<td>K220 220 ma</td>
<td>K681 16 ma</td>
</tr>
<tr>
<td>K230 150 ma</td>
<td>K683 160 ma</td>
</tr>
<tr>
<td>K273 50 ma</td>
<td></td>
</tr>
<tr>
<td>K281 0</td>
<td></td>
</tr>
<tr>
<td>K303 30 ma</td>
<td></td>
</tr>
</tbody>
</table>
These hash-filtered, 50/60 Hz transformers supply K731 Source and K732 Slave Regulator modules. The K743 also provides an auxiliary winding for use with K580 Dry Contact Filters and K681 or K683 Lamp Drivers (requires additional bridge rectifier). Type 914 Power Jumpers are convenient for connecting to tab terminals on these transformers and on the K732 and K943. Both transformers have holes at the corners of the chassis plate for mounting on K980 endplates:

<table>
<thead>
<tr>
<th></th>
<th>PLATE DIMENSIONS</th>
<th>HOLE CENTERS</th>
<th>MATCHING K980 Ctrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>K741</td>
<td>3½&quot; x 5&quot;</td>
<td>2½&quot; x 3⅛&quot;</td>
<td>2½&quot;</td>
</tr>
<tr>
<td>K743</td>
<td>5&quot; x 5&quot;</td>
<td>4&quot; x 3⅜&quot;</td>
<td>4&quot;</td>
</tr>
</tbody>
</table>

The K741 is sufficiently light in weight to be mounted on one side only, as at the end of a K943 mounting panel.
The table below shows how to obtain various currents. Line voltages within \( \pm 10\% \) from nominal and short, heavy secondary wires are assumed. One K731 is required in each case.

<table>
<thead>
<tr>
<th>60 Hz</th>
<th>50 Hz</th>
<th>K732</th>
<th>TRANSFORMER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1-1A</td>
<td>0.1-0.8A</td>
<td>0</td>
<td>K741 or K743</td>
</tr>
<tr>
<td>0.5-2A</td>
<td>0.4-1.6A</td>
<td>1</td>
<td>K741 or K743</td>
</tr>
<tr>
<td>1-3A</td>
<td>0.8-2.4A</td>
<td>1</td>
<td>2 K741s or K743</td>
</tr>
<tr>
<td>2-4A</td>
<td>1.6-3.2A</td>
<td>2</td>
<td>2 K741s or 2 K743s</td>
</tr>
<tr>
<td>3-5A</td>
<td>2.4-4A</td>
<td>2</td>
<td>3 K741s or 2 K743s</td>
</tr>
<tr>
<td>4-6A</td>
<td>3.2-4.8A</td>
<td>3</td>
<td>3 K741s or 2 K743s</td>
</tr>
<tr>
<td>5-7A</td>
<td>4.5-6A</td>
<td>3</td>
<td>4 K741s or 3 K743s</td>
</tr>
</tbody>
</table>

K741 — $22
K743 — $38
The H710 power supply is ruggedly built, low cost, regulated, floating output, five volt power supply that can be mounted in an H920 chassis drawer or used as a free standing unit. Remote sensing to correct for loss due to long lines is provided. When shipped from the factory, the remote sensing inputs are jumpered to their respective outputs. Especially useful in systems that require maximum repeatability from K303 timers in the millisecond region.

**INPUT VOLTAGE:** 105-125 VAC  
 or 210-250 VAC 47-63 HZ  
**OUTPUT VOLTAGE:** 5 vdc.  
**P-P RIPPLE:** Less than 20 mv.

**OUTPUT CURRENT:**  
0-5 amps. short-circuit protected for parallel supply operation.

**LINE AND LOAD REGULATION:**  
The output voltage will not vary more than 50 mv over the full range of load current and line voltage.

**OVERVOLTAGE PROTECTION:**  
The output is protected from transients which exceed 6.9 Volts for more than 10nsec. However, the output is not protected against long shorts to voltages above 6.9 Volts.

**POWER CONNECTIONS:**  
Input power connections are made via tab terminals which fit the AMP “Faston” receptacle series. Output power is supplied to solder lugs. All required mounting hardware is supplied with this unit. See 914 power jumpers.

**Dimensions:**  
Length: 8”  
Width: 5”  
Height: 6”  
Finish: Chromicoat

**H710 — $200**
DISPLAY SUPPLY  
K771

Shown above from the viewing side, the K771 supplies power and a convenient two-screw mounting for up to 6 K761 display tubes. Display tubes are stacked to the left, the first tube board being attached to the K771. The second tube board attaches to the first, and so on. Board mounting screws provide both mechanical mounting and electrical power connections. The two panel mounting screw locations dimensioned above have no. 6 steel threaded inserts. Several 1” holes using a standard chassis punch may be cut on 0.8” centers for viewing display tubes. To seal opening against dust, a 3” by 3.6” piece of Lucite® or Plexiglas® may be assembled between display and mounting surface. Power 120 VAC enters the supply from a terminal strip at the rear. Total depth behind mounting surface: 4”.

K771 — $26

TEST PROBE  
K791

K791 TEST PROBE

This pocket test probe contains two pulse-stretching lamp drivers for visual indication of both transient and steady-state conditions. Neither indicator lights on an open circuit. A built-in test point illuminator adds convenience. The probe introduces negligible loading of the point under observation. The black wire connects to any pin C. The red wire gets ac power from the system supply transformer, pin U or V of K731. Probe is hollow and fits unwrapped end of H800W pins for hands-off use if desired.

K791 — $27
These two double size modules offer an alternative to the K716 for obtaining field wiring connections in K series systems. The K782 has straight-through connections for use with K524, K580, K604, or K644 modules. The K784 includes 60 v clamp diodes for protection of K681 or K683 modules driving inductive loads. Strain relief holes and split lugs on both boards adapt them for such modules as K580 and K683 where 9-conductor ribbon or individual wires will be used.

Connector pins are also provided, so the connector board of types like K524 or K604 can be plugged into a shared H800-F block and bussed connections used. Both connectors are included, so that a single H800 could be shared if desired among up to four K782's with their respective connector boards.

The photo at right shows one way that these modules may be mounted, by bolting through the holes provided and mounting on K980 brackets. The attachment of a K743 transformer to the K980 is also shown here.

<table>
<thead>
<tr>
<th>K782</th>
<th>K784</th>
</tr>
</thead>
<tbody>
<tr>
<td>$12</td>
<td>$17</td>
</tr>
</tbody>
</table>
This convenient mounting hardware permits logic connector pin wiring to be done before logic is installed in the enclosure.

K940 is a mounting support that attaches to the enclosure. K941 is a removable bracket that mounts up to four H800 connector blocks. Any connections to external equipment are made through the ribbon connectors of interface signal modules (K508, K524, K604, K644) to the K716 Interface Block.

An installation of K-Series equipment in a NEMA-12 Enclosure is illustrated on the next page.

K940 — $3
K941 — $6
K940, K941 WITH K716 IN A NEMA-12 ENCLOSURE,
16 IN. DEEP  TOP VIEW
19" MOUNTING PANELS
K943-W-P, K943-F-P

These low cost, 19" panels have 64 sockets with either wire-wrap (W) or solder fork (F) contact pins. Shipped with connector blocks installed and pins A and C bussed.

No terminal strips are included in the K943, since power regulators K731 and K732 will normally be plugged in to make power connections. If hold-down is required to prevent modules from backing out under vibration, order a pair of end plates K980. These assemble by means of added nuts on the rear of the rack mount screws. They accept the painted 1907 cover plate, making a hold-down system that contacts the module handles and can allow flexprint cables to be threaded neatly out the end. Rack space: 5 1/4". See photos on next page showing K943-W-P, K980, 1907, and H001.

END PLATES
K980

Pair of plates for supporting 1907 cover to hold modules in K943 panel under shock and vibration. (Note: If vibration is anticipated, care must be taken not to nick logic wires. Use a quality wire stripping device.) Also used for mounting K741, K743, K782, K784.

COVER
1907

Blue painted or brown tweed painted aluminum cover with captive screws to mate threaded bushings in K980 and H001. Adds to appearance while protecting system against vibration and tampering.

BRACKETS
H001, H002

Pairs of brackets. H001 provides 3/4" standoff to mount 1907 over K943 wiring. H002 provides a 2" setback so a control panel with switches, lamps, etc. can be mounted flush with mounting rack or cabinet in front of logic wiring.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>K943-W-P</td>
<td>1</td>
<td>$96</td>
</tr>
<tr>
<td>K943-F-P</td>
<td>1</td>
<td>$96</td>
</tr>
<tr>
<td>K980 (pair)</td>
<td>1</td>
<td>$6</td>
</tr>
<tr>
<td>1907</td>
<td>1</td>
<td>$9</td>
</tr>
<tr>
<td>H001 (pair)</td>
<td>1</td>
<td>$8</td>
</tr>
<tr>
<td>H002 (pair)</td>
<td>1</td>
<td>$8</td>
</tr>
</tbody>
</table>

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Each of these molded socket assemblies holds 8 single size modules when mounted on a K941 mounting bar or H920 drawer. H800W has wire wrap pins; H800F has solder forks. Connector blocks fit tightly to insure zero play (important for automated wrapping).

H800F — $8
H800W — $8

REPLACEMENT CONTACTS
H801W, H801F

These contacts are offered in packages of 18 for replacement purposes. In each package, nine straight and nine offset contacts are included, enough to replace all contacts in one socket.

H801W is for wire-wrap connectors; H801F is for solder-fork connectors.

H801F — $4
H801W — $4
This is a connector block for a single flip-chip module. The H802 can be used to fit a single module in a confined or irregular space. Often the H802 is used as a connector for a cable at some remote location. The H802 is only available with wire wrap pins.
The H920 Module Drawer provides a convenient mounting arrangement for a complete digital logic system. The drawer has sufficient room to house up to 16 mounting blocks in addition to the H701 and H710 power supplies. Power supplies are not included in the H920 but must be ordered separately. When used without the power supplies, there is room for up to 24 mounting blocks. The drawer accepts both H800 and H803 mounting blocks and fits a standard 19" relay rack and all DEC cabinets. Width of the module drawer is 16¾" and depth is 19". When used with the H921 Panel, the height is 6¾". The module drawer comes equipped with a power bracket for distribution of power within the drawer, to other drawers or to mounting panels. The H920 comes with convenient mounting arrangements for both the H921 front panel and the H923 slide tracks. The H921 is a front panel designed to be used primarily with the H920 Module Drawer. It provides convenient mounting arrangements for switches, indicators, and other accessories which may be required in a logic system. The H921 comes predrilled and ready to mount to the H920. Height of the panel is 6¾" and width is 19".

The H923 chassis slides are designed to be used with the H920 Mounting Drawer. These slides allow the user to slide the drawer out of the cabinet or rack and tilt the drawer to any angle. H923 tracks may also be ordered directly from Chassis Trak, Inc., Indianapolis, Indiana, part number CTD 120.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H920 — $170</td>
<td></td>
</tr>
<tr>
<td>H921 — $ 5</td>
<td></td>
</tr>
<tr>
<td>H923 — $ 75</td>
<td></td>
</tr>
</tbody>
</table>
All incoming integrated circuits undergo computer controlled testing, with 40 dc and 16 ac tests performed in 1.1 seconds. This 100% inspection speeds production by minimizing the diagnosis of component failures in module test.
WIRING ACCESSORIES
913, 914, 932, 934, 936, H810, H811, H812

TYPE 913 PATCHCORDS
These patchcords provide slip-on connections for FLIP CHIP mounting panels and are available in color-coded lengths of 2, 3, 4, 6, 8, 12, 16, 24, 32, 48, and 64 inches. All cords are shipped in quantities of 100 in handy polystyrene boxes. Type 913 patchcords are for 24 gauge wirewrap and use AMP Terminal Type #60530-1. (Specify length when ordering.)

913 — $18/pkg. of 100

TYPE 914 POWER JUMPERS
For interconnections between power supplies, mounting panels, and logic lab panels, these jumpers use AMP "Faston" receptacles series 250. Specify 914-7 for interconnecting adjacent mounting panels, or 914-19 for other runs of up to 19 inches. 914-7 contains 10 jumpers per package; 914-19 contains 10 jumpers per package.

914-7 — $4/pkg.
914-19 — $4/pkg.

TYPE 932 BUS STRIP
Simplifies wiring of register pulse busses, power, and grounds. Same as used in K943.

932 — $0.60

TYPE 934 WIRE-WRAPPING WIRE
1000 ft. roll of 24 gauge with tough, cut-resistant insulation. (Use Teflon insulated wire instead for soldering.)

934 — $50

TYPE 936 19 CONDUCTOR RIBBON CABLE
Use on W Series connector modules or split into 9-conductor cables for use with K580, K681, K683, etc.

936 — $0.60/ft.

H810(24) — $99
H811(24) — $21
H812(24) — $10
The W021 and W028 provide cable connections to any module socket or mounting panel. The cable is a 19-conductor ribbon with nine signal leads and ten shields. The signal leads are connected to pins D, E, H, K, M, P, S, T and V. The shields are internally connected together and to pins C, F, J, L, N, R and U.

The W023 allows straight-through connections for all 18 pins. Pin A on this connector should not be used for logic signals, since it would be so easy to get power voltage on pin A by mistake. But W023 connector cables are convenient for supplying power and ground connections as well as signals to K724 and K725 interface shells.

<table>
<thead>
<tr>
<th>TWO CONNECTOR STANDARD CABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPES (connector type — cable inches — connector type)</td>
</tr>
<tr>
<td>W021-36R-W021, W028-36R-W021, W023-36R-W023</td>
</tr>
<tr>
<td>W021-60R-W021, W028-60R-W021, W023-60R-W023</td>
</tr>
<tr>
<td>W021-84R-W021, W028-84R-W021, W023-84R-W023</td>
</tr>
<tr>
<td>W021-120R-W021, W028-120R-W021, W023-120R-W023</td>
</tr>
</tbody>
</table>

Cable connectors are also available separately, as is 19-conductor ribbon cable (936). Please include suffix letters as shown when ordering.

| W021RU — $4 |
| W023RU — $4 |
| W028RU — $4 |
| 936 — $0.60/ft |
The W980 Module Extender allows access to the module circuits without breaking connections between the module and mounting panel wiring.
These blank modules offer convenient means of integrating special circuits and even small mechanical components into a FLIP CHIP system, without loss of modularity. Both single- and double-size boards are supplied with contact area etched and gold plated.

<table>
<thead>
<tr>
<th>Type</th>
<th>Pins</th>
<th>Description</th>
<th>Handle</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>W990</td>
<td>18</td>
<td>Bare board, split-lug terminals</td>
<td>attached</td>
<td>$2.50</td>
</tr>
<tr>
<td>W991</td>
<td>36</td>
<td>Bare board, split-lug terminals</td>
<td>attached</td>
<td>$5.00</td>
</tr>
<tr>
<td>W992</td>
<td>18</td>
<td>Copper clad, to be etched by user</td>
<td>separate</td>
<td>$2.00</td>
</tr>
<tr>
<td>W993</td>
<td>36</td>
<td>Copper clad, to be etched by user</td>
<td>separate</td>
<td>$4.00</td>
</tr>
<tr>
<td>W994</td>
<td>18</td>
<td>Perforated, 0.052” holes, 18 with etched lands. The holes are on 0.1” centers, both horizontally and vertically.</td>
<td>attached</td>
<td>$4.50</td>
</tr>
<tr>
<td>W995</td>
<td>36</td>
<td>Perforated, 0.052” holes, 36 with etched lands. The holes are on 0.1” centers, both horizontally and vertically.</td>
<td>attached</td>
<td>$9.00</td>
</tr>
</tbody>
</table>

The H830 is designed for clinching handle rivets on the W992 and W993 blank modules. Fits into any vise and once the module and eyelet are positioned, a slight tap of the hammer will clinch the eyelet.

The unit has a 3½” height and weighs 1 lb.

H830 — $10

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The Type 831 Power Control Panel features a 2-pole circuit breaker which provides convenient 1-step control and protection for entire systems, including auxiliary equipment. The panel fits standard 19-in. racks and is finished with a protective aluminum coating. Available in 4-, 10-, 20-, or 30-amp. capacity. (Specify amperage when ordering.)

PANEL HEIGHT: 3-7/16 in.

PANEL WIDTH: 19 in.

Space available for mounting other controls and indicators: 3 in. by 8 in.

831 — $51

RIVETING TOOL
TYPE H830
Many types of digital control systems can be interfaced to analog references or servos by means of the few versatile modules described here. The table below shows some of the many possibilities.

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital to Analog Converter, 9 bits (511 steps)</td>
<td>A613 D-A Converter, A702 Reference, H704 Supply</td>
</tr>
<tr>
<td>Digital to Analog Converter, 12 bits (4095 steps)</td>
<td>A613 D-A Converter, A704 Reference, H704 Supply</td>
</tr>
<tr>
<td>BCD Converter, 3 decades (999 steps)</td>
<td>A613 D-A Converter, A704 Reference, H704 Supply</td>
</tr>
<tr>
<td>Analog to Digital Converter, 9 bits (See Applications Note)</td>
<td>A613, A702, H704, A207 Operational Amplifier, K210 Counters</td>
</tr>
<tr>
<td>Analog to Digital Converter, 12 bits (See Applications Note)</td>
<td>A613, A704, H704, A207 Operational Amplifier, K210 Counters</td>
</tr>
<tr>
<td>BCD A to D Converter, 3 decades (See Applications Note)</td>
<td>A613, A704, H704, A207 Operational Amplifier, K210 Counters</td>
</tr>
</tbody>
</table>
These pantograph controlled insertion machines position and crimp pre-tested components onto four module boards at a time. A press will cut the modules apart after assembly is completed, minimizing handling up to that point.
This economical, general-purpose amplifier features a recovery time from saturation to 12 bit accuracy of 20 microseconds, making it suitable for use as a comparator as well as for buffering, offsetting, and scale-changing. For maximum flexibility, space is provided where feedback elements may be conveniently installed for a wide variety of uses. A few of these are shown on the next page.

The specifications below assume operation at room temperature (25°C) except where noted. Accidental shorting of output to ground is harmless.

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling Time within 10 mv after 10v step</td>
<td></td>
<td>6 µs</td>
<td>10 µs</td>
</tr>
<tr>
<td>Settling Time within 1 mv after 10v step</td>
<td>100,000</td>
<td></td>
<td>15 µs</td>
</tr>
<tr>
<td>DC Open-Loop Maximum Load (670Ω)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gain at 3 MHz (small signals)</td>
<td>unity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Limit for 20v p-p Output</td>
<td>60 KHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slewing Rate, Volts per Microsecond</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery Time after Overload</td>
<td>±15 ma</td>
<td></td>
<td>8 µs</td>
</tr>
<tr>
<td>Output Current Capability</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

108
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range</td>
<td>±10V</td>
<td></td>
<td>±10V</td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Mode Rejection Ratio</td>
<td>100KΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Impedance (Differential)</td>
<td>5MΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Impedance (Common Mode)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Offset, microvolts per °C (avg.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Current Unbalance</td>
<td></td>
<td>0.5 μa</td>
<td></td>
</tr>
<tr>
<td>Input Current Drift, nanoamps/°C (avg.)</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Temperature, Operating</td>
<td>0°C</td>
<td></td>
<td>60°C</td>
</tr>
<tr>
<td>Temperature, Storage</td>
<td>-20°C</td>
<td></td>
<td>125°C</td>
</tr>
<tr>
<td>+15v Current (No Load)</td>
<td></td>
<td>6 ma</td>
<td></td>
</tr>
<tr>
<td>-15v Current (No Load)</td>
<td></td>
<td>10 ma</td>
<td></td>
</tr>
</tbody>
</table>

Note: Settling Time can be reduced 50% by tying control pins L and M together. However, gain will be reduced to 15,000, and input voltage drift will approximately double.

PIN F IS TIED TO ANALOG GROUND
This versatile, low cost 12 bit converter is easy to use in either straight binary or binary-coded-decimal (BCD) applications. Its 50 microsecond settling time is limited mainly by the output amplifier, so it can follow a K Series counter operating at maximum (100 KHz) input rate. The 10 milliampere, 10 volt output capability is ample for use with SCR phase controllers or other servo and drive components.

### CODE PROGRAMMING PIN CONNECTIONS

<table>
<thead>
<tr>
<th>Straight Binary</th>
<th>Binary Coded Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect BE to BK</td>
<td>Connect BD to BK</td>
</tr>
<tr>
<td>BJ to BM</td>
<td>BH to BM</td>
</tr>
<tr>
<td>BN to BV</td>
<td></td>
</tr>
</tbody>
</table>

The specifications below assume operation at room temperature (25°C). Accidental shorting of output to ground is harmless.
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling Time within one LSB after 10v step</td>
<td></td>
<td>50 µs</td>
<td></td>
</tr>
<tr>
<td>Accuracy, Binary Connection</td>
<td>±0.015%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy, BCD Connection</td>
<td>±0.050%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantization Error, Binary Connection (as A-D)</td>
<td>±0.013%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantization Error, BCD Connection (as A-D)</td>
<td>±0.050%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Coefficient</td>
<td>±0.001%/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitive Loading without Oscillation</td>
<td>0.1 µf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage (Logic 1)</td>
<td>+5v</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage (Logic 0)</td>
<td>0v</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Current</td>
<td></td>
<td>10 ma</td>
<td></td>
</tr>
<tr>
<td>Output Voltage</td>
<td>0</td>
<td>+10v</td>
<td></td>
</tr>
<tr>
<td>Output Voltage (Additional Positive Ref.)</td>
<td>10v</td>
<td>+10v</td>
<td></td>
</tr>
<tr>
<td>+5v Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+15v Current (No Load)</td>
<td></td>
<td>10 ma</td>
<td></td>
</tr>
<tr>
<td>−15v Current (No Load)</td>
<td></td>
<td>10 ma</td>
<td></td>
</tr>
<tr>
<td>−10v Reference Current</td>
<td></td>
<td>7 ma</td>
<td></td>
</tr>
</tbody>
</table>
These Reference Supplies can provide the accurate reference needed in any D-A or A-D converter.

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Output</th>
<th>Current</th>
<th>Temperature Coefficient</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A702</td>
<td>−10v</td>
<td>±60 ma</td>
<td>1 mv/°C</td>
<td>30 mv, no load to full load</td>
</tr>
<tr>
<td>A704</td>
<td>−10v</td>
<td>−90 to +40 ma</td>
<td>1 mv/8 hrs, 1 mv/15° to 35°C, 4 mv/0° to 50°C</td>
<td>0.1 mv, no load to full load</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Adjustment Resolution</th>
<th>Input Power</th>
<th>Use</th>
<th>Output Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A702</td>
<td>5 mv</td>
<td>−15v/100 ma, +15v/15 ma</td>
<td>Load with 500 μf at load. May also be preloaded if desired</td>
<td>0.5 ohms</td>
</tr>
<tr>
<td>A704</td>
<td>0.01 mv</td>
<td>−15 ±2v/250 ma</td>
<td>See below for sensing and preloading</td>
<td>0.0025 ohms</td>
</tr>
</tbody>
</table>

REMOTE SENSING: The input to the regulating circuits of the A704 is connected at sense terminals AT (+) and AV (−). Connection from these points to the load voltage at the most critical location provides maximum regulation at a selected point in a distributed or remote load. When the sense terminals are connected to the load at a relatively distant location, a capacitor of approximately 100 μf should be connected across the load at the sensing point.

PRELOADING: The supplies may be preloaded to ground or −15v to change the amount of current available in either direction. For driving DEC Digital-Analog Converter modules, −125 ma maximum can be obtained by connecting a 270Ω±5% 1 watt resistor from the −10v pin AE reference output to pin AC ground (A704 only).
DEC thoroughly tests all finished modules, performing 100 ac and dc tests in less than 5 seconds. Most testing is done automatically on one of 3 computer operated test stations like this one.
DUAL POWER SUPPLY
H704, H707
± 15 VOLTS

H704

These supplies differ only in dimensions and output current capabilities: 400 ma and 1.5 Amperes respectively for the H704 and H707. May be mounted on the bars in an H920 drawer, taking the space of two connector blocks.

MECHANICAL CHARACTERISTICS

DIMENSIONS: 3\(\frac{1}{4}\) \(\times\) 3\(\frac{3}{4}\) \(\times\) 5 in. height (H704)
DIMENSIONS: 4" \(\times\) 5" \(\times\) 5\(\frac{1}{2}\)" height (H707)

CONNECTIONS: All input-output wires must be soldered to octal socket at the base of the power supply.

OPERATING TEMPERATURE: −20 to +71°C ambient

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H704 — $200
H707 — $400

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ELECTRICAL CHARACTERISTICS

INPUT VOLTAGE: 105 to 125 vac; 47-420 cps.
OUTPUT VOLTAGE: floating ±15v
OUTPUT VOLTAGE ADJUSTMENT: ±1v each output
REGULATION: 0.05% line, 0.1% load for both voltages
RIPPLE: 1mv rms max for both outputs
OVERLOAD PROTECTION: The power supply is capable of withstanding output short circuits indefinitely without being damaged.

IF REMOTE SENSING IS NOT USED, CONNECT:

IF REMOTE SENSING IS NOT USED, CONNECT: 5 TO 4
6 TO 7

WIRING: Digital/analog and analog/digital converters perform best when module locations and wiring are optimized. All Digital-Analog Converter modules should be side-by-side, with Type 932 bus strip used to bus pins E and pins F together on all converter modules. In an analog-digital converter, the comparator should be mounted next to the converter module for the bits of most significance. The reference supply module should be mounted nearby, and if the A704 is used, its sense terminals should be wired to pins E and F of the most-significant-bits converter module. The high quality ground must be connected to the common ground only at pin AC of the reference supply module, and this point should also be the common ground for analog inputs to analog-digital converters. Do not mount A-series modules closer than necessary to power supply transformers or other sources of fluctuating electric or magnetic fields.
BASIC K-SERIES APPLICATIONS

The best system designs come from the man who well understands both the objectives and the means available. Few are the circuit or logic designers who understand the specific problems to be solved in any one field, so the hope is that the applications notes in this handbook can equip an industry or process specialist with a fairly thorough knowledge of the electronic means available.

The basic applications notes in this section are thought to be fundamental enough to interest every designer. "Advanced" applications described in the next section are not necessarily difficult to understand, but many are of interest only to those with a specific design objective.

Many basic applications must be described along with a specific product to clarify the function of that product. Use the thumb index or the index below to refer to these.

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<td>Decoders: 8, 10, 16, 32 Addressable Lines</td>
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<td>28</td>
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<tr>
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<td>115</td>
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</table>
K-SERIES CONSTRUCTION RECOMMENDATIONS

A high percentage of all failures in electronic systems result directly from hasty planning of nonelectronic aspects. Much time and trouble can be saved by planning mechanical assembly before construction begins. Wiring methods and lead dress, heat distribution and temperature control, power supply reliability and line fault contingencies, and the attitudes and habits of people working near the system all merit forethought. Important opportunities for reliability, maintainability, and convenience will be lost if early and consistent attention is not given the topics below.

Environment

a. Temperature

Module temperature ratings are \(-20^\circ\text{C}\) to \(65^\circ\text{C}\) (\(0^\circ\text{F}\) to \(150^\circ\text{F}\)) except K202, K210, K220, and K230 which are limited to \(0^\circ\text{C}\) (\(36^\circ\text{F}\)) minimum. These ratings are for average air temperature at the printed board, and take local heating by high dissipation components into account. Free, unobstructed air convection is required for reliable operation; the plane of each module must be essentially vertical for this reason.

Convection is required not only to remove heat but also to distribute it, and movable louvres or baffles used to obtain self-heating under frigid conditions must not interfere with air movement within and around modules.

b. Motion

Transport or use in trucks or aboard ships can vibrate modules sufficiently to work them out of their sockets. K273, K604, K644, K731, K732, and K303 modules with K374 or similar controls attached are most subject to disturbance.

If modules are mounted in a K943 19-inch panel, use K980 endplates and a 1907 cover.

If modules are mounted on the hinged door of an enclosure, position the K941 so a support bolted to the side of the enclosure will contact the modules when the door is closed, taking care not to let the support interfere with ribbon cable on K508, K524, K604, and K644.

Mercury contact relays in K273 modules should be maintained within \(30^\circ\) of vertical while operating to insure correct logic output.

Controls such as K374, etc. will hold their setting in vibration, but are easily disturbed by repeated contact with loose wiring, etc.

Finally, take pains not to nick logic wires if vibration is likely to be encountered. Use a quality wire stripper. One of the new motor driven rotary types could easily pay for itself by reducing wiring time and avoiding vibration induced wire breakage.

c. Contaminants

Sulphurous fumes will attack exposed copper or silver; their presence demands the coating of ribbon connections and K731 heatsink cladding with suitable insulating varnish or plastic. A combination of high humidity and
contaminated atmospheres requires such treatment on all printed wiring of K303 timers and controls, since at maximum settings even a few microamperes of leakage will affect their timing. Varnish or coatings are neither required nor recommended in less hostile conditions, and in any case it is desirable to exclude contaminants.

d. Convenience

Adjustments should be mounted so the least critical are easiest to reach. Calibrated controls such as K374, etc. should be positioned in a logical pattern before K303 sockets are wired. Ruggedness and feel should govern the selection of remote timer controls likely to be operated in moments of preoccupation or alarm.

Pluggable connections to K716, K724-K725, and (optionally) to K782-K784 allow electricians to complete their work while the logic itself is being built or checked elsewhere. Plan cable routing to simplify installation of electronics last. Take advantage of the ease with which a K941 mounting bar can be fastened to a pre-installed K940 foot.

Logic Wiring

a. General Information

Wire wrapping is the most suitable technique for the sockets used with K series modules. Some prefer AMP Termi-Point (trademark) but neither AMP nor DEC can guarantee full compatibility for this system. Solder fork connectors are optional; wrapped connections may also be soldered. For large volume repetitive systems using K943 mounting panels, DEC offers a machine-wrapping service.

Never solder or wire wrap with any tool if there are modules installed, unless the tool is grounded to the frame to drain static charges, and unless AC operated devices work from isolation transformers. It is safest to avoid AC operated wire wrap tools together. Hand-operated pistol-grip wire wrapping tools are surprisingly efficient and easy to use. If automatic machine wrapping is contemplated, plan for only two wraps per pin.

b. Wire Types

Teflon (trademark) insulation over size 22 tinned solid copper wire is best for soldering. Size 24 tinned solid copper wire must be used for wrapping H800 and K943 pins. Teflon (trademark) insulation may be used, but some prefer to sacrifice high temperature performance by using Kynar (trademark), to get greater resistance to cut-through where soldering is not involved.

Type 932 bussing strip allows module power and ground pins A and C to be connected conveniently, and is also helpful if several modules have common pin connections.

c. Procedures

First solder in all bussing strips. Next tie all grounds and grounded pins together. Finally point-to-point wire all other connections.

Run all wires diagonally or vertically. Do not run wires horizontally except to adjacent pins or along mounting bar between modules. Horizontal zig-zag wiring interferes with checking and is prone to insulation cut-through. Leave wires a bit slack so they can be pushed aside for probing. Cabling is definitely not recommended. Wires should be more or less evenly distributed over the wiring area.
When wrapping, avoid chains of top-wrap-to-bottom-wrap sequences which entail numerous unwrappings if changes must be made. Properly sequenced wraps require no more than three wires to be replaced for any one change in two-wraps-per-pin systems. Never re-wrap any wire. For best reliability, do not bend or stress wrapped pins, for this may break some of the cold welds. Follow tool supplier's recommendations on tool gauging and maintenance etc. As a convenience, DEC stocks three Gardener-Denver tools under numbers H810, H811, and H812. See specifications pages.

Field Wiring

a. AC Pilot Circuits

All screw terminals used in the K-Series have clamps so that wires do not need any further treatment after insulation is stripped. All terminals can take either one or two wires up to 14 gauge.

K716 terminals have been arranged so AC inputs all go to one end of the interface block, and AC outputs all go to the other end. The eight terminals nearest the center are typically connected only to each other and to a few return and AC supply wires. Input and output leads should be segregated so they do not block entry to the ribbon connector sockets. If sockets face to the left, AC inputs will be above and all other connections below. Wires should be routed down the connector side of K716 blocks to cable clamps or wiring ducts placed parallel with K716s. (See diagrams on K716 data page.)

Plan the logical arrangement of field wiring terminals and indicators before module locations are selected to avoid excessive folding or twisting of ribbon cables. (See recommendations on module locations below.)

b. DC and Transducer circuits

DC outputs from K644, K656, K681, and K683 and AC outputs from K604 and K614 are high level; wiring is noncritical. Low level inputs, however, may require special treatment to avoid false indications. Low level signals should at least be isolated from AC line and DC output signals throughout the field wiring system, and, as a minimum, individual twisted pairs should be used for signals and return connections.

For lower signal levels or longer wiring runs, shielded pairs may be required, with the shield grounded only at one point, preferably at the logic system end unless one side of the transducer is unavoidably grounded. Conduit which may be grounded indiscriminately is not an effective substitute for shielded, insulated wiring.

All signals except line voltage AC inputs use the straight-through connections of K716 terminals 15 through 24. Within the K716, leads are shortest to terminals 15, 17, 18, 19, and 20; use these terminals for minimum noise on K524 low level signals.
Module Locations

a. End Sockets (K941)

The first sockets to assign are those for K731 and K732 regulators, and for K303 timers. If possible, mount regulators nearest the foot of a K941 mounting bar, so their extra bulk projects into the space between the mounting surface and the first H800 block on the bar. Controls mounted on the same mounting surface opposite K731 source modules may be as much as \( \frac{5}{8} \)" deep without touching modules.

Sockets at the outer end of K941 mounting bars are the only locations where K303 timers can have integral controls mounted. Even where the use of K370-group controls is not initially planned, assignment of K303 modules to these outer locations is recommended. Also, these sockets should be the first reserved as spares if any unused locations are available. This way maximum flexibility will be preserved for possible design changes or additions.

b. Interface Modules

AC and DC interface modules such as K508, K524, K604, and K644 should be assigned locations that simplify cabling. Ribbon cables can be twisted by a succession of 45° folds, but a neat installation should be planned. Assign the location and position of K716 interface blocks first. Consider such features as logical arrangement of indicator lights for trouble shooting, ease of routing and tracing field wiring, and directness and length of ribbon cable runs back to the logic modules.

After K716 locations and assignments have been selected, assign socket positions for interface modules (K508, etc.). The order should be coordinated so the combined ribbon cables will lie flat together. Excess ribbon cable can be easily and neatly folded away. Lengths other than 30" are not available since these modules cannot be tested and stocked until cables are cut and soldered. This should cause no difficulty if module locations are assigned thoughtfully.

c. Display Modules

If K671 decade displays are required, select their locations after regulator and interface modules have been assigned sockets. The 12" cables on these modules are oriented for convenient assembly of displays above logic modules, to be viewed from outside the door or enclosure in which K940 and K941 hardware is mounted. Used this way, the digits of lower significance have cables below those of more significant digits.

For neatest cabling and quickest module wiring, counter and display modules should be arranged so the counter input will be nearest the K940 mounting surface. Notice that pin connections on K671, K210, and K220, and K230 modules are coordinated, so that a side-by-side pairing of flip-flop and associated K671 modules will result in short, neat, easy wiring. Ribbon cable passes easily between modules, so it is not necessary to restrict K671 modules to the topmost row. However, the limited cable length will usually restrict them to the top mounting bar in systems using more than one K941.

Do not fold or arrange ribbon cables so that they lie flat on the upper edges of modules, as this will restrict the flow of cooling air.
**K-SERIES LOGIC IN A NEMA-12 ENCLOSURE, 16 IN. DEEP, TOP VIEW**

**System Power**

a. **Supply Transformer**

Any filament or "control" transformer rated at 12 v or 12.6 v RMS on nominal 120 v line voltage may be used to supply power to K series logic. However, use of a 12 v instead of a 12.6 v transformer reduces maximum current ratings from K731 and K732 by 15%, as does a 5% voltage drop from any other cause such as resistance in secondary wiring or line voltage below the nominal 10% tolerance.
K716S IN INDUSTRIAL ENCLOSURE

Transformer current rating should be for capacitor-input filter, about 50% higher than the rating required for resistive loads. Thus a single K731 1 amp regulator requires a center-tapped transformer with ¾ ampere rating on resistive loads at 12.6v, or with two 6.3v windings rated ¾ ampere each.

These transformer selection considerations can of course be eliminated by using K741 or K743 transformers with noise filtering built-in.

b. Noise Filtering

Hash filter capacitors of 0.1 mf each are recommended from each side of the power transformer secondary to chassis ground. In environments where the AC line may carry unusually large amounts of noise, line filters such as Sprague Filterols (trademark) are advisable. K series systems must not share 12 volt power with any electromechanical device, since the transformer itself is the primary filter for medium-frequency line noise rejection.

c. Power Wiring

In systems not requiring full use of the quick-change features of the K716 and K940, transformer secondaries can be wired directly to pins U and V of regulator modules. If power connections are to be removed with maximum speed, a W021 connector board may be used to bring 12 VAC power into the system. It is best to limit current through any pin to about 2 amperes, so in large systems several W021 pins are needed for each side of the secondary.
d. Alternate Power Supplies

Any source of 5 VDC ± 10% may be used for K series systems at ordinary room temperatures, provided noise, hash, spikes, turnon-overshoot, etc. are reasonably well controlled. K series modules are far less sensitive to noise on power lines than computer-speed circuits, but it is still possible to cause malfunction or damage if extreme noise is present.

Temperature coefficient of the K731 regulator is selected to compensate for that of timers and other circuits, so operation over temperature extremes with constant-voltage supplies involves a sacrifice in timing consistency. Output fanouts are also degraded if constant voltage supplies are used at extreme low temperatures. Derate linearly from 15 ma at room temperature to 12 ma at −20°C (0°F) for constant-voltage power supplies.

e. Line Failure

When unscheduled shutdown of a K-series system cannot be tolerated in spite of AC power failure, some form of local energy storage is required. To withstand short-term failures it is possible to add extra capacitance from pin A to pin C. However, manual grounding of pin D (turnon level) may be required to start the system, since the external capacitance will appear to the regulator as a short and output current will be limited to a low value. For each ampere millisecond of dc power storage beyond the rise of K731 OK level, 10,000 mfd is required. The supply itself provides one half ampere-millisecond internally. K732 slave regulators each provide one ampere-millisecond internally. However, these survival times are only available when regulators are operating at or below 75% of their nominal ratings.

A 5 volt battery, or a 6 volt battery with series diode(s) to drop the voltage to 5 volts, may be used as an alternate source of power in case of line voltage failure. In very small systems (with some types of batteries) it may be practical to use the battery itself as a shunt regulator, charging it through a simple full-wave rectifier and dropping resistor circuit from the same kind of transformer used with K-series regulators. Unless the current is very low with respect to battery size, however, some means of switching the battery connection will be required. Below is shown a circuit which can be used for current requirements to 1 ampere. The same principle can be extended to larger systems with slightly more complex circuitry.

![Power Failure Switch for Emergency Battery](image-url)
### BASIC APPLICATIONS

#### RELAY LOGIC TO K SERIES

<table>
<thead>
<tr>
<th>K SERIES</th>
<th>MIL.</th>
<th>N.E.M.A.</th>
<th>GENERAL</th>
<th>ELECTRO-MECHANICAL</th>
<th>J.I.C.</th>
<th>2-INPUT AND</th>
<th>EXPANSION TO 5-INPUT AND</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
<td><img src="image.png" alt="Diagram" /></td>
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<tr>
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<th>GENERAL</th>
<th>K SERIES</th>
<th>MIL.</th>
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<td><strong>J.I.C.</strong></td>
<td><strong>(FORM C)</strong></td>
<td><strong>N.E.M.A.</strong></td>
<td><strong>MIL.</strong></td>
</tr>
<tr>
<td><strong>2-INPUT EXCLUSIVE</strong></td>
<td></td>
<td><strong>F(M,T)</strong></td>
<td><strong>F(M,T)</strong></td>
</tr>
<tr>
<td><strong>OR</strong></td>
<td></td>
<td><strong>H(N,0)</strong></td>
<td><strong>M(N,0)</strong></td>
</tr>
<tr>
<td>(A) OR (B) NOT BOTH</td>
<td></td>
<td><strong>D(K,R)</strong></td>
<td><strong>D(K,R)</strong></td>
</tr>
<tr>
<td>(A)</td>
<td></td>
<td><strong>A OR B</strong></td>
<td><strong>A OR B</strong></td>
</tr>
<tr>
<td><strong>BISTABLE (FLIP-FLOP)</strong></td>
<td></td>
<td><strong>SET</strong></td>
<td><strong>SET</strong></td>
</tr>
<tr>
<td>(A)</td>
<td></td>
<td><strong>RST</strong></td>
<td><strong>RST</strong></td>
</tr>
<tr>
<td><strong>OFF DELAY</strong></td>
<td></td>
<td><strong>T SECS DELAY</strong></td>
<td><strong>T SECS DELAY</strong></td>
</tr>
<tr>
<td><strong>OFF-DELAY</strong></td>
<td></td>
<td><strong>CONTACTS SWITCH T SECS.</strong></td>
<td><strong>CONTACTS SWITCH T SECS.</strong></td>
</tr>
<tr>
<td><strong>M(T)</strong></td>
<td></td>
<td><strong>NOT A</strong></td>
<td><strong>NOT A</strong></td>
</tr>
<tr>
<td><strong>M(N,0)</strong></td>
<td></td>
<td><strong>D(K,R)</strong></td>
<td><strong>A OR B</strong></td>
</tr>
<tr>
<td><strong>M(T)</strong></td>
<td></td>
<td><strong>NOT</strong></td>
<td><strong>NOT</strong></td>
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<td><strong>M(N,0)</strong></td>
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<td></td>
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</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td><strong>M(T)</strong></td>
<td></td>
<td><strong>NOT</strong></td>
<td><strong>NOT</strong></td>
</tr>
</tbody>
</table>

*KSO* INPUT SPLIT LUG 3,4,5,7,8,9
OUTPUT J,L,N,R,T,V

*KSO* INPUT SPLIT LUG 3,4,5,7,8,9
OUTPUT J,L,N,R,T,V

SET T, 0 US TO 30 SECS
OUTPUT LEVELS CHANGE T SECS AFTERT START

SET T, 0 US TO 30 SECS
OUTPUT LEVELS CHANGE T SECS AFTERT START
DECODER: BCD TO 10 LINE
### ELECTRO-MECHANICAL

<table>
<thead>
<tr>
<th>J.I.C.</th>
<th>GENERAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Crossbar Selector Diagram" /></td>
<td><img src="image2" alt="General Diagram" /></td>
</tr>
<tr>
<td><img src="image3" alt="Home-to-5 Diagram" /></td>
<td><img src="image4" alt="Step Diagram" /></td>
</tr>
</tbody>
</table>

**Crossbar Selector**

**Home-to-5**

**Step**

---

130
<table>
<thead>
<tr>
<th>K SERIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E.M.A.</td>
</tr>
<tr>
<td><img src="image1" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**K SERIES**

**INPUT SPLIT LUG**

3, 4, 6, 7, 8, 9

**OUTPUT**

J, L, N, R, T, V

**STEP**

K980

D (M, R)

F (M, T)

H (N, U)

**1/3**

K113

**K210**

**H (N, U)**

**0**

**1**

**2**

**4**

**8**

**TO K161 DECODER**

**INPUT SPLIT LUG**

3, 4, 6, 7, 8, 9

**OUTPUT**

J, L, N, R, T, V

**STEP**

K980

D (K, R)

F (M, T)

H (N, U)

**1/3**

K113

**K210**

**H (N, U)**

**0**

**1**

**2**

**4**

**8**

**TO K161 DECODER**

**131**
K SERIES SEQUENCERS — GENERAL

A fundamental part of many K Series systems is a sequencer that controls the progressions from one state or operation to the next state or operation. Four logic elements are available to define the state or operation currently in effect, and there are also several choices of method for moving from each state to the next, and for deriving output signals that include any arbitrary set of states. This note considers each sequencer in a general way, so that their overall merits can be compared before starting detailed design with the 1 or 2 most appropriate. The simplest sequencer of all, consisting of logic gates alone, is not mentioned here; but of course if AND and OR functions by themselves can do the job, splendid.

1. TIMER SEQUENCER

Several independent K303 timers connected in cascade form a very flexible, completely adaptable sequencer. If each timer input is driven by the direct (non-inverted) output of the previous timer, removing logic "1" from the first will cause all the outputs to fall like hesitant dominoes. A pushbutton, limit switch, etc. can then reset all timers by restoring "1" at the first until the next cycle is wanted. Or by connecting the timers in a loop with an odd number of inversions a self-recycling sequencer can be obtained.

The complete adjustability of timer sequencers can be a disadvantage in some applications. When more than 3 or 4 steps are needed, the sheer number of knobs to twiddle begins to lead toward possible confusion and perhaps "provocative maintenance."

2. COUNTER SEQUENCER

One K210 counter provides up to 16 sequence states, and many more are obtainable by cascading. The counter may be stepped along by a fixed-frequency source such as the line frequency, or by a K303 clock. It is also possible to generate stepping pulses by completion signals from the processes being sequenced. K184 rate multipliers can be conveniently used to produce such pulses. Counter sequencers recycle without external aids at 9 or 15 (BCD or binary connections) and may be set to recycle at other steps as shown in K210 specifications.

Counter sequencers offer the most discrete states for the money, and the entire sequence can be scaled up or down in time simply by adjusting the input stepping rate. However, if many different output signals are to be derived from a counter sequencer, the gating can become complex unless the signals required happen to fit those available from K161 octal decoders or from the counter directly.

3. SHIFT SEQUENCERS

K230 shift registers can be connected as ordinary ring counters or as switch-tail ring counters. Specialized shift sequencers such as Barker
code (pseudo-random) sequencers are also possible. The most generally useful type is the switch-tail (Johnson code) ring counter, in which the last stage is fed back inverted into the first. This provides two states for every flip-flop, or 8 states if all four flip-flops in a K230 are utilized. The pattern achieved is the same falling-domino behavior obtained with the non-recirculating timer sequencer, except that the “dominoes” fall up one-by-one after they have finished falling down. Either fixed frequency or event-completion signals can be used to step a shift sequencer, just as for counter sequencers.

Shift sequencers cost more per state than counter sequencers. Their only advantage lies in the fact that any state or any collection of contiguous states can be detected by a simple 2-input gate. Not only does this feature simplify the derivation of many overlapping output signals, but it also offers excellent flexibility for modifications after construction. The need for only two connections to generate any once-per-sequence signal to start and end at any arbitrary state even permits practical patch-panel programming of output signals.

4. POLYFLOP SEQUENCERS

If the state or operation in progress is to be determined in many cases by a combination of external factors, instead of primarily by the sequencer itself, a polyflop may be the best solution. A polyflop is simply a multi-state circuit which will remember the last state into which it was forced until the next input comes along. Polyflops can have any number of states, though the practical limit is probably 8 or fewer. Set-reset flip-flops are a very common special case of the polyflop, having 2 states. If you want a name for the next six types you could call them triplop, quadraflp, pentaflp, hexaflp, septaflp, and octaflp.

The general polyflop is built from as many K113 inverting gates as there are states required, each with input AND expansion sufficient to gate together all outputs by the one that gate controls. Thus any one low output will force all other outputs high. Polyflops do not establish any fixed order through the possible steps as the other three sequencers do, and so perhaps should be called state memories rather than state sequencers. However, there are some situations in which a polyflop is found to be a superior replacement for one of the more sequencers, such as where several different outside signals must be able to force the control into corresponding specific states immediately without passing through the normal sequence.

### SUMMARY

<table>
<thead>
<tr>
<th>Sequencer Type</th>
<th>Relative Cost per State</th>
<th>Modification Flexibility</th>
<th>Other Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timer</td>
<td>highest</td>
<td>easiest</td>
<td>Can be self-stepping</td>
</tr>
<tr>
<td>Counter</td>
<td>low-med</td>
<td>fair</td>
<td>Best for many states, few outputs</td>
</tr>
<tr>
<td>Shifter</td>
<td>medium</td>
<td>good</td>
<td>Suitable for patch panel setup</td>
</tr>
<tr>
<td>Polyflop</td>
<td>medium</td>
<td>fair</td>
<td>States may be forced in any order</td>
</tr>
</tbody>
</table>
TIMER SEQUENCERS

The simplest and most obvious way to sequence operations or states on a machine or in a control system is to use several timers in cascade. Below is shown a simple three-state timers sequencer.

A pushbutton, clock, or another sequencer can provide signal A that resets all timers and begins the sequence. Any number of timers may be cascaded, but if many steps are needed one of the less flexible sequencers should be considered as a means of reducing the number of adjustments and the cost.

Outputs other than those available directly from the timers can be obtained by a two-input gate connected to appropriate direct or inverter timer outputs. For example, a signal true during both T₂ and T₃ can be obtained by ANDing output D with the inversion of output B. The possibility of deriving any once-per-cycle output from this type of sequencer with two-input gates only is a virtue shared with switch-tail shifting sequencers.
The inverted output from the last timer in the chain may be used to provide the initiate signal resulting in self-recycling. However, sufficiently large timing capacitors must be in use to allow the initiate signal to rise all the way to \( +5 \text{ V} \) if normal relations between timing RC and time delays are to be maintained.

Three inversions, or any odd number of inversions must be contained within a self-recycling loop.

Many variations are possible by combining timer sequencers with other types of sequencers, branching to auxiliary sequencer chains, gating timer inputs from external devices, etc.

Finished wiring has a neat appearance and is easy to troubleshoot if wired point-to-point as recommended.
COUNTER SEQUENCERS

Counter sequencers offer the largest number of discrete steps for the money, since for N flip-flops up to $2^N$ states are obtainable. A single K210 counter, for example, offers up to 16 states for $27.

A source of timing signals, such as the "line sync" output from the K731 or a K303 clock may be used to advance a counter sequencer at uniform increments of time. In addition, event completion signals may be used to gate, augment, or substitute for the uniform time signal. One way to substitute for time signals is to use a K184 Rate Multiplier as if it were four separate differentiating pulse generators with ORed outputs.

The principal disadvantage of counter sequencers is gating complexity, if many outputs must be derived which are not simply the flip-flop outputs themselves. Counter sequencers are most suitable for high-resolution sequencing of relatively few outputs whose relationship to sequencer states is unlikely to be modified after construction.

A crosspoint matrix offers reasonably low cost and good flexibility for developing counter sequencers with large numbers of states. For example, the 64 state sequencer shown here costs about $100 before any 2-input state detectors are added.
The desired states may be detected one-by-one using any two-input AND gate such as those of gates K113, K123, or K134, or two-input gates on other modules like K210 counters, K230 shift registers, K303 timers, K604 or K614 AC switches, K644 or K656 DC drivers, etc. Or several states may be combined by ORing the outputs of several two-input AND gates as shown below.
SHIFTER SEQUENCERS

An alternate to the Counter Sequencer for generating many outputs, especially where some of the output sequences may be revised after construction, is the switch-tail shift ring.

Any one state can be detected by a single 2 input gate. For example, state 2 is true if B is high and C is low; state 4 is true if A and D are both high, etc. Moreover, any contiguous array of states may be detected by a gate of only two inputs. For example, state 2, 3, and 4 can be combined by a two-input gate that looks for A and B both high. This convenient characteristic not only reduces the cost and complexity of output gating, but also makes last minute changes easy since no new gates have to be added to modify the steps to which a given output gate responds, so long as they are contiguous. Also, notice that state 0 is on an equal footing with the others so that "contiguous" states may include or span the zero or home state.

The two input gating rule could be exploited to permit patch-panel coding of a general-purpose sequencer. One possible arrangement for such a panel is shown here, for a four flip-flop sequencer. In use, one would simply AND start and finish signals that span the desired state or states.

<table>
<thead>
<tr>
<th>START</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
</tr>
<tr>
<td>FINISH</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
<td>⊗</td>
</tr>
<tr>
<td>STATE</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

PATCH PANEL

For the special case of four states to be spanned, only one connection is required. Observe that to span more than half the available states, it is necessary to detect their complement and invert.

Switch-tail shift rings can be driven from all of the same sources as counter sequencers, and may be extended to as many states as desired. If N is the number of shift register flip-flops, 2^N states will be obtained in the sequencer.
POLYFLOP SEQUENCERS

Just as a flip-flop can be set to one of two states and remember it, a logic circuit that has three, four, or more states will remember the last of its several states to which it has been set.

The fundamental principle of the polyflop is that each inverting AND gate must have an input from all other outputs but its own.

<table>
<thead>
<tr>
<th>POLYFLOP</th>
<th>K113</th>
<th>K003</th>
<th>MODULE COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIFLOP</td>
<td>1</td>
<td>0</td>
<td>$11.00</td>
</tr>
<tr>
<td>QUADRAFLOP</td>
<td>1-1/3</td>
<td>1-1/3</td>
<td>$20.00</td>
</tr>
<tr>
<td>PENTAFLOP</td>
<td>1-2/3</td>
<td>1-2/3</td>
<td>$25.00</td>
</tr>
<tr>
<td>HEXAFLOP</td>
<td>2</td>
<td>2</td>
<td>$30.00</td>
</tr>
<tr>
<td>SEPTAFLOP</td>
<td>2-1/3</td>
<td>4-2/3</td>
<td>$44.33</td>
</tr>
<tr>
<td>OCTAFLLOP</td>
<td>2-2/3</td>
<td>5-1/3</td>
<td>$51.00</td>
</tr>
<tr>
<td>NONAFLOP</td>
<td>3</td>
<td>6</td>
<td>$57.00</td>
</tr>
</tbody>
</table>

The table above shows the components needed to build polyflops in the practical range of sizes. Module cost figures refer only to module sections actually used, and there is a significant amount of wiring required for the larger polyflops. Nevertheless, there will be circumstances in which a polyflop is more efficient than either a more conventional sequencer or a collection of ordinary set-reset flip-flops. Through the OR-expansion capability of K113 gates, external signals can be readily gated into a polyflop using low cost gate expanders. Selected output is low; all others high.
USING K303 TIMERS AS ONE-SHOTS

By itself, a K303 timer goes to the one state when its input goes high and waits there, not starting to time out until the input returns low. Sometimes, however, it is convenient to start the entire cycle on an input change from low to high, without waiting for the input to return low. This behavior is that of the "one-shot" (also called single-shot or monostable multivibrator).

A K113 gate with a capacitor tied from its OR expansion node to ground can be used to obtain the necessary differentiating action. This capacitor should be the same size as the timing capacitor being used on the associated K303 circuit.

The K113 delay is about 3% of the maximum delay obtainable when using the same capacitor with a 250 KΩ timing resistor on the K303. The delay of the K113 is fixed, so the minimum K303 delay obtainable in this use is larger than normal.

The input must remain high for this same 3% interval, and should dwell in the low state at least twice this long for good repeatability.
USING K303 TIMERS FOR FREQUENCY SETPOINT

A K303 timer will reset to the start of its timing cycle when its inputs become high regardless of its previous state. This feature can be exploited to distinguish two pulse repetition rates, to detect a missing pulse in an otherwise continuous pulsetrain, or to close a frequency-regulating feedback loop. (Note: Where critical requirements are placed on K303 timing consistency in the millisecond range, consider the use of a low-ripple supply such as H710 to minimize modulation of the timing period at the ripple frequency.

![Diagram of input and output signals with K303 setting, missed pulse, and end of pulsetrain labeled]

Input signal can be a square wave or pulses of any width down to 0.3% of the maximum delay available with the timing capacitor used. (Pulsewidths down to 0.1% or less may be used if timing consistency can be sacrificed). Timer delay would normally be set 30% to 50% longer than the nominal pulse repetition rate to detect missed pulses in a train, or at the geometric mean between two pulse periods which are to be distinguished.

By cascading timers, pulses as short as 300 nanoseconds may be stretched to any length needed. However, pulses less than several microseconds in length do not produce consistent or predictable time delays from the K303, and are only recommended for pulse-stretching (using built-in 0.002 mf timing capacitor).
COMBINING K WITH M-SERIES MODULES

There are several types of applications in which a combination of M and K Series modules is better than either one alone, such as interfacing a K Series system to a computer or interfacing an M Series system to electromechanical devices. Here are the things to consider and recommended designs for both pulses and levels in each direction.

TIMING

Timing considerations are important, but unfortunately are not reducible to simple rules: as in any other logic design task, interfacing K with M Series modules requires adherence to all timing constraints of the output device, the input device, and the logic loops (if any) as a whole. As a minimum, M Series signal driving K Series circuits must last long enough (at least 4 microseconds even if no propagation within the K Series is required) so that the K Series will not reject it as if it were noise; and as a minimum, K Series signals driving M Series circuits must be received by M Series inputs that will not be confused by ultra-slow risetimes.

**K TO M SERIES LEVELS**

![Diagram of K to M Series Level Converter]

Note: Total lead length connected to input of first M Series gate should be less than 6 inches, to minimize any tendency toward oscillation while active region is being traversed. Do not use slowed K Series levels. If noise still gets through, a .001 capacitor from M Series input pin to ground can be added.

**M TO K SERIES LEVELS**

1. Diode gate inputs (K113, K123, etc.) and drivers with flexprint cables (K604, K644, K671) may be paralleled freely with M Series inputs.

2. M Series outputs should not be paralleled (wired AND) with K Series outputs.

3. K303 inputs and K220, K230 readin gate inputs require the full 5 volt K Series swing, and normally should not be paralleled with M Series inputs. Also in this category are clear inputs to K202, K210, K220, and K230. M Series gate outputs will rise all the way to +5V if no M Series inputs are paralleled these points.

4. Other K Series inputs generally may be driven directly, but in some cases heavy capacitive loading will slow the transitions.
M TO K SERIES PULSES

Use a type M302 delay multivibrator set for at least 5 μsec (capacitor pins H1-L2 or S1-S2). Observe same restrictions on K Series inputs to be driven as listed above under "M to K Series levels."

Loading
Driving M from K Series modules, each risetime-insensitive input should be regarded as a 2mA K Series load, and K Series inputs may be freely mixed with M Series inputs up to the total K Series fanout of 15 milliamperes. M Series inputs could be regarded as 1.6mA each if more complicated rules and qualifications concerning use with K303 timers and reduction in low-output noise rejection were established, but the 2mA equivalence is simpler and safer.

Driving K from M Series, each milliampere of K Series load should be regarded as one M Series unit load.
COMBINING K WITH A SERIES MODULES

The voltage breakdown ratings of K series gate module inputs (K113, K123, K134) is high enough to withstand the ±10 volt output swing of an amplifier such as A207, with correct gate output levels. This fact allows the A207 to be used not only as operational amplifier, but also as a comparator. A 12 bit slow speed analog-to-digital counter-type converter is made possible by using the A207 output directly as a logic signal.

In operation, the counter starts at zero and counts up until the D to A converter output just exceeds the analog input. As the comparator inputs reverse their polarity relationship, the comparator output switches and inhibits the clock. The counter is left holding a number representing the analog input voltage.

The 20 microsecond recovery time of the A207 used as a comparator restricts operation to below 50 KHz. In the system shown here, the comparator “done” signal forces the clock output to the high state. Operation is re-started by clearing the counter or by an increase in the analog voltage. If a control flip-flop were added between the comparator and the gate, action could be halted regardless of input voltage change until a new “start” signal. Maximum conversion time is 4095 times 30 microseconds, or about 120 milliseconds. (The extra 10 microseconds allows for counter carry propagation time and the time required for the A613 output to change one small step).
A faster converter may also be built using up/down counters or by building a successive-approximation type of converter.
COMBINING K WITH R SERIES MODULES

For conversion from R series or other zero-and-minus levels to K series levels, the W603 (seven circuits, $23) may be used. When driving gate module or timer inputs, and most other K series inputs as well, pins B and V may be left open if desired (no $+10$ V supply). For conversion from K series to R series levels, use W512 (seven circuits, $25). For a more complete description of these FLIP CHIP modules, ask for the DIGITAL LOGIC HANDBOOK C-105.

There are two modules in the R series which can be used directly in the K series: The R001 and R002 gate expanders. The R001 is convenient for adding one extra input to a K-Series expandable AND gate, while the R002 can facilitate multiple inputs to several expandable AND gates from the same logic signal.

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R001 DIODE NETWORK

R002 DIODE NETWORK

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<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>O</td>
<td>E</td>
<td>F</td>
<td>H</td>
</tr>
<tr>
<td>J</td>
<td>O</td>
<td>K</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>N</td>
<td>O</td>
<td>P</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>T</td>
<td>O</td>
<td>U</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R001 — $4
R002 — $5
PULSE GENERATOR FROM NAND GATES

An effective pulse generator is formed by adding a capacitor to the OR node of a K113 inverting gate, as shown below. The circuit converts positive level transitions to pulses for clearing flip-flops, etc. Pulse width is slightly greater than 1000 μC: 1.0 microfarad produces 1.0 to 1.5 millisecond pulses, 0.01 microfarad produces 10 to 15 microsecond pulses. The input must remain low for several times the pulse width for reasonable pulse width consistency.

![Pulse Generator Diagram]

Each K003 gate expander module includes a 0.01 mf capacitor from pin B to ground, suitable for use in this circuit to obtain pulses approximately ten microseconds wide. This is essentially the same scheme used to obtain one-shot behavior with K303 timers.

Inverted output pulses for clearing flip-flop registers, etc. may be obtained by substituting a K113 for the K123 gate shown.
USING K210s FOR LONG ODD-MODULUS COUNTERS

The pulse generator shown on the previous page can be incorporated with K210 counters to obtain counts at non-binary moduli above 16, the limit for a single K210. Below is shown a modulus 24 counter, as would be required for a digital clock.

The basic principle involved is to detect the largest number to be permitted, and to generate a clear pulse when it disappears due to the reception of one more count. The same method may be extended to counters of any length, provided the clear pulsewidth is wide enough to override any possible carry propagation.
Shaft Angle Pickup Quadrature to Pulse Converter

Photoelectric shaft-angle transducers generate signals A and B in quadrature. Where maximum resolution and/or two-way counting is desired, the scheme below can be used to interface the amplified transducer outputs to the counter control shown on K220 data pages.
ANNUNCIATORS

In the simplest type of annunciator, a single alarm device is triggered by any abnormal occurrence, and a lamp is lighted by the occurrence to identify it. An inexpensive annunciator of this type can be built by taking advantage of the four Schmitt triggers and differentiators in the K184 module as indicated below. If silver contacts are to be sensed, auxiliary load and higher voltage must be used, preferably 120 VAC with K604-K716 or K614. Any number of inputs may be handled by ORing K184 outputs (wired OR possible for up to 5 K184s). The normal 5 μsec K184 pulselength should be stretched to 140 μsec for use with a slowed-down alarm flip-flop by putting a 0.1 mf capacitor from each K184 pin J to ground.

**SIMPLE ANNUNCIATOR FOR FOUR DRY CONTACTS**

In larger systems or where an abnormal occurrence may be too brief to be identified from a simple direct driven indicator, flip-flop memory must be added to each line to set up this sequence of operations:

<table>
<thead>
<tr>
<th>ALARM STATUS</th>
<th>ANNUNCIATOR LAMP STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No Alarm</td>
<td>Off</td>
</tr>
<tr>
<td>2. Alarm — Unacknowledged</td>
<td>Flashing (2Hz)</td>
</tr>
<tr>
<td>3. Alarm — Acknowledged</td>
<td>Steady</td>
</tr>
</tbody>
</table>

The Flash Supply is generated at a suitably low frequency by a K303 Clock with K375 Timer Control. This supply is available for distribution to other similar stages in a system.

The Alarm F.F. is set with an Alarm Input at Logic 1, the K580 controls the Alarm 0 to 1 response time. (See K580 data sheet) This allows the Lamp to flash. The Alarm F.F. is not cancelled, should the Alarm Input return to Logic 0. The initial Alarm must first be acknowledged manually before the Alarm F.F. is reset. Acknowledging the Alarm changes the Lamp from Flashing to Steady, and prepares the Alarm F.F. for Reset by the Alarm Input returning to Logic 0.
K Series Modules per Annunciator

<table>
<thead>
<tr>
<th>MODULE TYPE</th>
<th>NUMBER REQUIRED</th>
<th>NUMBERS OF CIRCUITS USED</th>
<th>COST PER LINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>K003</td>
<td>1 @ $ 4.00</td>
<td>3 of 3</td>
<td>$ 4.00</td>
</tr>
<tr>
<td>K113</td>
<td>1 @ $11.00</td>
<td>1 of 3</td>
<td>$ 3.60</td>
</tr>
<tr>
<td>K123</td>
<td>1 @ $12.00</td>
<td>3 of 3</td>
<td>$12.00</td>
</tr>
<tr>
<td>K134</td>
<td>1 @ $13.00</td>
<td>1 of 4</td>
<td>$ 4.33</td>
</tr>
<tr>
<td>K580</td>
<td>1 @ $20.00</td>
<td>1 of 8</td>
<td>$ 2.50</td>
</tr>
<tr>
<td>K681</td>
<td>1 @ $15.00</td>
<td>1 of 8</td>
<td>$ 1.80</td>
</tr>
</tbody>
</table>

TOTAL $28.23

The cost of common items, K303, K375, Power supplies etc., must be spread equally over the number of Annunciators in a system to get the true cost per stage.
THUMBWHEELS AND MULTIPLEXING THEM WITH K581

Binary-coded decimal thumbwheel switches of many sizes and types are available to provide convenient manual data entry into K220 and K230 readin gates via K580 switch filters. Below are listed some of the many types that can be used this way:

<table>
<thead>
<tr>
<th>MANUFACTURER’S TYPE</th>
<th>PANEL CUTOUT HEIGHT</th>
<th>WIDTH PER DIGIT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digitran 315</td>
<td>1.380”</td>
<td>0.500”</td>
</tr>
<tr>
<td>Digitran 13015</td>
<td>2.000”</td>
<td>0.500”</td>
</tr>
<tr>
<td>Digitran 715</td>
<td>0.980”</td>
<td>0.500”</td>
</tr>
<tr>
<td>Digitran 8015</td>
<td>0.980”</td>
<td>0.500”</td>
</tr>
<tr>
<td>Digitran 9015</td>
<td>1.375”</td>
<td>0.600”</td>
</tr>
<tr>
<td>EECo 5305</td>
<td>0.960”</td>
<td>0.500”</td>
</tr>
</tbody>
</table>

*Note: Additional “zero digits” width generally required in panel cutout.

The simplest hookup uses one K580 for every two decimal digits as shown here.

Power for the unmultiplexed system can be obtained from a 10 volt DC power supply or by using the circuit shown here with the auxiliary 12.6v winding on the K743 transformer.
Where more than one or two thumbwheel registers are needed it may be economic to multiplex several digits through the same K581 circuits as shown below. This scheme requires diodes to be mounted on the switches, as provided for by all of the types listed above. IN4001 diodes may be used.

To sequence through the registers, it is necessary to turn on one K683 circuit at a time; this can be done by a K161 binary to octal decoder. Since no BCD decade can draw more than 60 milliamperes, as many as four decades can be handled on any one K683 switch. Circuits may be paralleled for larger registers.

Notice that K581 outputs will be one diode drop above ground in the "low" state: This restricts multiplexing to use with K220 or K230 readin gates, or to K113, K123, or K134 inputs at 1 milliampere only. If the diode outputs (connector) on K683 are used, noise rejection will be reduced to levels that would normally be unacceptable. Direct (solder lug) connections are definitely recommended.
FIXED MEMORY USING K281

Switch registers such as those shown on the preceding page may be considered as memory devices. Very often a system that needs thumbwheel memory (or flip-flop memory) can also benefit from memory that is not readily changed. By using a K281 board with diodes cut out where “zero” is to be recorded, many types of sequence or character (symbol) codes may be permanently stored in a digital system.

Variations

More 4-bit words:
   a) Use same K161 and K681
   b) Duplicate K281 and K134, tying K134 outputs together
   c) Use pin K inhibit on K134s to select 8 words
   d) Up to 40 4-bit words may be obtained (fanout down to 3)
   e) For more 4-bit words use longer words and gate outputs

Longer Words:
   a) Use same K161 and K681
   b) Duplicate K281 and K134; two for 8 bits, three for 12 bits, etc
   c) Single K681 capable of word lengths to 28 bits
   d) Get more than 8 words as in getting more 4-bit words

Serial Scanout:
   a) Connect word address lines to scanning counter
   b) Tie together K134 outputs
   c) Select word at K134 pins N, R, T, V.
   d) Second K161 can select word at K134 inputs
   e) Scanning and word-address K161s may be swapped
   f) This system is expandable in two dimensions also

Note: The K681 Lamp Driver lacks the noise immunity and output slowdown designed into all of the general-purpose K-Series logic modules. For this reason it is important to take advantage of congruent pin assignments by assigning adjacent module slots to K161, K681, K281, and K134 modules used in memory applications.

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PARALLEL COUNTERS

The counters shown elsewhere in this handbook are "serial" counters: that is, the input to a counter module of high significance is the simple output of the next less significant flip-flop, resulting in a time difference between groups of outputs (within anyone K210, K220, or K230 module all outputs switch essentially simultaneously).

If a long counter is driving a large decoder, or if flip-flop outputs from different parts of the counter are being gated together for any purpose, carry propagation time down a serial counter can give rise to false transients lasting several microseconds from the decoder or gating. In effect, the carry propagation time causes the counter to pass through one or more wrong counts on the way to the correct state.

The solution is to feed count pulses in parallel to all modules simultaneously, but gating the pulses to modules of high significance with the "1" outputs from all bits of lesser significance. Observe that modules of higher significance would need input gates expanded to 9, 13, or 17 inputs for 12, 16, and 20 flip-flop counters respectively.
JAMMING DATA INTO K220, K230

The "clear" and "read ones" inputs on these modules may be combined to obtain the effect of a "jam." That is, completely new data may be stored in a single operation regardless of previous flip-flop states. However, the "read ones" (pin D) input must wait to rise at least 4 microseconds after the clear input rises, to give the clearing action time to die away. A simple way to accomplish this delay is shown below.

![Diagram showing the delay circuit](attachment:image)

10 \( \mu \text{s} \) OR MORE

DIODE AND CAPACITOR IN K003 AS RISE DELAY

This circuit gives about 10 microseconds of rise delay. The K003 capacitor discharges on jam input fall through the K003 diode, but the diode opens to force the pin D load current alone to recharge the capacitor, which takes time. The delay may be reduced if desired to about 5 microseconds by connecting another one milliampere pull-up (pin D to pin E on the K003 shown above).

Several "read ones" inputs may be driven from a single K003 section, provided the capacitance is multiplied by the same number. However, the heavy capacitive loading may cause slow falltimes on the jam input line. Pin D inputs on K220 and K230 may be regarded as 1 milliampere loads in this application.
K184 RATE MULTIPLIER

The K184 Rate Multiplier accepts an input pulse frequency \( f_1 \), via a Binary Counter, multiplies this by a Binary Fraction \( F \), and emits a pulse train, with average frequency \( f_0 = f_1 \times F \). Note that \( f_0 \) is always less than \( f_1 \), also that the Counter and Fraction are Binary; the Fraction being presented in reverse order to the K184. FIG 1a shows how a K184 with the Binary Fraction preset on switches, generates the product frequency \( f_0 \).

Since this frequency is average, and not periodic, some digital smoothing may be added; \( f_1 \) can then be preselected, to control Hydraulic or Pneumatic Valve opening and closing rates, Stepping Motor velocities etc.

The resolution of the system is increased by cascading K184 modules and Counters. The K184 outputs, \( f_0 \), are simply commoned in this case.
PRINCIPLE OF K184 OPERATION

As shown above, the input clock frequency $f_1$ generates a binary sequence in the Clock Counter. The 1, 2, 4, and 8 Counter outputs, when connected to the K184 Clock inputs, generate pulses in the K184 on $0 \rightarrow 1$ transitions. Note that no two $0 \rightarrow 1$ transitions are ever in coincidence. Also notice that of all possible pulses, all but one are obtainable if each $0 \rightarrow 1$ transition is allowed through; but when all bits simultaneously return to the zero state, no pulse is available. Thus the maximum output rates for 4, 8, and 12 bit rate multipliers are $15/16$, 255/256, and $4095/4096$ of the input rates.
ADVANCED APPLICATION

RATE SQUARER

This circuit shows one of the many fascinating and useful tricks possible with rate multipliers. Here the output rate varies as the square of the input rate, so that, for example, a flywheel rotation rate could be read out in units of stored energy, etc.

SEQUENCE OF OPERATION

0. K230 holds previous rate number; K210s cleared
1. Gate f₀ to K210 counter for fixed period
2. Stop counter at end of interval; clear K230s and read in
3. Clear K210 and return to step 1.

<table>
<thead>
<tr>
<th>MODULE</th>
<th>COST</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>K210</td>
<td>@</td>
<td>$27.</td>
</tr>
<tr>
<td>K230</td>
<td>@</td>
<td>36.</td>
</tr>
<tr>
<td>K184</td>
<td>@</td>
<td>18.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$162.00</td>
</tr>
</tbody>
</table>

NOTE: f₀ is regarded as a fraction, where 1.0 is that frequency which just fills the counter during the count interval. Average output rate is the product of current count rate times the average rate in the previous interval.
K184 AS A DIGITAL INTEGRATOR

If the fraction \( F \), to a K184 is derived from a Counter also incremented by the input frequency \( f_i \), \( f_o \) increases, on average, in a linear fashion.

As shown below, if the FRACTION K210 overflows from 1111 to 0000, \( f_o \) will fall to zero and begin again to increment as before. The result is a Digital Sawtooth generator. \( f_o \) against time \( t \) is shown here.

Resolution can be increased by module cascading. If the Fraction Counter is a K220 UP/DOWN Counter connected for Binary operation,\(^*\) then the slope of \( f_o \) can be reversed and controlled symmetrically.

\(^*\)(Pins BD, BE grounded)
The output of the K184 shown above, is on average, a linearly increasing frequency when the K220 counts UP, and a linearly decreasing frequency on K220 count DOWN. This facility is of use in controlling Stepping Motor Acceleration on K220 UP counts, and Deceleration on DOWN counts. The Fraction Counter must not be allowed to overflow.

The response of $f_o$ shown above is average and must be smoothed digitally to remove unacceptably large variations in pulse spacing; which would cause for example a Stepping Motor to change velocity instantaneously during the Acceleration period.

For more on rate multipliers, see references on K184 data page.
SERIAL ADDER

When speed is not paramount, one can sum the contents of two K230 shift registers bit-by-bit at low cost. The result can go back into one of the source registers.

Clock output CLK, 1 to 0 transitions, shift serially the addend and augend contained in K230 Shift Registers, A and B. The contents of the Registers are serially summed with the Carry In bits from the Carry flip-flop.

Carry Out signals, and CLK signal 1 to 0 transitions, cause the Carry Out flip-flop to be Set or Reset, ie Carry or No-Carry.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>carry in</th>
<th>sum</th>
<th>carry out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
STEPPING MOTORS

INTRODUCTION

There are two fundamental parts to the design of any stepping motor drive system: Designing the logic for correct sequencing, and electromechanical design. Several logic designs are shown on the next few pages; here first is a brief discussion of electromechanical aspects.

Much of the emphasis in stepping motor system design is on maximizing stepping rates. There are two components in maximizing stepper speed: Maximizing the rate of motor current rise and delay, and operating within the motor's limitations of torque, friction and stiffness during the critical acceleration — deceleration phase. Successful design results in accurate stepping with no missed or gratuitous steps.

To optimize the response speed of any magnetically operated device, a minimum requirement is that the ratio of circuit inductance to circuit resistance be less than the desired response time. Thus if response of 1 millisecond is required in a one henry winding, the total of winding resistance and series padding resistance should be greater than 1000 ohms. If this ratio (L/R or henries-divided-by-ohms) equals or exceeds the desired response time in seconds, electrical effects tend to be the dominant limitation on speed and override mechanical factors.

The design problem is complicated by the increase in winding inductance as motion is accomplished. The inductance at turnoff may be many times the inductance at turnon in efficient devices such as solenoids. However, many types of stepping motors are designed to achieve maximum performance at the expense of efficiency, and the inductance of these motors may vary only a negligible amount (less than 10%) as rotor position changes. Since inductance ratios are generally unpublished, the best approach may be to start with equal resistance and then measure the actual current rise and fall times, increasing the turnoff resistance if necessary later. (In all of this, the driving transistors are assumed to switch in zero time, as they respond in microseconds whereas L/R ratios are generally in the millisecond range.)
Notice that during turnoff the switching transistor experiences a voltage equal to the supply voltage for the equal case, but larger than the supply voltage if additional turnoff resistance \( R_{pp} \) is added. Since the voltage rating of the driver is the limiting factor on the minimum \( L/R \) that can be achieved with a given inductance, the ratio of drive transistor voltage rating to supply voltage should be adjusted as indicated below for optimum electrical response:

\[
\frac{V_T}{V_S} = \frac{L_{off}}{L_{on}} = \frac{R_L + R_F + R_{pp}}{R_L + R_F}
\]

Operating within the stepper’s limitations of torque, friction, and stiffness during acceleration and deceleration is trickier than it looks, especially since some crucial constant may be omitted from published specifications for the device. There is often the wish to avoid abrupt (full frequency) starts and stops to achieve maximum stepping rates. Often only one or two steps need to be slowed to achieve maximum acceleration error-free. Too gradual change in stepping rate can actually encourage errors if inertia is moderate and friction low, caused by an actual resonant reversal of rotation at some particular step.

All of the logic circuits shown on the next pages can be used with any clock rate profile. It is best, however, to use an abrupt start-stop system unless the need for ultimate performance warrants a full study of system dynamics, including the use of a tachometer on the stepper shaft to observe the effect of proposed frequency profiling.
SLO-SYN® STEPPER SEQUENCER

A K202 flip-flop module, connected as shown, forms a reversible switch-tail ring counter. With the "direction" input logic 1, 1 to 0 transitions on the "step input" index a bifilar stepping motor forward. With logic 0 on the direction input, the direction is reversed.

A d.c. driver controlled by the switch-tail counter provides power for the stepping motor.

*SLO-SYN is a trademark of Superior Electric Co.
RESPONSYN® STEPPER SEQUENCER

This sequencer uses the same two bit shift register with inverted feedback as the SLO-SYN sequencer, but the outputs are gated to obtain the different drive pattern required by these motors.

*RESPONSYN is a trademark of United Shoe Machinery Corp.
**FUJITSU STEPPER SEQUENCER**

FUJITSU Stepper motors can be driven forward and reverse, with the module arrangement shown. The table describes the stepping sequence required by a FUJITSU 5 torquer motor (with or without hydraulic servo amplifier).

<table>
<thead>
<tr>
<th>STEP</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
FUJITSU STEPPER MOTOR SEQUENCE.
ANALOG-TO-FREQUENCY CONVERTERS

When a relatively slow-varying or constant analog signal must be transmitted some distance through noise, some form of current-to-frequency or voltage-to-frequency conversion is appropriate. There are really two distinct sets of benefits to be gained:

1. Analog noise will be averaged, and may be almost entirely nullified even if it is comparable to the signal in amplitude. Normally the frequency is sampled for an exact internal number of line-frequency cycles to average power frequency coupling to zero. High noise frequencies are mostly averaged out by the conversion device itself.

2. Digital noise will be averaged also, since one or two extra pulses or missed pulses represent a small fraction of the total number. In addition, the digital form of the measured quantity is inherently noise resistant since noise less than the switching threshold at the receiver has truly no influence whatever.

The improved transmissibility of analog data both before and after the conversion to an equivalent frequency has to be paid for in reduced speed of response to changes. (From the viewpoint of an information theoretist, such a transmission mode would be said to deliver high redundancy and low information rate.) But many sensors on slowly varying processes which are distant from an associated digital system are ideally suited for this treatment.

The diagram below shows how an operational amplifier may be utilized to provide direct conversion from an analog voltage to an equivalent frequency with errors in the tens of millivolts. This scheme measures how long current in the input resistor R takes to charge the capacitor C ten millivolts. Each time this occurs, the output switches to the other state and discharges the capacitor rapidly.

![VOLTAGE-TO-FREQUENCY CONVERTER Diagram](image)

Resistance R should be about 1000 to 10,000 ohms to achieve a balance between error due to wide pulsewidth at high frequency and error due to the biasing effect of amplifier input current. To minimize the effect of amplifier switching time, capacitor C should be large enough (100 mfd with $R=1000\Omega$, for example) to limit maximum full-scale frequency to around one kiloHertz. Nearly any quality silicon diode and PNP transistor with at least 30 volt ratings could be used, and the small capacitor with its associated current limiting resistor is not critical either. Other components should be selected carefully to minimize drift and temperature coefficient.

K303 clock circuits can be modified by the additional parts shown below to achieve lower performance conversion at a saving. Basically, a current source controlled by the input signal being converted replaces the action of the timing resistor R shown in the Handbook diagrams. Transistors can be any high gain Silicon NPN type such as 2N2219.
If output frequencies are counted for an integral number of power-frequency cycles, clock filler will be compensated along with line frequency pickup on the analog leads.

NOTE:
The small voltage drop (1.5V max) available limits linearity to ±5% or so for this circuit.

FOR POSITIVE INPUTS

NOTE:
Use largest practicable voltage swing. Resistor R should be approximately 3KΩ for each volt of full-scale input swing. Linearity can be improved to about ±1% of full scale by using input voltage swings upwards of 10 volts.

FOR NEGATIVE INPUTS
USING K604, K614 WITH 240 VOLTS

These isolated AC switches have semiconductors and other components rated for 240 volt service. However, the Triac switches used were rated primarily for phase control applications. The difference is that some switching applications require an "off" switch to remain substantially off in the presence of transients and noise, without conducting for even one half of one cycle. Since a transient voltage, larger than the breakdown voltage of these devices (400 volts) can cause them to start and remain conducting until several milliseconds later when the load current returns to zero, the K604 and K614 contain transient-clipping devices across each circuit which go into conduction between the peak voltage of a 120 volt line (200 volts) and the Triac breakdown voltage (400 volts).

Triac switches are not readily available at present with breakdown ratings above 400 volts. However, K604 and K614 switches can successfully be used in 240 volt service if two types of application are distinguished:

1. Critical loads: For example, a hydraulic solenoid valve controlling the liquid metal on a die-casting machine, an ignition transformer on a process boiler, a trip solenoid on a punch press; any use involving both fast response and a potential safety hazard. For such applications, two circuits should be connected in series, so that any undesired conduction will be limited to the actual duration (usually microseconds) of a transient or noise spike. Wiring K614 outputs in series is simple because two terminals are provided on each circuit. To put K604 outputs in series, use K782 terminals or see K716 data page for connector cable information. Note indicator lamp connections in diagram below.

![Series Connected AC Switches Diagram]
2. Uncritical loads, where spurious conduction for several milliseconds could not be damaging or hazardous. Since the other components are rated for 240 volt service already, simply remove the transient-clipping varistors. These are axial-lead-devices with a black body and metal end-caps, about 2 cm long and 8 mm diameter. Lamp return voltage may be supplied from the load common (240 volts) if a rectifier diode is provided to obtain half-wave operation. In a system containing both modified and unmodified circuits segregate and mark them. Use of unmodified units with 240 volts directly will destroy them by grossly overheating the varistors.
PART II: CONTROL AND DATA ACQUISITION SYSTEMS

Digital equipment is used mainly in four classes of industrial application: solid state control, data logging, computer-based data acquisition, and computer-based control.

Solid state controllers take over the logic, on-off control, and sequencing functions of relay control systems, but with increased speed and reliability, reduced size, and greater flexibility. Solid state analog-to-digital and digital-to-analog converters allow analog sensors and transducers to be used along with digital control techniques. (See the K Series section for a complete description of solid state control techniques).

SOLID STATE CONTROL

In data logging, solid-state logic links an A/D converter or direct digital input to a recording or printout device to provide automatically sequenced, unattended data gathering.

DATA LOGGING
Computerized data acquisition starts with data logging and adds the sorting, computation, display and printout features of the general-purpose computer. It provides operator guides, computes control optimizing and presents management aids.

**COMPUTERIZED DATA ACQUISITION**

Computer based control includes digital and analog output devices that close the control loop at data processing speeds. It also provides a powerful, flexible control not available any other way.

**COMPUTER BASED CONTROL**
DATA LOGGING STATIONS

With a little additional control logic, a recording device turns an A/D converter into an independent data logging system.

Transportable versions can add temporary data logging functions to an existing process or control system, for quick problem diagnosis or general investigation. Unattended data loggers are useful at inaccessible sites or in dangerous locations.

Once connected to sensors and placed in automatic self-sequenced operation, a data logger takes periodic measurements and stores data on punched paper tape or magnetic tape. If there are many inputs, channel-identification can be recorded along with the data. A real-time clock can be added to record time-of-day periodically.

After a period of unattended operation, recorded tape may be sent to a computer for reduction, analysis, or printout.

Punched paper tape is economical and can be interpreted by almost any computer. Incremental tape recorders handle larger volumes of data at faster rate. These special start-stop tape transports record data one character at a time on magnetic tape, with high information density (200 or 556 characters per inch). The format is the same as that used with standard computer magnetic tape equipment, so that the tape can be played back into a computer continuously at high speed.

Even in a heavily-instrumented process controller, some extra data logging may be needed now and then to investigate new areas. In a paper mill, for example, a logger might be installed temporarily to gather data about dryer temperature, paper moisture content, paper speed and the number of faults in a given production run. A simple control input panel permits recording of identifying codes such as production run number, date, or type of paper. Sensors (for example, retransmitting slide wires on graphic recorders) can supply the A/D converter section of the logger with temperature, speed, and moisture analog signals. A digital fault indicator signal can be fed directly to the logger control. Left unattended, the logger will accumulate data over as many productions runs as desired. Data tapes can be collected periodically and run through a data processor for reduction and analysis. When the job is complete at one location, the data logger can be disconnected and installed elsewhere to investigate other problems. There is no need to disrupt the process or interfere with normal control functions.
INDUSTRIAL COMPUTER INSTALLATIONS

Since the first computer-controlled process went "on stream" in 1959, high-speed computers, built by Digital Equipment Corporation, have played an increasing role in new plant instrumentation. DIGITAL has supplied over 100 computers for this purpose, both directly to the end users and to instrumentation companies for inclusion in complete plant systems.

In steel mills in the U.S. and Europe, blast furnaces and open hearths are being pushed to higher production and safer operation with PDP computers. Slab mills and finishing mills are being monitored and controlled with a resulting increase in both throughput and yield.

Heavy chemical plants throughout the world use computers in their process control systems. In distillation towers, reaction vessels, heat exchangers, and extraction columns, the computer can maintain temperatures, control flow rates, and adjust other process parameters to reduce cycling, maintain optimum conditions, maximize yield, and increase profitability. Control can be exercised on an overall plant basis, rather than unit by unit.

Nuclear reactors present one of the most difficult of all control jobs — and are now being successfully handled by computers. In a nuclear reactor, as in all process control functions, safety of the operators and the surrounding community is a paramount consideration. But, where a chemical plant may take several minutes to achieve an "out-of-control" state, a nuclear reactor may reach this point in seconds or fractions of seconds. PDP computers are being used to control several of the more complex reactor systems in the free world.

A cookie plant in Chicago is totally controlled by a PDP computer. Ingredients are mixed, their flow adjusted, and the proper oven temperatures maintained — all without operator intervention. The computer even adjusts batches to a variety of recipes based on the inventory of the ingredients in the batch.

Power utilities have turned to PDP computer based systems to control plant start-up, power generation, and power network distribution. The digital computer, with large auxiliary storage systems, can follow precise and detailed start-up procedures, can quickly and accurately supply calculations from which generation and distribution decisions can be made, and can also keep the extremely accurate records required by the Federal Power Commission.

All of the above applications, and many more, require the computer system to be able to read thermocouple and strain gauge values, to sense and change valve positions to control stepping motors, and to otherwise interface to analog and digital elements in the process. To this end, DIGITAL supplies complete data acquisition systems (INDAC) including a full line of both high and low level signal conditioning and control equipment — A/D converters, multiplexers, integrating digital voltmeters, scanners, amplifiers, sample-and-hold systems, thermocouple reference junctions, sense and pulse lines and D/A converters.
In most control installations, variables are monitored by some sort of recording equipment so that operators can keep track of current status and process trends and disturbances. Multi-channel analog graphic recorders permit a comparison of many variables referenced to a known time base. However, stripcharts can only be interpreted with limited accuracy and the reduction and correlation of data take considerable time and effort.

The high speed, accuracy and data handling flexibility of digital computer systems can lead to data gathering techniques beyond the ability of simple displays and recorders. Once process variables are converted to digital form, all the resources of automatic digital data processing may be applied to the task, from a simple strip printout to sophisticated data reduction and correlation resulting in a labeled and tabulated printout. Data acquisition applications range from a single-channel A/D converter measuring slow-changing data once per minute to an automatically sequenced multi-channel system that scales inputs, performs limit checks and logical decisions, and formats data for recording on magnetic or punched tape.

The basic elements of a computerized data acquisition system are illustrated below.

**DATA ACQUISITION SYSTEM**

**Analog Inputs**

Process sensors such as thermocouples, potentiometers, strain gauges and flow meters convert physical events or quantities to proportionally-varying electrical signals. These signals must be converted to digital numbers acceptable to a data processor.

Signal conditioning may be required for impedance matching, to supply excitation voltage for passive transducers, to provide amplification for low-level signals, or to transmit signals over long lines.

Multiplexing is required to time-share the A/D converter when many inputs must be scanned.
The type of analog-digital converter and multiplexer combination can determine whether signal conditioning is needed. Multiplexer-converters that use solid state switching operate at the highest scanning rates but require high-level input signals. A converter system that uses guarded three-wire-multiplexing and differential amplification, or one using a voltage-to-frequency conversion method, will often accept low-level signals from strain gauges or thermocouples without conditioning.

Digital Inputs
In addition to converted analog inputs, the computer can accept digital or contact-closure information. Process-related on-off signals such as alarms, limit indications, and selector switch settings can then be correlated with the analog data. Direct digital transducers such as turbine flow meters and digital shaft position encoders interface to digital input channels without the intermediate A/D conversion.

Digital inputs may need signal conditioning to match the computer’s logic levels. Excitation voltage may be needed for contacts. Pulses must be stored long enough for the computer to sample them.

A few digital inputs are simply gated into the computer at programmed intervals. Computing time is saved if the digital input system interrupts the computer and requests read-in only when the data changes, or when an external “read” request occurs.

When the number of input lines exceeds the computer word length, a scanning technique must be used. The digital input channel connects a group (12, 18, or 36 lines) of digital signals to the computer input lines, then connects the next group of signals to the same input lines, and so on. Systems of this type can be expanded to handle thousands of inputs. Input groups can be selected by the computer program, or the scanner can sequence from group to group automatically, interrupting the computer when each group is ready to be sampled.

Real-time Clocks
A special variety of digital input is the real-time clock. The simplest type generates timing pulses that cause a computer interrupt; an internal computer memory location counts elapsed time. The clock source can be either a multivibrator or the 60 Hz power line. Another type, a preset interval timer, is set up by the computer and enabled to count. When the count equals a preset value, an interrupt is generated. The third type is a true elapsed-time counter that can be set to zero, then sampled at any time by the computer.

Role of the Computer
DATA HANDLING: Once the inputs are brought into computer memory, the data can be verified, manipulated, formatted, printed out, and displayed in a variety of ways. The arbitrary voltage or frequency readings from the A/D converter can be compared against limits and converted to meaningful engineering units (3.26 millivolts from one sensor may correspond to ± 132°F; from another sensor, the same voltage might signify “84 gallons per minute”). Standard data handling programming can be used to sort the data, arrange related data in labeled columns, add the time of reading, and initiate print-out by high-speed printer or CRT display. Formatted data can be accumulated by drum or disc mass-storage, then transferred to magnetic tape for later analysis at an off-site data processing center. Through communication links, data can be transferred to remote processors as it is collected. Operators can select blocks of data for display, or adjust conversion factors, by simple keyboard input requests.
Functions that can be performed by the computer in a data acquisition system are summarized below.

Input Data Scanning:
Control the A/D converter, multiplexer, and digital line scanners
Control variable-gain scaling amplifiers preceding the A/D Converter
Modify the scanning sequence based upon either the input data, or operator command, or both
Maintain time of day without the need for an elaborate clock
Count pulses, measure periods and frequencies of recurrent digital inputs

Data Formatting:
Linearize transducer outputs
Correct transducer outputs for zero offset effects
Convert raw data to physical units
Check converted data against upper and lower limits for out-of-tolerance conditions; alarm monitoring, faulty transducer detection
Perform signal averaging, integration, and filtering
Perform logical checks on the data

Calibrating, Failure Detection:
Calibrate analog-to-digital converters by measuring voltage standards
Detect equipment failures in the operating system

Storage, Display, Printout:
Control recording, printout, display devices
Communicate with an operator and present data via printers, X-Y plotters, meters, lights, etc. for best operator comprehension
Maintain data file for on-demand inspection by an operator
Assemble pre-processed data for visual display, recording, or off-line data reduction
Provide “quick-look” results for processes which are of finite time duration after the run is done
Retransmit data over long lines to a remote computer

OPERATOR AIDS: Even without any hardware control links back to the process, a computer-based data acquisition system provides information that will contribute to increased production or process efficiency.

Overall process monitoring can be assisted by a cathode ray tube display system controlled by the computer. CRT displays can be programmed to select stored data and display it in the best form for quick operator comprehension. The equivalent of many process-flow-chart graphic display panels can be stored in computer mass memory, updated as new information is acquired, and displayed when the operator requests.

Oscilloscope-type traces can be presented, prepared from information collected over time scales of seconds, minutes, or days. Simultaneous values of many variables can be compared. Points on curves can be selected by light pen and numerical values printed out on demand. Used in this mode, a cathode-ray tube display functions like a strip-chart recorder, except that it is not a permanent record of the variables being examined. Magnetic core and tape or drum memory form the permanent record, while the display selects
only what the operator needs. Guided by such displays, a central operator can provide essential supervisory control during critical periods such as startup.

COMPUTATION: The ability of the computer to compute, as well as sort and display information, contributes to effective control. Even when the task is basically data gathering, collected data can be analyzed to relate performance to variations in raw materials, equipment design, and ambient conditions. Mathematical models of the process and the applied control techniques can be verified by experiment, and refined to predict the effect of important variables.

MANAGEMENT AIDS: Management aids are another important by-product of computer-based data acquisition. Used off-line, the computer can process production statistics and perform other relatively routine operations. Management can improve decision making and operational control by establishing a detailed process information system. The computer can provide information for: financial planning, production planning, production scheduling and operational control, and accounting information.

COMPUTER-BASED CONTROL SYSTEMS

A computer-based control system uses the basic data acquisition input equipment to pick up analog and digital signals from process sensors. To close the control loop, digital-to-analog converters and digital output channels provide the analog, contact closure, logic level, and pulse outputs required to drive process controllers and actuators. A simple control system with data acquisition input equipment and analog and digital control output facilities is illustrated below.
Analog Outputs
Digital-to-analog converters produce program-controlled voltages to serve as set-point reference voltages for analog controllers, or to drive process actuators directly.

When more than one D/A output channel is needed, the computer output lines are multiplexed to each D/A converter buffer-register in sequence. Data stays in each channel's buffer until it is updated, so the analog outputs hold their assigned values indefinitely.

In some cases, it may be desirable to update all D/A converters at the same instant, rather than one at a time. This can be done with double-buffered D/A converters. These contain an input buffer register that is updated as described above, plus a second register that stores the previous value and controls the value of the D/A converter output.

Digital Outputs
In order to provide drive signals for digital control equipment such as annunciators, indicators, relays, contactors, latching relays, solenoids, or stepper motors, digital output channels are used. These accept parallel computer words under program control, store the words in buffer registers, and convert each bit to on-off digital signals: indicator or relay drive current, contact closures, positive or negative logic levels, set/reset pulses for latching relays, or medium-power outputs.

Role of the Computer
In a control system, the computer acquires data and calculates solutions to control problems, often for many individual control loops in a large plant or processor. In addition, it must deliver control information to the process through analog and digital output channels.

On-Off Control. Startup, power sequencing, interpretation of panel switch inputs, or driving annunciators and solenoids mainly involve the solution of combinational logic statements plus time sequencing.

Setpoint Control. One major application for process control computers is to regulate or replace the computations performed by analog controllers. In this type of control, the computer provides a setpoint reference voltage to the controller. This is an effective way to control the operating range of many control loops with a minimum of operator attention. A single operator at the computer console or display panel can monitor hundreds of individual control loops and make adjustments through keyboard entries. Or the entire operation can be controlled by a supervisory program that continually evaluates plant performance and optimizes each control loop.

Direct Digital Control (DDC). Another approach used in recent process system designs is direct digital control (DDC). Analog controllers are eliminated completely; all the computation is done by the computer, which attends to many individual control loops in sequence, at data processing speeds.
Multiprocessor Systems

Experiments with advanced control techniques and off-line data processing functions, are important side-benefits in a computer process control installation. However, these advanced functions cannot interfere with the basic tasks of on-line closed-loop control, data gathering, and alarm monitoring. Computer installations, because of their powerful data-gathering and correlating ability, almost always suggest areas of growth, and lead to the discovery of easier or more reliable control techniques not anticipated during the initial design phase. Reserves of input/output and data processing capacity are soon put to use. But changes to hardware or programming are resisted because of the off-line time required to assemble and check new programs or to complete and test equipment modifications.

The system illustrated below provides maximum flexibility and growth potential, without compromising the essential on-line control function. Small satellite control computers handle the basic on-line control operations, while a central data processing system supervises and optimizes the overall operation and provides for off-line activity.

The local (satellite) instrumentation control centers could consist of PDP-8/L computers equipped with multiplexed input and output equipment selected from standard subsystems. These interface with standard process instrumentation with a minimum of special hardware or signal conditioning. Data logging, recording, and special control facilities can be added according to the requirements at individual sites.

Satellite computers or data loggers communicate with the central computer via standard data serializer channels. Many satellite stations can be handled by a PDP-8/L or -9 so equipped. This transmission scheme permits interconnecting cable runs up to 2500 feet on standard twisted-pair telephone lines, and much longer distances by modulated frequency data transmission techniques. Satellites can be mounted on mobile carts, with phone jacks installed at each local site at which control is required.

Each satellite can operate independently, scanning its inputs, scaling and applying correction factors, comparing inputs against alarm limits, handling operator-demand functions, calculating control algorithms, and delivering direct control outputs. Significant data can be assembled and transmitted over the communication link for monitoring by the central computer.

The central processor is thus free to supervise the entire operation, coordinate individual satellites, and develop operating-guides and optimization. New or modified programs can be developed off line, as in a stand-alone installation. A real-time library can be maintained and updated without interrupting real-time control. Peripheral equipment selected for the central installation can be expanded to provide an extensive program-preparation and storage center.

Through central program control, set points of the peripheral processors can be optimized, or changes can be made in the control algorithms by program substitution. This yields great flexibility in control technique without hardware modifications and without taking the satellite controllers off line.

Satellite units need not be identical. One site might be reserved for input monitoring and formatting, with a separate site distributing the required digital and analog control output signals. A third independent site might be devoted to operator displays, trend recording, or logging printouts.
MULTIPROCESSOR CONTROL SYSTEM
Digital Equipment Corporation's INDAC Series of computer-based systems are ready to start work the day they are delivered. The basic system configurations are pre-designed with all hardware completely integrated into the system. All standard and optional INDAC hardware is supported by an extensive library of general purpose software as well as special easy-to-use software packages designed specifically to perform data acquisition functions.

INDAC Systems are designed around the field-proven and highly successful PDP general purpose computers and standard peripheral equipment. The basic system configuration includes a standard PDP system controller, one or more voltage to digital converters and/or a digital data input unit. This configuration forms a flexible Data Logging System. The addition of a peripheral auxiliary memory device such as magnetic tape or disc extends the system capabilities and forms a Data Collection and Analysis System. A Status Log and Alarm system requires adding Manual Input and/or a Status and Alarm Console. The process can be placed under computer control by closing the loop with digital to voltage converters and/or digital data output units.

**INDAC System Configuration**

The Basic INDAC system consists of the shaded boxes shown in INDAC systems composite diagram. The system is modular and easily expanded; a system can be purchased which is adequate for present needs and be expanded to meet the demands of plant growth or modification.

With the exception of the Manual Entry, Status and Alarm Consoles and signal conditioning equipment, all hardware shown in the dotted boxes is standard, modular and field installable. The Manual Entry, Status Alarm Consoles, and signal conditioners, are custom designed to meet your particular requirements.

An abbreviated description of each block of the system diagram appears after the figure. Extensive and detailed information on any unit is available.

**INDAC Software**

INDAC software is designed to service the broad data-gathering functions of industry from the experimental bench to the production line. INDAC represents a composite Hardware/Software system designed with the emphasis on simplicity for the beginner without sacrificing powerful data reduction and analysis for the advanced user.

The proven PDP-8 solid-state computer with over 2000 installations has been coupled with a fast 3-wire, scanning IDVM and DF32 disk storage to provide one programmable device that takes the place of many hardwired devices performing single functions. The experimenter or production engineer may now obtain results in minutes instead of hours, results that are not subject to transfer errors from strip charts or recording devices, results that can show calculated averages, means, fits and tolerance exceptions, results now, that allow the user to vary his experiment while he is performing it.
The software language has been tailored specifically to the industrial user. A unique concept in experimental control allows a user to specify a Snapshot or “SNAP” of his entire system or any part of the system. Just as a photographer sets up his subjects and establishes the background, the INDAC user points his “camera” toward the entire system of sensors or focuses his “camera” on some subset that is not behaving properly or that requires close attention. INDAC also permits motion picture analysis by allowing the user to repeat his SNAPS at a predetermined frequency, or a frequency variable by computer analysis, console input or special setpoint panels. DEC provides a wide range of INDAC support routines, callable by the user to perform functions such as linearizing thermocouples, resolving strain gauges and solving equations. DEC also supplies supporting software in the form of an EDITOR — a special program simplifying source creation and FOCAL — a powerful calculating program to assist data analysis.

Software Specifications
INDAC software is divided into three segments to provide the greatest possible error checking before fully committing costly experiments.
A. GENDAC
B. Compiler
C. Object-Time Executive

A. GENDAC
An advanced software tool that allows each user to custom-tailor the specific configuration of hardware he has purchased to produce a minimal software system for his application. Only the software required to process the system purchased is extracted — the result: increased capacity to run experiments or specify analysis.

B. The Compiler
A very powerful program making full use of the DF32 or RF/RS08 disk. Advanced users will recognize the computational capability of FORTRAN; but, the completely renovated I/O sections permit the beginner to specify his process with ease and confidence. Special worksheets prepared by DEC, specifically for INDAC users, allow the beginner to organize his thoughts and prepare his program as though he were specifying his experiment or operation.

C. The Object-Time Executive
The Executive contains an interpretive driver with a console monitor and a complete I/O servicing section. The Executive allows the user to initiate his program by console command. The interpretive driver examines prepared parameters and may initiate the system immediately at load time or defer operation as specified. The Executive handles the full range of DEC optional equipment.

The INDAC Hardware/Software approach to a total system provides all the power of computer-assisted logging and experiment control plus the data reduction and presentation that only a computer can offer.
INDAC SYSTEMS COMPOSITE DIAGRAM

* CONSOLE I/O TYPEWRITER
ON SYSTEMS USING A PDP-8/L, B/D/L SYSTEM CONTROLLER INCLUDES A PAPER TAPE READER AND PUNCH. THE PDP-9 UTILIZES A SEPARATE HI-SPEED PAPER TAPE READER AND PUNCH.
Each INDAC System is built from standard DIGITAL hardware. Basic features and functions of each hardware unit are described below. The standard pre-packaged system can be easily modified to meet special requirements. The systems are truly modular and can be customized to any required degree. Complete technical information and specifications are available for each system component.

**CONTROLLERS** — DIGITAL offers a range of field-proven PDP general-purpose digital computers for a wide variety of data processing and control functions. PDP's are constructed of highly reliable FLIP CHIP digital circuit modules, and include built-in provisions for marginal checking. The resulting overall reliability has earned PDP's a reputation for trouble-free performance. An exceptionally varied line of input-output devices is available, and versatile facilities are provided in the computers to handle these and other devices.

A complete, well-documented package of programming aids accompanies each PDP computer. The package includes a FORTRAN compiler, a symbolic assembler, on-line debugging routines, an editor, and utility, arithmetic, and maintenance routines. The arithmetic subroutines include a floating point package. Input-Output subroutines are prepared for most of DIGITAL's standard optional devices. Extensive maintenance routines are provided. Supporting these programming aids are free training courses at DIGITAL and membership in DECUS, the Digital Equipment Computers Users Society. DECUS provides a means for users to exchange ideas and programs through regularly scheduled symposia. A library of fully documented programs is maintained. Several of the PDP computers are detailed below.

**PDP-8/I**

The PDP-8/I is made with the most advanced TTL monolithic integrated circuits. This design feature makes the controller compact, gives it high reliability and noise immunity.

- **Word Length:** 12 bits
- **Memory:** 4096 to 32,768 words
  - 1.5 microsec cycle time
- **Addressing:** 128 words direct 4096 words
  - single level indirect
- **Add Time:** 3 microsec
- **Multiply Time:** 6 microsec (hardware option)
- **Input/Output Transfer Rate:**
  - Via Data Break: Up to 667,000 words/sec
  - Via I/O Bus: Up to 210,000 words/sec
Number of I/O Devices: 64 max on I/O Bus
7 max on Data Break
(option)
1 on Data Break
(standard)

PDP-8/L
PDP-8/L is the lowest-cost full-scale digital computer recently available. The basic PDP-8/L configuration includes the same fully parallel processor and 4096-word core memory as the PDP-8/I, along with operator’s console and ASR-33 Teletype. Like the PDP-8/I, the PDP-8/L is a single-address, fixed-word-length computer using two complement arithmetic.

Special Features:
Fully parallel processor
Monolithic TTL integrated circuits, identical to those used on the PDP-8/I
Compact size
Full PDP-8/I instruction set
Positive I/O bus
New memory protection feature
ASR-33 Teletype included in base price
Positive data break
I/O conversion panel (required for all current data break options)
Peripheral expansion kit (required for addition of paper tape reader and punch, card reader, plotter and control, scope control, and real-time clock)

CYCLE TIME: 1.6 µsec.
WORD LENGTH: 12 bit.
CORE MEMORY SIZE: 4096 words, expandable to 8192 words.
Digital-to-analog and analog-to-digital converters
Power failure protection

INSTRUCTIONS: 39 instructions may be executed by the basic machine including Teletype. The augmented instructions are microprogrammed to produce more than 200 commands.

INPUT/OUTPUT CAPABILITY:
64 different devices can be individually selected and addressed by command pulses.
PDP-9

System efficiency and accuracy can often be increased by using a controller with a word length greater than 12 bits.

The PDP-9 controller offers several distinct advantages to a data acquisition system. The PDP-9's 18-bit word length saves computer time and memory locations when input data or calculations result in words greater than 16 bits.

The PDP-9 has an input/output transfer rate of up to 18,000,000 bits per second and can address up to 8,192 words directly. The 8,192 word page size reduces program time and difficulty by decreasing the number of indirect address instructions needed.

A comprehensive software package including FORTRAN IV, a MACRO Symbolic Assembler, a monitor system, and diagnostic routines is provided with the basic machine. With the modular software package, PDP-9 users can take full advantage of configurations with mass storage devices and central processor options.

Basic configuration includes a 8,192 word memory, real time clock, Hi-speed Paper Tape Reader and Punch, and a model KSR33 Teleprinter.

Word Length: 18 bits
Addressing: 8,192 words directly
Memory: 8,192 to 32,768 words
1 microsec cycle time
32,768 words single level indirect

PDP-9/L

The PDP-9/L is available at a 4096-word level that fits easily into a dedicated systems environment. Its basic software includes COMPACT, a complete programming system for the 4K PDP-9/L, which offers Assembler, Editor, Math Package, debugging programs (ODT, Trace), and utility programs, all with complete upward compatibility.

Expanded, the PDP-9/L can take full advantage of the powerful Advanced Software System developed for the PDP-9, which encompasses such features as background/foreground programming and FORTRAN IV — medium-scale features for workloads simply beyond the capabilities of compacts. With our background/foreground system, program development can take place concurrently with on-line system functions. Other Advanced Software resources are the macro assembler MACRO-9, debugging system (DDT-9), Symbolic Editor, Peripheral Interchange Program (PIP-9), Linking Loader, Input/Output Programming System, Input/Output Monitor, and Keyboard Monitor.

Special Features:
- 4096 18-bit words of core memory, expandable to 32,768 words.
- 1.5 microsecond cycle time, 3 μsec add time, 13 μsec multiply, 14 μsec divide.
- 8 data channels.
- Up to 256 input/output devices.
- Compact, a complete software system for the 4K PDP-9/L.
- PDP-9/L Advanced Software System for larger machines, offering FORTRAN IV and background/foreground monitor.
- Peripheral options including CRT displays, DECTape, IBM-compatible magnetic tape, disks, printers, plotters, card readers, and analog-to-digital converters, as well as virtually unlimited interfacing capabilities using plug-in Digital modules.
- Price: $19,900, complete with ASR-33 Teleprinter.
ANALOG-TO-DIGITAL CONVERSION
AND MULTIPLEXER SUBSYSTEMS

Five types of high and low level multiplexed analog-to-digital Conversion and Multiplexer subsystems are available for use with the PDP computers. Model AF01 accepts up to 64 single-ended inputs in the 0-10 vdc range with 6- to 12-bit resolution, 35 μsec conversion time, and provisions for sample-and-hold and operational amplifier plug-ins. Model AF04, a guarded scanning digital voltmeter, provides resolution to 0.001%, 10 millivolt to 300 volts range with over-ranging, up to 1000 scanned inputs, 6-digit decimal readout, and 140 db minimum common mode rejection. Characteristics of these units are compared in the table below.

Increased Multiplexer capacity is provided by the AM08 or 9 plus AM02 and/or B mounting hardware. This combination allows the user to have up to 1024 single ended hi level channels. To handle up to 1024 channels of hi/lo level signals requires amplifier(s) (ie AG01) and AM03A's and/or AM03B's. This combination allows full differential guarded multiplexing of signals of 10 mv full scale to 150 vdc full scale. Both Mux systems may be used with the AD08A, AD08B or AF01 converters.

The AD08A and B A/D converters are low cost devices available for the PDP-8 Family of computers.

Subsystems for PDP Computers

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD08A</td>
<td>Single channel 10 bit A/D Converter.</td>
</tr>
<tr>
<td>AD08B</td>
<td>Multiplexed (16 ch) 10 bit A/D Converter.</td>
</tr>
<tr>
<td>AF01</td>
<td>Multiplexed (64 ch) 6-12 bit A/D Converter.</td>
</tr>
<tr>
<td>AM08</td>
<td>1024 channel Multiplex control for the PDP 8 family.</td>
</tr>
<tr>
<td>AM09</td>
<td>1024 channel Multiplex control for the PDP 9 family.</td>
</tr>
<tr>
<td>AM02A</td>
<td>Mounting and input connectors for up to 128 channels of hi level signals — Use A121 MOS-FET switches.</td>
</tr>
<tr>
<td>AM02B</td>
<td>Mounting and input connectors for up to 256 channels of hi level signals — use A121 single pole switch.</td>
</tr>
<tr>
<td>AM03A</td>
<td>Mounting and input connectors for up to 64 channels of hi or low level signals — use A111 three pole switch modules.</td>
</tr>
<tr>
<td>AM03B</td>
<td>Mounting and input connectors for up to 128 channels of hi or low level signals — Use A111. (James Micro Scan) switch modules.</td>
</tr>
<tr>
<td>AG01</td>
<td>Fixed gain differential amplifier.</td>
</tr>
<tr>
<td>AG02</td>
<td>Programmable gain differential amplifier.</td>
</tr>
<tr>
<td>AF04</td>
<td>Guarded Scanning Integrating Digital Voltmeter.</td>
</tr>
<tr>
<td>AC01</td>
<td>8 channel Sample and Hold option for the AD08B, AF01, and AM02.</td>
</tr>
<tr>
<td>AH02</td>
<td>Sample and Hold option for the AD08A and B and AF01.</td>
</tr>
<tr>
<td>AH03</td>
<td>Hi performance Operational Amplifier for the AD08A, AD08B, and AF01.</td>
</tr>
</tbody>
</table>
### EXAMPLES OF SUBSYSTEM CONFIGURATIONS

<table>
<thead>
<tr>
<th>Hi Level</th>
<th>Single Ch.</th>
<th>16 Ch.</th>
<th>64 Ch.</th>
<th>128 Ch.</th>
<th>256 Ch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDP-8</td>
<td>AD08A or ADC1 &amp; ADC8</td>
<td>AD08B</td>
<td>AF01A</td>
<td>AF01A or AD08B &amp; AM08 plus AM02A</td>
<td>AF01A or AD08B &amp; AM08 plus AM02B</td>
</tr>
<tr>
<td>PDP-9</td>
<td>ADC1 &amp; ADC9</td>
<td></td>
<td>AF01B</td>
<td>AF01B &amp; AM09 plus AM02A</td>
<td>AF01B &amp; AM09 plus AM02B</td>
</tr>
<tr>
<td>Lo Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDP-8</td>
<td></td>
<td></td>
<td>AF01A or AD08A &amp; AG01, AM08 &amp; AM03A</td>
<td>AF01A or AD08A &amp; AG01, AM08 &amp; AM03B</td>
<td></td>
</tr>
<tr>
<td>PDP-9</td>
<td></td>
<td></td>
<td>AF01B &amp; AG01, AM09 &amp; AM03A</td>
<td>AF01B &amp; AG01, AM09 &amp; AM03B</td>
<td></td>
</tr>
</tbody>
</table>

Note: For additional expansion up to 1024 channels in 64 channel increments, consult DEC Engineering.
### Analog-To-Digital Conversion and Multiplexing Modules

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>A121</td>
<td>FET analog multiplexer switch — four spot switches per module</td>
<td>$65.00</td>
</tr>
<tr>
<td>A111</td>
<td>Guarder 3PST relays multiplexer switch. Used for multiplexing low level analog signals. Two stitches per single height double width module</td>
<td>$93.00</td>
</tr>
<tr>
<td>A200</td>
<td>Operational Amplifier, signal height double width module</td>
<td>$130.00</td>
</tr>
<tr>
<td>A400</td>
<td>Sample and Hold module. Double height double width module</td>
<td>$330.00</td>
</tr>
<tr>
<td>A608</td>
<td>10 bit D/A converter module. Outputs 0 to +10 v at 10 ma. Double height module</td>
<td>$350.00</td>
</tr>
<tr>
<td>A609</td>
<td>Same as A608 except output is ±10v FS</td>
<td>$375.00</td>
</tr>
<tr>
<td>A800</td>
<td>10 bit A/D converter module conversion time 10 μsec, accuracy 1 part in 1024. Requires an external reference supply. Double height module</td>
<td>$400.00</td>
</tr>
<tr>
<td>A801</td>
<td>Same as A800 except external reference is not required</td>
<td>$450.00</td>
</tr>
</tbody>
</table>

### Digital-To-Analog Conversion Modules

Digital-to-Analog Conversion

To supply the variable dc voltages for analog controller setpoint references or for driving process actuators, several types of digital-to-analog converters are available. Analog output channels at 12-bit precision are supplied by the AA01A D/A converter, which supplies up to three channels. For large numbers of individually controllable dc outputs, the AA05 D/A Converter and Control provides up to 24 10-bit outputs and, with AA07 expansion logic, can be enlarged up to 40 10-bit channels. For any of these D/A converters, operational amplifiers are easily installed to increase output current or reduce output impedance.

- **AA01A**: 1 to 9 twelve bit converters interfaced to PDP computers. Standard AA01A has an output of 0 to-10VFS with a 1,000 ohm source impedance. An amplifier option is available to lower source impedance and modify output voltage.
- **AA05**: Multiplexer Control for up to 64 D/A converter (A608 thru A611). Also provides mounting space for up to 24 D/A conversion modules.
- **AA07**: Expansion chassis used in conjunction with AA05 to expand channel capacity from 24 channels to 64 channels.

*Refer to Logic Handbook for complete specification.*
Prepackaged multi-channel digital input and output subsystems are available as custom options to all the PDP Computers. These subsystems are physically and electrically integrated with the computer installation. Only the input and output connections are needed to put the system into operation.

Digital input subsystems gate contact closure or logic level inputs to the computer on programmed command. Pulse inputs are stored until they can be sampled. When many input lines are involved, they are scanned in groups corresponding to the computer word length.

Digital output subsystems deliver contact closures, switch ac or dc power, or provide pulses on programmed command.

Contact DEC Engineering for complete specifications and prices on the various digital input and output subsystems.
PERIPHERAL EQUIPMENT

Standard Equipment

Console Teleprinter and Control. All PDP computers are equipped with a tele-
type console teleprinter as standard equipment. The teleprinter can be used
to type in or print out information at rates up to 10 characters per second.
For PDP-8 and 8S, the built-in paper tape reader and paper tape punch (10
characters per second) serve as the basic paper tape input/output
facility. The paper tape reader and punch are not interfaced to the PDP-9 or
PDP-10, which have a separate high speed paper tape reader and punch as
standard equipment.

High Speed Paper Tape Reader and Punch, Type PC01. This equipment is
standard on the PDP-9 and PDP-10, and is available as an option to PDP-8
and 8S. The perforated paper tape reader can photoelectrically sense 8-chan-
nel paper tape at a rate of 300 characters per second. Under program con-
trol, data may be read in either alphanumeric or binary modes. The use of a
paper tape reader buffer and buffer full flag permits the continuation of
processing during the reading functions.
The 50 character-per-second paper tape punch is mounted on the same
chassis as the reader. A single output instruction causes an 8-bit character
to be transferred from the PDP accumulator to a punch buffer, from which
it is punched on the tape. Fan-fold paper tape is normally used with the
paper tape reader and punch.

Magnetic Tape Equipment

DECTape, a unique fixed address magnetic tape system, allows on-line pro-
gram debugging or high speed loading and readout. Density is $375 \pm 60$ bpi;
tape speed is 80 ips with a 15 kc character rate. Reads and writes in both
directions: redundant tracks allow less than one transient error in $10^{10}$
characters. Total storage, the equivalent of 4000 feet of perforated tape, is
three million bits per reel.

Other magnetic tape systems include automatic and programmed controls
and high or low density transports. Formats are IBM compatible at recording
densities of 200, 556, and 800 bpi. Transfer rates range from 15 to 90
thousand characters per second. Transports include an electro-pneumatic
design of high performance and low tape stress and wear.

DECTape. The DECTape system provides a unique fixed-address magnetic tape
facility for program and data storage and retrieval. To achieve extreme reli-
ability, convenience, and low cost, DECTape features:
- Fixed position addressing to permit the selective reading or up-dating of
  information without the necessity of reading or rewriting the entire block.
- Automatic word transfers, via the PDP data channel facility, to allow con-
current processing and data transfer.
- Bidirectional operation to allow reading, writing, and searching in either
direction.
- Redundant phase recording to insure transfer reliability, reduce the prob-
  lem of skewing, and minimize bit dropouts.
■ Prerecorded timing and mark tracks to simplify programming and permit block and word addressability.

■ Three-inch diameter tape reels, each holding 3,000,000 bits of information, recorded at 375 bpi and 80 ips.

DECtape Control. The DECtape Control (Type TC01 for PDP-8, Type TC02 for PDP-9, Type TD10 for PDP-10) controls up to eight DECtape transports, Type TU55. Binary information is transferred to and from the PDP computer using the data channel facility. Mode of operation, function, and direction of motion are controlled by status registers which can be loaded and read by the computer. More than one DECtape control can be interfaced to any PDP computer.

DECtape Transport, Type TU55. The DECtape Transport, Type TU55, provides bidirectional reading and writing of three-inch diameter DECtape reels. Each reel can hold 3,000,000 bits of information recorded at 375 bits per inch. Tape moves at 80 inches per second and requires no vacuum columns or capstans.

Industry-Compatible Magnetic Tape Systems. Both 7-channel and 9-channel IBM-compatible magnetic tape systems are available for PDP computers. Transports that operate at 45 inches per second and triple density tape are currently available, and 75 ips transports will soon be announced.

Automatic Magnetic Tape Control. The Automatic Magnetic Tape Control, Type TC58 for PDP-8, TC59 for PDP-9, and TU20 for PDP-10, transfers data to and from IBM-compatible transports via the data channel facility. Up to eight transports can be handled by a single control, and both BCD and binary modes are available. One control can handle both 7-channel and 9-channel transports at both 45 and 75 ips. Read/write functions are controlled by status registers which can be loaded and read by the PDP computer.

Magnetic Tape Transports, Type TU20 and TU20A. The Type TU20 Magnetic Tape Transport can read and write 7-channel IBM-compatible tapes at 45 inches per second and 200, 556, and 800 bits per inch.

Its 9-channel counterpart, the Type TU20 Magnetic Tape Transport, operates at the same speed and recording densities. The TU20A reads or writes either 8-bit or 6-bit characters.

Magnetic Tape Transport, Type TU79 (for PDP-10). The TU79 Magnetic Tape Transport is an advanced single capstan tape drive capable of reading or writing up to 36,000 characters per second at a recording density of 200, 556, or 800 bits-per-inch. Tape speed is 75" per second. Industry standard seven or nine-channel ½ inch tape is used. TU79 is housed in a 31" free-standing cabinet.

Incremental Magnetic Tape Recorders

Incremental tape recorders permit economical, low speed writing or reading of IBM-Compatible tapes. DIGITAL supplies interfaces that adapt the PDP-8 or PDP-9 computer to standard commercial lines. Interfaces are supplied for Incremental Write Only or Incremental Wire — Continuous Read modes of operation. All units employ standard ASCII codes. Direct user purchase and shipment to DIGITAL is preferred. DIGITAL installs the unit in a standard DIGITAL equipment cabinet, connects the interface, and checks out the combination. Rack-mounted models are required.
Plotting Equipment

*Incremental Plotter and Control, Type 350.* The Type 350 Incremental Plotter and Control uses Cal Comp Model 563 or 565 plotters at rates of 12,000 or 18,000 points per minute. Paper width is either 31 inches (Model 563) or 12 inches (Model 565), and plotting increments of 0.005 and 0.01 are available.

*Incremental Plotter Type XY10 (for PDP-10).* The XY10 plotter control interfaces Calcomp 500-series Digital incremental plotters to the PDP-10 I/O bus. The XY10 plotter control can be housed in the same cabinet as the CR10 card reader control and the LP10 line printer control. The control accommodates Calcomp Models 565, 563, 502, and 518 (not supplied). These plotters provide plotting surfaces from 11 x 120 inches to 54 x 72 inches, with resolutions from 0.010 inches to 0.002 inches per step.

**Disc Files**

Discs provide random access bulk storage for large blocks of data (e.g. core dump, system library programs, data files) to and from computer memory.

*Disc File Type DF32.* A fast, low-cost, random-access, bulk-storage device and control for the PDP-8 and PDP-8/S computers. Operating through the 3-cycle break channel of these computers, the DF32 provides 32,768 13-bit words (12 bits plus parity) of storage, and is economically expandable to 131,072 words using Expander Disc Type DS32.

Transfer rate is 66 μsec per word with average access time of 16.67 msec for 60-cycle power, or 80 μsec per word and 20 msec access with 50-cycle power. There are 16 data tracks each storing 2048 words. NRZI recording is used at a density of 1100 bpi.

Two basic assemblies comprise the DF32: the storage unit with read/write electronics, and computer interface logic. The storage unit contains a nickel-cobalt plated disc driven by a hysteresis synchronous motor. Data is recorded on a single disc surface by 16 read/write heads which are in permanent or fixed position. A photo-reflective marker is used on the disc's outer perimeter to denote beginning and end of timing and address tracks.

Disc motor and shaft, read/write data heads, timing and address heads, and photocell assembly are mounted to a base plate. The base plate is mounted on a rack assembly which permits sliding the unit in and out of a standard Digital Equipment Corporation cabinet.

The disc is designed for rack mounting in a 19 inch relay rack. Overall dimensions of the DF32 are 10½ inches high, 19 inches wide, and 23½ inches deep.

*Disc Fill Type RD10 (for PDP-10); See description under PDP-10 Computer.*

**Printers**

*Strip Printers.* To accommodate strip printers as an economical source of hard copy, DIGITAL supplies interfaces that adapt the PDP-8 or PDP-9 computer to three standard commercial lines. All units use the ASCII code and most offer a choice between numeric and alphanumerical character sets.

Direct user purchase and shipment to DIGITAL is preferred. DIGITAL mounts the unit in a standard DIGITAL equipment cabinet, connects the interface, and checks out the combination. Rack-mounted models are required.
GASCHROM-8
Gas Chromatography System

GASCHROM-8 is a computer-based gas chromatograph system that can service 20 or more chromatographs simultaneously. It can automatically reduce and analyze data accurately, repetitively and economically.

- Detects and identifies peaks and shoulders
- Calculates peak areas and peak retention times
- Allocates overlapping peak areas
- Corrects for baseline shift
- Calculates component concentrations
- Identifies peaks
- Applies response factors
- Types a complete analysis report, and allows automatic calibration and on-line updating of analysis methods.

The GASCHROM-8 is designed to save the analyst time, to reduce the possibility of human error, and to increase the efficient scheduling of laboratory instrumentation.

Special Features:

A variable scanning rate
A library facility that maintains up to 100 methods of analysis
An automatic calibration feature for the analyses methods
Interfaces with laboratory equipment and process G.C.’s.
Verifies itself by closing loop control with process G.C.

The facility to update on-line analysis methods, including:
  Print out
  Entry of new methods of analyses
  Deletion of methods
  Alteration of methods
  Audit trial dumps
Quickpoint-8 is the first numerical control tape preparation system that incorporates a low cost computer. It is designed to make two or three axis point-to-point tape preparation easier. It also can be used for two-axis profiling with point-to-point machines.

Special Features:

Absolute or incremental input coordinates: eliminates virtually all computational work.

Shorthand symbols: defines geometrical patterns such as grids, bolt hole circles, and various arrays.

Geometric or random patterns: allows parts programmers to define either pattern and then store temporarily or permanently for use on the same piece part or on different parts.

Automatic output: processes a paper tape in the correct code and format, with properly inserted auxiliary functions.

Erase Feature: allows the operation to erase any line while typing the line.
GEOMETRIC COMMANDS

Geometric commands generate points for 2-axis point-to-point or profiling operations. For instance, a single geometric statement can generate 90 points on a 90° arc in a matter of a few minutes.

INC INCREMENT: Allows incrementing along X or Y axis by specifying in order direction (R, L, U, or D for Right, Left, Up, or Down), increment (distance between holes), and number of holes.

\[
\begin{align*}
\text{INCREMENT} & \\
\rightarrow & \quad \leftarrow \\
+ & \quad + \quad + \quad + \quad + \quad + \quad + \quad + \quad + \\
\text{R} & \\
\end{align*}
\]

LAA LINE AT ANGLE: Allows incrementing along a line at an angle to the X axis by specifying, in order, the increment value, angle, and number of holes.

BHC BOLT HOLE CIRCLE: Allows for computation of bolt holes by specifying, in order, the radius of circle, angle from X axis of first hole, and number of holes.

ARC ARC: Allows for computation of holes along an arc by specifying, in order, the radius of arc, angle from X axis of first hole, incremental angle between holes, number of holes.

GRD GRID: Allows for computation of holes in a grid pattern by specifying in order, direction, increment, and number of lines of each axis.

\[
\begin{align*}
\text{INCREMENT} & \\
\rightarrow & \quad \leftarrow \\
+ & \quad + \quad + \quad + \quad + \quad + \quad + \quad + \\
\text{Y} & \\
\text{INCREMENT} & \\
\uparrow & \quad \uparrow \\
+ & \quad + \quad + \quad + \quad + \\
\text{U} & \\
\text{INCREMENT} & \\
\rightarrow & \quad \leftarrow \\
+ & \quad + \quad + \quad + \quad + \\
\text{R} & \\
\end{align*}
\]

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DEC PRODUCT SUMMARY

DIGITAL manufactures a broad line of general purpose computers and offers a unique line of peripheral equipment and options. PDP-10 is the largest DIGITAL PDP (Programmed Data Processor) computer. PDP-10 is an industry leader in multi-program time-sharing with over one million user hours already logged and proven software. The 36-bit PDP-10 will time-share, batch process, and run hybrid-simulation all simultaneously at an amazingly low price. The 18-bit PDP-9 and 9/L are medium sized DIGITAL computers at small computer prices. PDP-9 offers extensive processing power, background/foreground programming, and many real-time capabilities. And the 12-bit PDP-8 family has made DIGITAL the world's leading manufacturer of small computers. PDP-8, the all time winner, was the first computer to break the $20,000 price barrier and then the PDP-8/S broke the $10,000 barrier. Now, their faster, more economical and more compact successors PDP-8/I and PDP-8/L offer TTL integrated circuit module construction. Many manufacturers have found PDP-8 family computers ideal to build into an integrated system. DIGITAL, for example, builds PDP-8 family computers into an expanding group of systems called Computerpacks. These are integrated hardware and software packages for turnkey use in a number of computer applications. DIGITAL has several Computerpacks for the laboratory, others for typesetting, navigation, education, industrial control and outer acq. and small computer time-sharing. Many original equipment manufacturers use PDP-8 family computers as the central processor for their systems.
PDP-8/I

The PDP-8/I offers the power, speed, and expandability of the highly successful PDP-8, but at a significantly lower price. It provides a new ease of interfacing with a wide range of DEC peripherals, including the new random access disk file. It offers a programming system field-proven in nearly 3,000 Family-of-Eight installations. And, features TTL integrated circuit module construction.

The basic PDP-8/I system features a 1.5 microsecond random access core memory and includes 4096 words of 12-bit core memory, with a plug-in capability of 8192 words in the basic machine; keyboard printer and tape reader punch. Pre-wiring is also included for a high speed paper tape reader and punch, a 100 card-per-minute card reader, an incremental plotter and a scope display as well. Core memory can be expanded to 32,768 words.

In addition to DIGITAL’s new DECdisk, the PDP-8/I operates with a number of other optional devices such as DECTape, high speed perforated tape readers and punches, card equipment, a line printer, analog-to-digital converters, and cathode ray tube displays.

Specifications:

Word Length: 12 bits
Memory: 4096 to 32,768 words; cycle time 1.5 microseconds
Add Time: 3.0 microseconds
In-Out Transfer Rates: 7,992,000 bits per second
Standard I/O Device: ASR-33 Teletypewriter with paper tape reader and punch
PDP-8/L

PDP-8/L is the lowest-cost full-scale digital computer available. The basic PDP-8/L configuration includes the same fully parallel processor and 4,096-word core memory as the PDP-8/I, along with operator's console and ASR-33 Teletype. Like the PDP-8/I, the PDP-8/L is a single-address, fixed-word-length computer using two's complement arithmetic. The operation and performance of the 8/L are essentially the same as the 8/I. Like the PDP-8/I, the PDP-8/L is constructed of TTL integrated circuit modules for economy, ease of maintenance, and compactness (the 8/L measures 8¾ inches high, 19 inches wide, and 20¾ inches deep). The basic difference between the PDP-8/I and the PDP-8/L is that the PDP-8/L does not have most of the internal pre-wiring which allows peripherals to plug directly into the 8/I.

The PDP-8/L has a positive input/output bus that is functionally similar of the PDP-8/I. The 8/L is slightly slower than the 8/I: its memory cycle time is 1.6 microseconds, versus 1.5 microseconds for the 8/I. There is no extended arithmetic option available for the PDP-8/L, and core memory can only be expanded to 8,192 words.

Specifications:

Word Length: 12 bits
Memory: 4096 to 8196 words; cycle time 1.6 μsec
Add time: 3.2 microseconds
In-Out Transfer Rates: 7,500,000 bits per second
Standard I/O Devices: ASR-33 Teletypewriter with paper tape reader and punch.
COMPUTERPACKS

Computerpacks are integrated hardware and software systems that provide a total response to the requirements of a particular computer application. Each Computerpack includes a PDP-8 Family general-purpose computer, an interface with the instruments or equipment used in that particular application, and a specialized software package. The user, whether he’s a research scientist, newspaper publisher, or machine tool manufacturer, need only push a button to get fast, accurate, and reliable results.

And a special bonus comes with every Computerpack: a general-purpose digital computer from the most popular line of small computers ever. When its special-purpose job is done for the day, the PDP-8 Family computer is glad to work overtime on general purpose tasks, like monitoring budgets or solving messy mathematical problems. DIGITAL has Computerpacks for navigation, typesetting, education, nuclear magnetic resonance, gas chromatography, signal averaging, small computer time-sharing, industrial data acquisition and control, numerical control tape preparation, pulse-height-analysis, and data communications.

And integrated applications packages from DIGITAL are not limited to the Computerpacks listed here. New Computerpacks are being developed all the time. DIGITAL can provide all the ingredients for someone who wants to build his own Computerpack: computer, peripheral equipment, and software experience.
LINC-8

The LINC-8 is a computer-based system designed to control experiments and collect and analyze data in the laboratory. The system combines the features of the PDP-8 and the LINC computers, and allows the researcher to choose between the two programming systems available. The researcher simply uses one of the two consoles in the system. Typical biomedical applications for the new system are: arterial shock wave measurements, in-phase triggering of stimuli from EEG alpha waves, processing of single-unit data from the nervous system, EKG processing, and operative conditioning applications.

Other applications for the LINC-8 include research in physics, chemistry, meteorology, oceanography, psychology, radiation, seismology, and acoustics.

The original LINC hardware and software were developed for on-line, real-time laboratory research under grants from the National Institutes of Health and the National Aeronautics and Space Administration. Development began at Massachusetts Institute of Technology and continued at Washington University in St. Louis.

The LINC-8 system includes: a built-in multiplexed analog to digital input facility, a relay register, dual digital LINCTape transports, an alphanumeric oscilloscope display and an ASR-33 teletypewriter. The LINC-8 takes advantage of the PDP-8's input/output bus for additional convenience in interfacing other laboratory instrumentation to the LINC-8 system.

With the LINC-8, the researcher has the option of using the LINC software which has been designed to allow the researcher to write his own programs after minimum instruction or he may use the more advanced PDP-8 programming system which includes FORTRAN. The LINC-8 system "talks" with researchers by displaying instructions and results on the oscilloscope display. Displays combine English language with data displays. To familiarize customers with the new system, Digital offers four courses in programming and maintenance of the LINC-8. These are included in the basic system purchase price.
PDP-9

The PDP-9 is a stored-program, general-purpose digital computer, designed to handle a variety of on-line and real-time scientific applications calling for more computation power than offered by the PDP-8. The basic PDP-9 features a 2-microsecond add time, 8,192 words of 18 bit (plus optional parity bit) core memory; a real-time clock; a 300-character-per-second paper tape reader; a 50-character-per-second tape punch; and input-output teleprinter (Teletype Model KSR-33). Input/Output can be via programmed transfers, data channel transfers, or direct memory access. The maximum I/O transfer rate is 18,000,000 bits-per-second.

Single address instructions are used, with auto-indexing and one level of indirect addressing permitted. A single memory reference instruction can directly address any location in a block of 8,192 words of memory. PDP-9 has a Direct Memory Access channel plus four built-in Data Channels.

The memory can be expanded in 8,192-word increments to a total of 32,768 words. Mass storage devices, such as DECtape, IBM compatible magnetic tape, disks and drums are available as options for the PDP-9, as are a wide variety of other input-output devices and central-processor additions.

A comprehensive software package including FORTRAN IV, a MACRO Symbolic Assembler, a monitor system, and diagnostic routines is provided with the basic machine. With the modular software package, PDP-9 users can program in a device-independent environment to take full advantage of configurations with mass storage devices and central processor options. And with the PDP-9 background/foreground monitor, new software can be tested concurrently with on-line system functions.

Applications for the PDP-9 include its use in biomedicine, process control, chemical instrumentation, display processing hybrid systems and data communications. A special configuration, the PDP-9 MULTIANALYZER, has been designed for physics applications.

Specifications:

Word length: 18 bits
Memory: 8,192 to 32,768 words in 8,192 word increments.
Cycle time: 1.0 microseconds
Add Time: 2 microseconds
In-Out Transfer Rate: Up to 18,000,000 Bits per second
Standard I/O Devices: A 300 character-per-second paper tape reader, a 50 character-per-second paper tape punch and a 10 character-per-second KSR-33 teletype.
Options: DECtape, IBM Compatible magnetic tape, drums, CTRS, A/D converters, line printers, card readers, plotters, etc.
PDP-9/L

The PDP-9/L is available at a 4096-word level that fits easily into a dedicated systems environment. Its basic software includes COMPACT, a complete programming system for the 4K PDP-9/L, which offers Assembler, Editor, Math Package, debugging programs (ODT, Trace), and utility programs, all with complete upward compatibility.

Expanded, the PDP-9/L can take full advantage of the Advanced Software System developed for the PDP-9, which encompasses background/foreground programming and FORTRAN IV — medium-scale features for workloads simply beyond the capabilities of compacts. With our background/foreground system, program development can take place concurrently with on-line system functions. Other Advanced Software resources are the macro assembler MACRO-9, debugging system (DDT-9), Symbolic Editor, Peripheral Interchange Program (PIP-9), Linking Loader, Input/Output Programming System, Input/Output Monitor, and Keyboard Monitor.

Specifications:

- 4096 18-bit words of core memory, expandable to 32,768
- 1.5 microsecond cycle time, 3 \( \mu \)sec add time, 13 \( \mu \)sec multiply, 14 \( \mu \)sec divide
- 8 data channels
- Up to 256 input/output devices
- COMPACT, a complete software system for the 4K PDP-9/L
- PDP-9/L Advanced Software System for larger machines, offering FORTRAN IV and background/foreground monitor
- Peripheral options including CRT displays, DECTape, IBM-compatible magnetic tape, disks, printers, plotters, card readers, and analog-to-digital converters, as well as interfacing capabilities using plug-in Digital modules
- Price: $19,900, complete with ASR-33 Teleprinter
PDP-10

PDP-10 is an expandable, 36-bit computer system. All PDP-10 systems begin with two basic hardware elements: central processor and core memory. The same central processor is used in every PDP-10 configuration, but core memory can be composed of any mix of several modules. The modules vary in size, speed, and cost.

The PDP-10 includes an extremely powerful processor with 15 index registers, 16 accumulators, and from 8,192 to 262,144 words of 36-bit core memory, a 300-character-per-second paper tape reader, a 50-character-per-second paper tape punch, a console teleprint, and a seven-level priority interrupt subsystem. The PDP-10 features an I/O bus which provides 200K word/sec transfer rate; interfaces up to 128 devices with processor. It has 366 instructions, all different and logically complete.

The PDP-10 is designed for on-line and real-time, time-sharing, batch processing, and hybrid simulation applications such as physics and biomedical research, process control, as a departmental computation facility, in simulation and aerospace, chemical instrumentation, display processing and as a science teaching aid.

The software package includes real-time FORTRAN IV, BASIC, a control monitor, a macro assembler, a context editor, a symbolic debugging program, an I/O controller, a peripheral interchange program, a desk calculator and library programs. All software systems assure upward compatibility from the standard 8,192 words of memory through the multiprogramming and swapping systems at both the symbolic and relocatable binary level.

PDP-10 features a 1-microsecond cycle time, a 2.1-microsecond add time, I/O transfer rates up to 7,200,000 bits per second and a modular, proven software package that expands to make full use of all hardware configurations. Memory can be expanded in 8,192 word increments to the maximum directly addressable 262,144 words.
GENERAL PURPOSE ANALOG-DIGITAL CONVERTER/MULTIPLEXERS

Digital offers a wide range of analog-digital and digital-analog converters from a 10-bit single-buffered D/A Converter contained on one double-width FLIP-CHIP™ Module card to multiplexed integrating digital voltmeter with guarded reed relay scanner providing 140db of common mode rejection and expandable to 2,000 input channels.

Digital’s analog-digital converter/multiplexer system is a combined unit with interface for the PDP-8/I, PDP-8/S and PDP-9 computers. The converter and multiplexer are available either as separate units or as a combined unit without computer interfacing. Optional equipment includes input amplifiers and sample and hold circuitry. The converter offers seven front panel selections of speed and word length. Maximum speed: 6 bits, 1.6% accuracy, 9 microseconds. Maximum accuracy: 12 bits, 0.025% accuracy, 35 microseconds. The multiplexer includes from one to 16 multiplexer switch modules, depending on the number of channels required. Any multiple of four channels may be selected to a maximum of 64. The time required to switch from one channel to another is 10 microseconds to within 1 millivolt of the final voltage. The multiplexer/converter combination is conveniently packaged in a single chassis 19 inches wide by 8-11/16 inches high by 19-1/2 inches deep.

DIGITAL also offers a new analog-digital converter for use with the PDP-8/I or PDP-8/S computers to convert an analog input signal to a ten-bit binary number. The A/D Converter is a general purpose successive-approximation type with an accuracy of 0.1% of full scale ±1/2 LSB and a conversion time of 10 μsec. The converter includes cables for connection to the PDP-8 or PDP-8/S I/O Bus and a complete software package with IOT’s and diagnostics.
COMPUTER LAB

The COMPUTER LAB is a new high performance low-cost digital logic trainer. The COMPUTER LAB uses the same monolithic integrated transistor-transistor logic circuitry used in DIGITAL’s latest PDP computers.

The digital logic fundamentals presented by the COMPUTER LAB constitute the basic knowledge required to pursue a career in computer technology as computer technician, engineer, programmer or operator. The COMPUTER LAB will also help the math-oriented student to understand “New Math” concepts because computer logic operates with binary numbers according to Boolean algebraic laws.

Wiring is easy because of the standard logic symbology used on the front panel and the color coded Patchcords which are easily inserted and removed. An improper circuit will not damage the COMPUTER LAB. The faulty circuit merely “waits” for correction.

Features:

- Transistor—Transistor logic circuitry as used in DIGITAL’s PDP computers
- Teaches modern computer logic
- Easy to use: MIL-STD 806 logic symbology on front panel
- Portable: Dimensions of 12 1/2” x 17” x 3 1/4”, weighing only 11 lbs.
- Comprehensive Workbook provides:
  — Ten detailed chapters
  — More than 30 experiments
  — Over 200 hours of laboratory study
  — Dozens of tables and diagrams
  — An extensive appendix section of supplementary information
- Teacher’s Guide with answers, additional text, extra problems, and course plans.
- Low cost: COMPUTER LAB, Workbook and Patchcord set, ready to use $445.00
Discrete components for DIGITAL Modules are positioned and crimped in place at rates up to 2,200 per hour on pantograph controlled inserting machines. Board layouts put like parts in rows, minimizing the effort required to follow the template. Several templates for each module type are generated by numerically controlled milling machines.
DIGITAL EQUIPMENT CORPORATION
Dept. A.
146 Main Street
Maynard, Mass 01754

GENTLEMEN:
Please send a free copy of: ☐ Digital Logic Handbook
☐ Computer Lab Workbook  ☐ Control Handbook

Name _______________________________________
Position _____________________________________
Company _____________________________________
Business _____________________________________
Street _______________________________________
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Telephone: 591-2446 Telex: 781-4068

Digital Equipment Corporation (service only)
c/o Azabu, P.O. Box 23, Tokyo, Japan
Telephone: 431-1554
K Series modules offer the solid-state advantages of small size, reliability, flexibility, and low cost coupled with the additional bonus of easy interconnection. These modules, specifically designed for control systems, feature high noise immunity, ease of design and installation, and hardware compatible with standard industrial enclosures. All-silicon semiconductors and monolithic integrated circuits provide all the logic functions formerly performed by relays, and many which were not practical with relays.