Pinball wizardry

Ever wondered how a pinball machine works? This article takes you for a guided tour of these complex machines.

Neil Dunn

Until quite recently, that seductive demon the pinball machine rattled and clattered its way through a five year life span totally unaided by modern electronic technology. Many of these vintage models are still in service today. With their innards exposed they resemble an old fashioned telephone exchange — there are banks of relays, solenoid operated rotary switches and motor driven counters. All of this electro-mechanical gadgetry is usually powered by a single 28 V source.

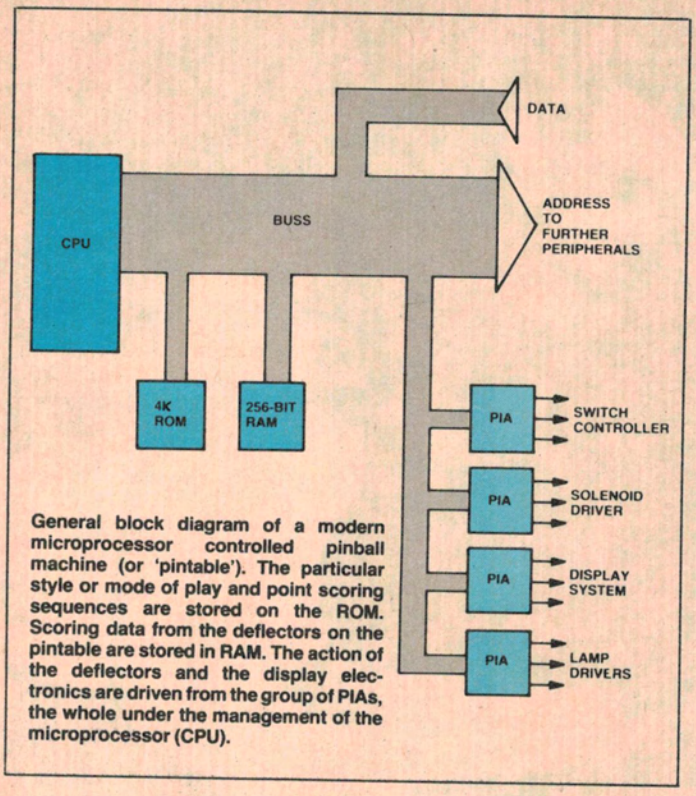
Alternating current is used for the solenoid array, which gives the high current relay contacts at least some chance of survival.

General illumination for the scenery and back glass is provided by 6.3 V 'dial lamps'. Bayonet cap mounted types are used for greater reliability. With anything up to 30 of these lamps used for general illumination and a similar number switched intermittently by relays, currents can easily reach 18 amps. It doesn't require much imagination to visualise the effect of a short on the tightly packed wiring loom if the lighting circuit is unprotected!

Playing the game

A brief review of the game will be helpful at this point. The player starts by projecting a 24 mm steel ball to the top of a sloping playfield area. The fun really begins as the ball commences its short but eventful journey to the dreaded outhole at the bottom of the playfield.

During its travel the ball will come into contact with various strategically placed obstacles. These fall into two ▶



General block diagram of a modern microprocessor controlled pinball machine (or 'pintable'). The particular style or mode of play and point scoring sequences are stored on the ROM. Scoring data from the deflectors on the pintable are stored in RAM. The action of the deflectors and the display electronics are driven from the group of PIAs, the whole under the management of the microprocessor (CPU).

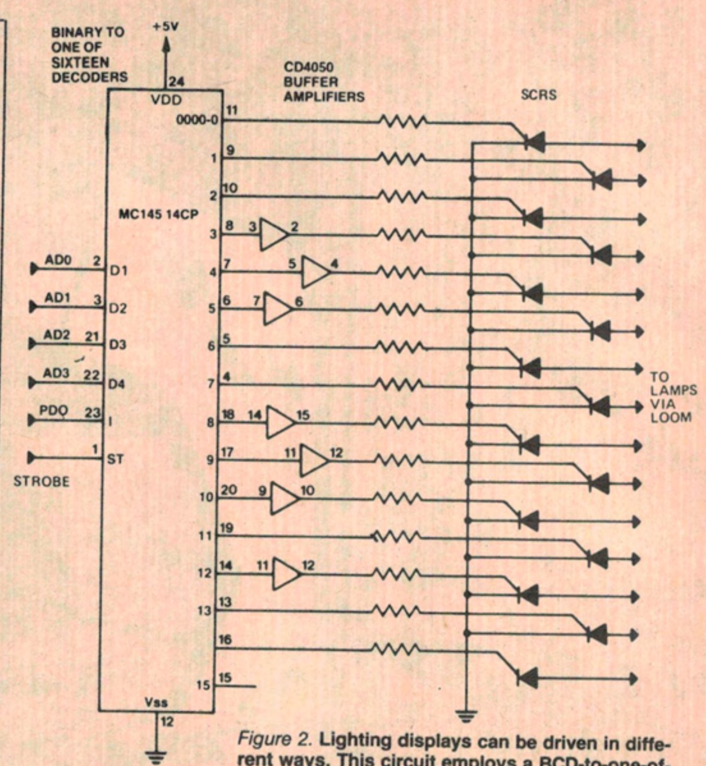


Figure 2. **Lighting displays can be driven in different ways. This circuit employs a BCD-to-one-of-sixteen decoder driving an array of SCRs which control the lamps.**

categories: passive deflectors, which are simply high quality rubber O-rings stretched around posts, and active deflectors which, generally speaking, sense the presence of the ball by means of leaf switches and use solenoid power to increase its speed on some new, and usually quite random, trajectory.

Every time the ball hits a deflector the player scores points — perhaps ten, perhaps ten thousand — which are accumulated in a mechanical counter. Simple logic circuits are usually incorporated so that particular sequences of deflector impacts accumulate bonus points. If the score reaches a predetermined total, the player wins a free game.

The player can try to hold the ball in play, and thereby gain points towards that elusive free game score, by controlling two or more 'flipper' arms which are capable of diverting the ball from its downward path.

To prevent anyone tilting the whole table to keep the ball in play, most pinball machines include one or more mercury or pendulum switches which make contact when the table is tilted more than a few degrees, actuating a relay which stops the game.

Flippers

These electro-mechanical devices have not been changed or adapted to electronic control in even the newest generation of microprocessor driven pintables. The power required for this function is quite considerable. Most

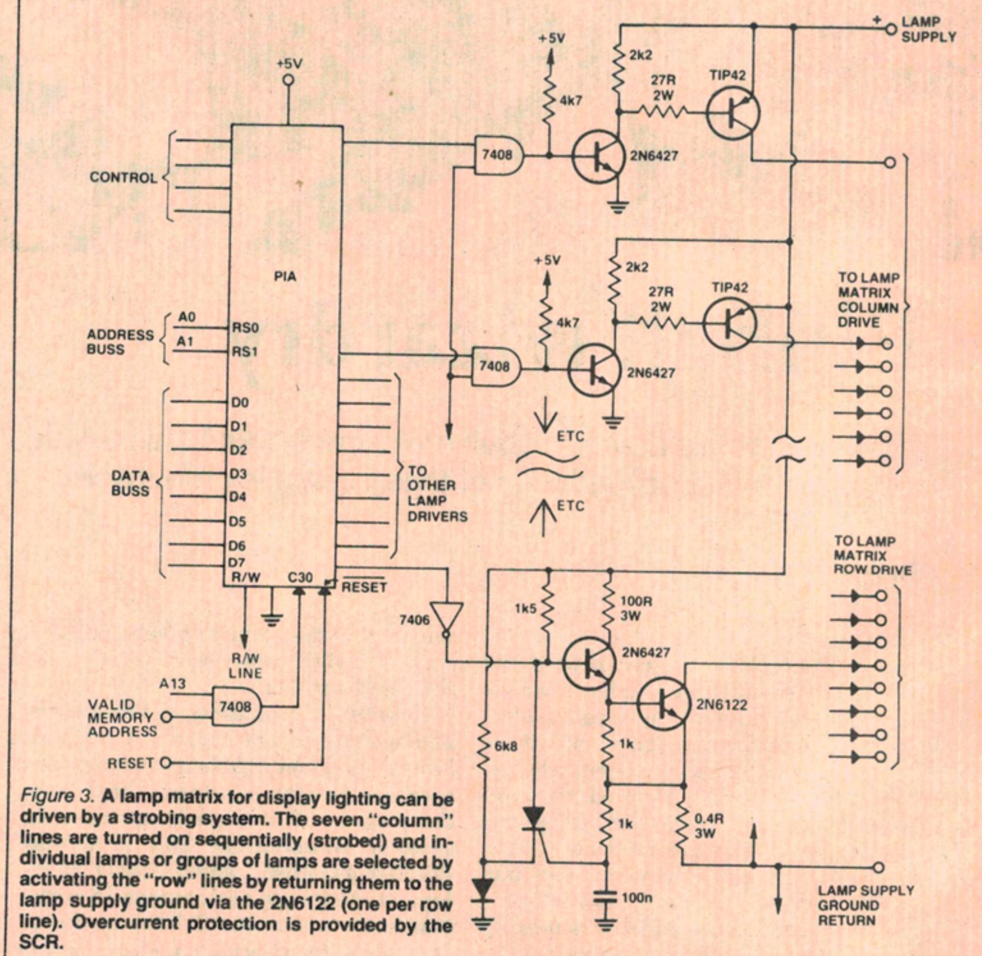


Figure 3. **A lamp matrix for display lighting can be driven by a strobing system. The seven "column" lines are turned on sequentially (strobed) and individual lamps or groups of lamps are selected by activating the "row" lines by returning them to the lamp supply ground via the 2N6122 (one per row line). Overcurrent protection is provided by the SCR.**

flipper solenoids, which are linked to the flipper bar by connecting rod and crank pin, operate from about 24 V and draw starting currents around 10 amps.

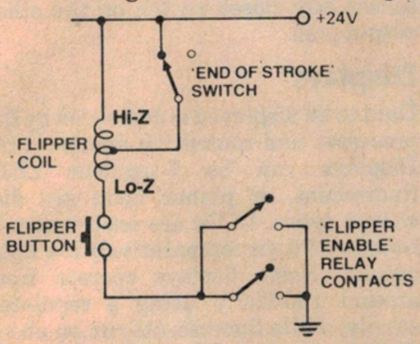


Figure 1. **The flippers are driven by a solenoid having two coils — one high impedance (Hi-Z), one low impedance (Lo-Z).**

Figure 1 shows a typical flipper circuit. The 'flipper enable' relays are closed when a coin is inserted in the slot. Note that in the rest state the 'end of stroke' switch is closed. This means that the higher impedance coil of the solenoid is effectively shorted out. Pressing the flipper button causes a high current to flow in the Lo-Z coil which generates an intense magnetic field, operating the flipper.

At the end of the flipper stroke a mechanical linkage opens the 'end of stroke' switch. This cuts off the low impedance coil and allows current to flow through the high impedance coil instead, which maintains a strong enough magnetic field to hold the flipper in position without drawing excessive power.

Lighting

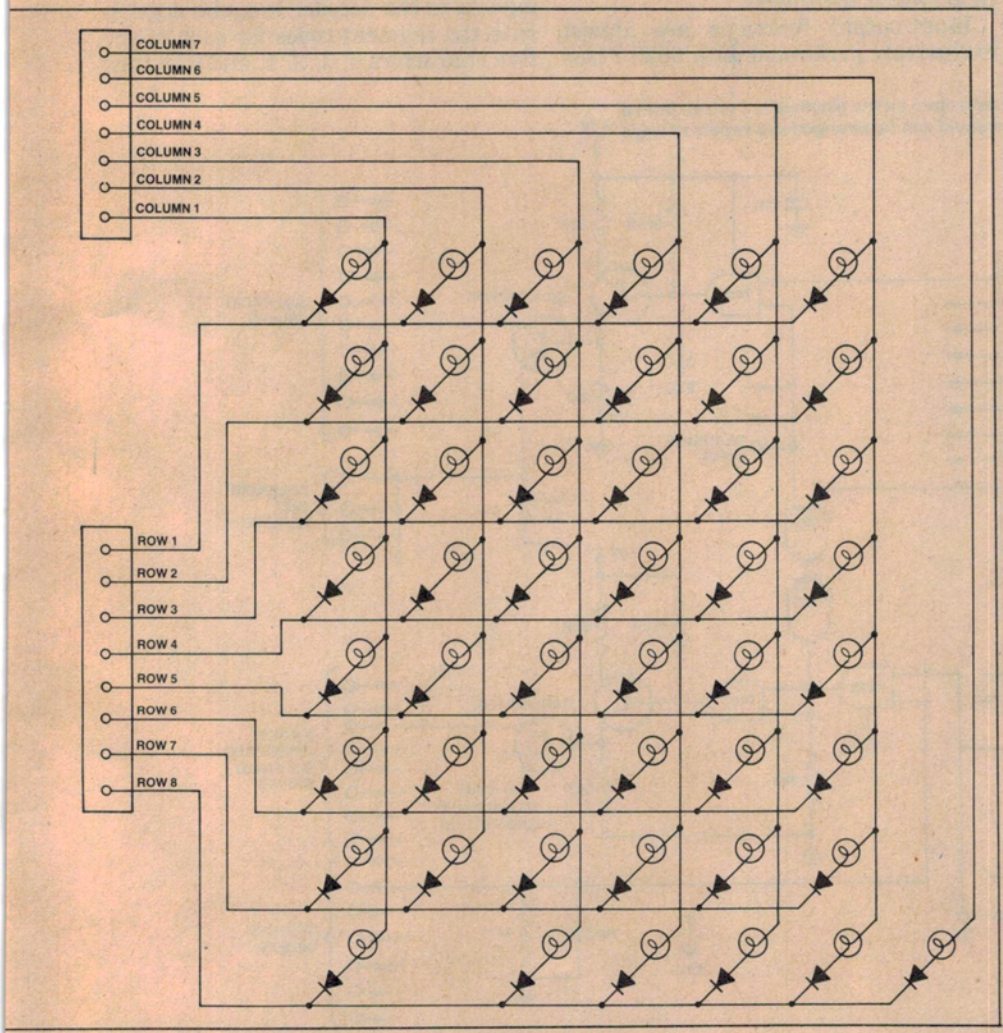
The more modern machines, with their strobing light shows and spectacular artwork are much more inviting than their predecessors. There may easily be as many as 60 lamps, which are controlled or driven in one of two ways.

The first alternative is to use individually driven transistors or SCRs. A typical circuit is shown in Figure 2. The SCRs or transistors (usually low power Darlingtons) are driven directly from TTL outputs or in some cases, CMOS running at 5 V.

The second method is to form a matrix of seven strobe lines and eight return lines. Figure 3 illustrates this. The eight strobe line drivers are turned on sequentially and only one is on at a time. A lamp anywhere in the matrix can be controlled simply by controlling the return line driver at the time the lamp's strobe line is active. All the return lines may sometimes be switched in at the same time so that each strobe driver must be able to conduct eight times the current of each of the return line drivers, but only for 1/8th of the time. This strobing technique reduces power supply current. Because each lamp's duty cycle is only 1 in 8, a high voltage supply is needed to put a strong enough pulse through the filament to provide a satisfactory RMS power output. Overcurrent protection is usually provided in the return line drivers as short circuits in lamp holders would otherwise be disastrous! This arrangement will allow the system to withstand a permanent short circuit on any lamp circuit without any other lamp being affected.

Data and strobe signals are usually provided directly by a microprocessor. As with all matrices of this type, isolating diodes are used on each lamp so that only one strobe line at a time will be active. Scanning speed is invariably high enough to eliminate flicker, so that all lamps may appear to be illuminated simultaneously.

In the system using individual SCRs the data source is usually a CMOS 4-to-16 line decoder/latch driving 15 lamps. Four of these are used, each one being accessed by the processor as a separate 4-bit output port. The disadvantage of this is that only four lamps can be on simultaneously.



Microprocessors

The most popular choice of CPU is the 6800 series. Around 3-4 Kbytes is typical for ROM space and about 256 bytes of RAM. At least part of this RAM is low power CMOS (usually 5101-L3) with battery backup from lithium or auto-recharging nickel cadmium cells. This special requirement is due to the accounting functions normally found in a pinball machine. Records are kept of the number of coins through each of the coin slots, the number of free games won and special scoring functions etc. All of this data must be maintained during the power off period.

One point of interest with battery supported RAM is that the processor must be held in a reset state during power down. It is otherwise possible that RAM data could be corrupted as supply voltages fall.

The chip enable input on the CMOS RAM is usually driven from the system reset line to ensure RAM validity. ▶

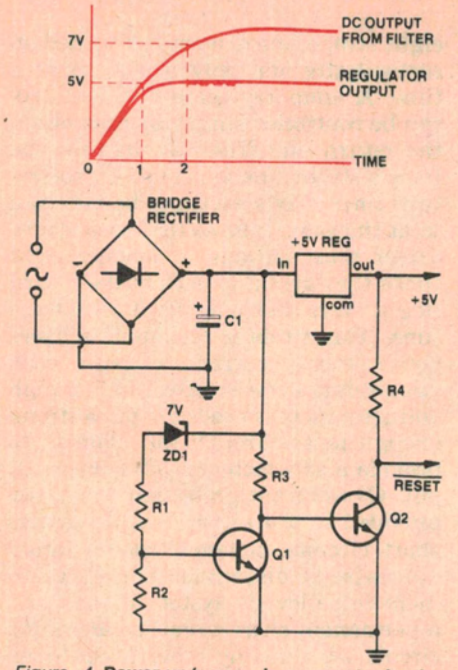


Figure 4. **Power-up/power-down reset circuitry ensures RAM validity at all times.**

The power-up/power-down reset circuit shown in Figure 4 is typical. It relies for its operation on the voltage differential between input and output terminals of the +5 V regulator. When power is turned on, the voltage across the filter capacitor C1 starts to rise, providing base current to Q2 via R3. Q2 will therefore conduct and its Vce will be low, thereby providing reset to the system as the regulated 5 V supply rises.

Note that Q1 is not conducting at this early stage because the zener voltage of ZD1 must first be overcome to provide base current to Q1. As the filter capacitor voltage rises still further and ZD1's voltage is eventually surpassed, Q1 conducts and diverts the base current away from Q2. Hence Q2 stops conducting and the reset is removed (time 2 on the graph). Since the processor and clocks etc. have been capable of running since time 1 (when the voltage across C1 reaches 5 V), an effective power up reset has been produced. If power is removed the reverse process takes place as the filter capacitor discharges below seven volts and Q1 is turned off.

The processor is not kept particularly busy, its major tasks being to scan and update the digit display and to scan the 50 or so switches that may exist. During a game the processor is of course performing calculations on scores and making logical decisions as each playfield switch is engaged.

Input/output functions are almost exclusively performed with 6820 PIAs. Again a matrix technique is used to oversee as many as 60 independent switches. The PIA provides 1-in-8 strobe pulses on one output port and senses any closed switch on the other output port.

Displays

Data to be displayed is generated by the processor and routed via another PIA. Displays can be 7-segment LED, fluorescent, or planar neon gas discharge types. LEDs are least common because of their comparatively low light output. Neon displays operate from around 180-200 V using a regulated supply, while fluorescents run on about 60 V.

The cathodes of corresponding elements of each digit in the display are connected in common to make seven separate cathode data lines. A CMOS 4-bit-to-7-segment latched decoder feeds a constant current transistor driver in each of these lines with a 1 or a 0, depending on which segments have to be lit to display a particular character. To see how the system works, let's suppose that the processor wants to display the number 43210. First it sends signals to the decoder to make it generate the segment codes for each of the five characters 4, 3, 2, 1, and 0 in turn

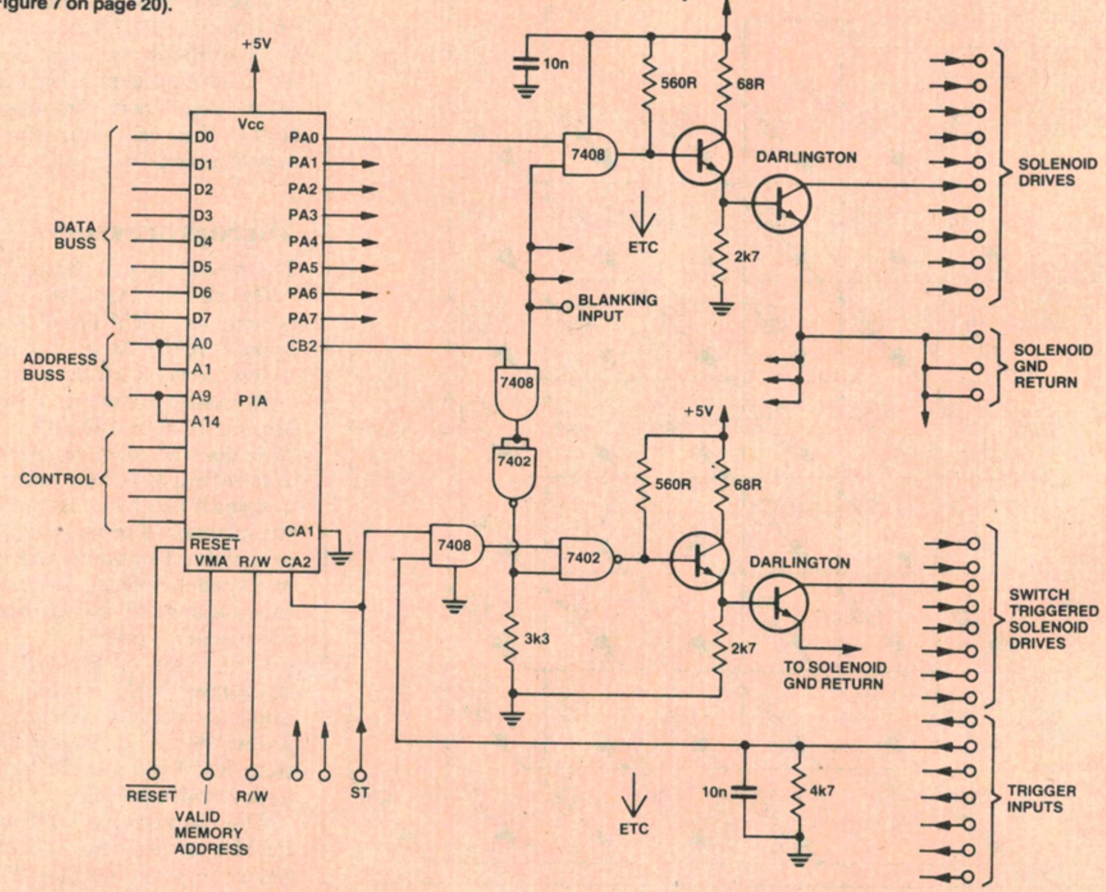


Figure 6. **The various solenoids used for the active deflectors on the playfield are driven from a PIA. Switch inputs for scoring and to activate the solenoid can be arranged in a variety of ways (see text and Figure 7 on page 20).**

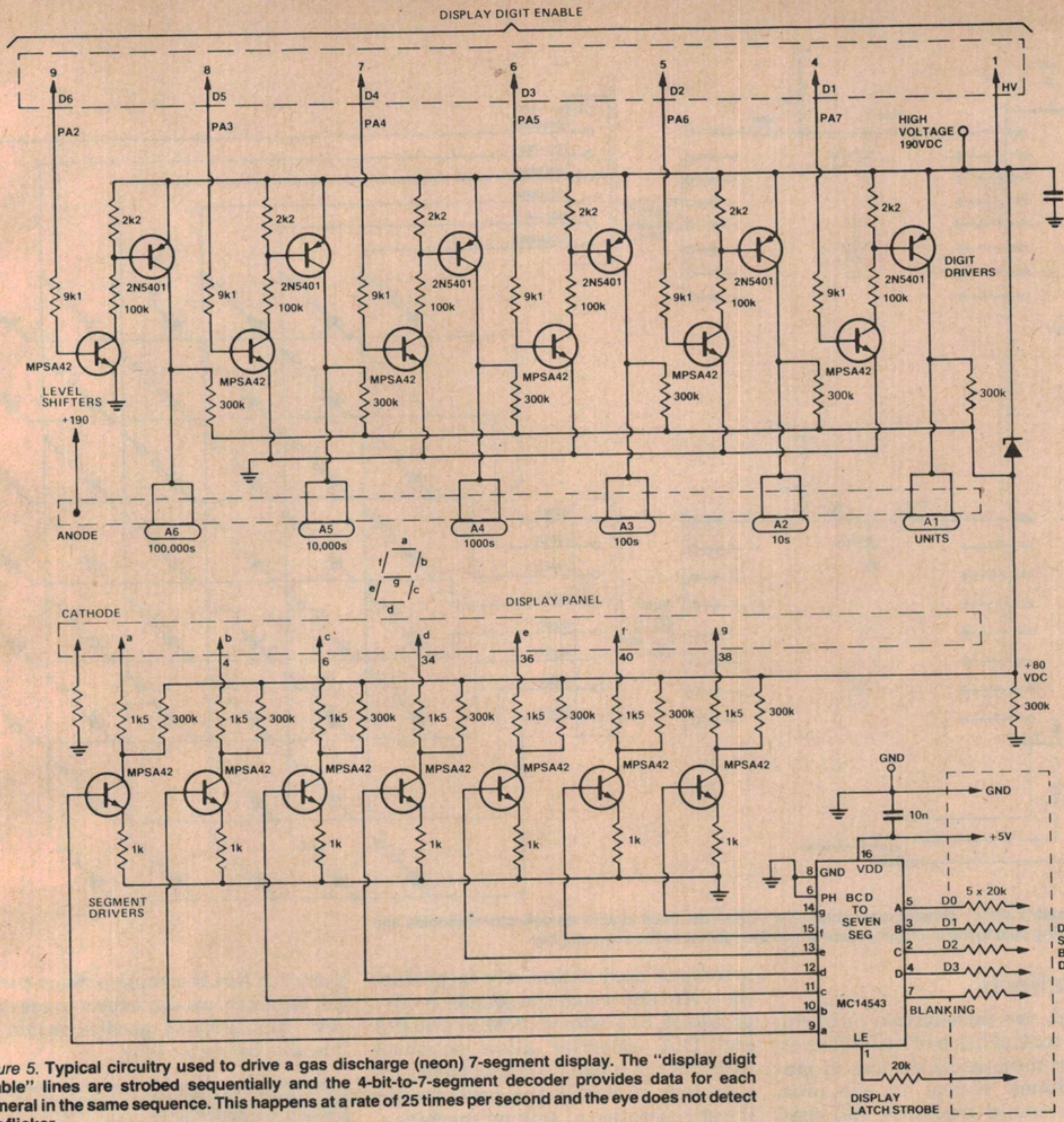


Figure 5. **Typical circuitry used to drive a gas discharge (neon) 7-segment display. The "display digit enable" lines are strobed sequentially and the 4-bit-to-7-segment decoder provides data for each numeral in the same sequence. This happens at a rate of 25 times per second and the eye does not detect any flicker.**

and repeat the sequence for as long as 43210 is meant to be displayed. If all six anode lines (one for each digit in the display) were activated, the result would be that the numbers 44444, 33333, 22222, 11111, and 00000 appeared on the display successively. But the anode for each digit is program controlled by another signal from the processor to make sure that it is only raised to operating voltage when the correct segment code is being presented to the cathodes. A multiplexer scans all six anodes in turn with the result that the correct character is displayed in each location. If the scan rate is faster than 25 times a second the human eye does not detect any flicker and the number 43210 appears to be steadily displayed.

Because of their high operating voltages, neon displays need high voltage driver transistors such as MPSA42s. Anode voltage is equal to the supply voltage in the 'on' state and about half this value in the 'off' state. Cathodes are driven towards ground when they are 'on' and held at half supply voltage when 'off'. This is done to stop possible arcing between cathodes and adjacent anodes.

Fluorescent displays work at a lower voltage and are most commonly driven by integrated devices, their filaments being supplied with ac from a separate transformer secondary winding.

Deflectors

Obviously, the active deflectors are the only ones that present any control problems. 'Bumpers' and 'kicking rubbers' run at around 24 volts and draw three to five amps. Back emf from their solenoids at turn off is quenched by 1 A diodes mounted at the coil terminations. The driver transistors are typically BD647 or TIP120 Darlingtons. The 2 V Vce sat. of a Darlington would not permit continuous operation of these devices without considerable heatsinking, but since all these active deflectors are only intended for momentary operation, heatsinks are not used.

There are two common methods of sensing/driving these devices. In the first, sense switches mounted on the device are detected directly by the processor, which calculates the new score and selects the appropriate solenoid driver, usually via a PIA and a 4-to-16 line decoder (74154).

The alternative method is to use two sets of switches on the device. One set actuates a transistor switch (BD647 and gating), which provides solenoid power. The other switch, which is usually mechanically coupled to the solenoid plunger, provides the score input to the processor. ▶

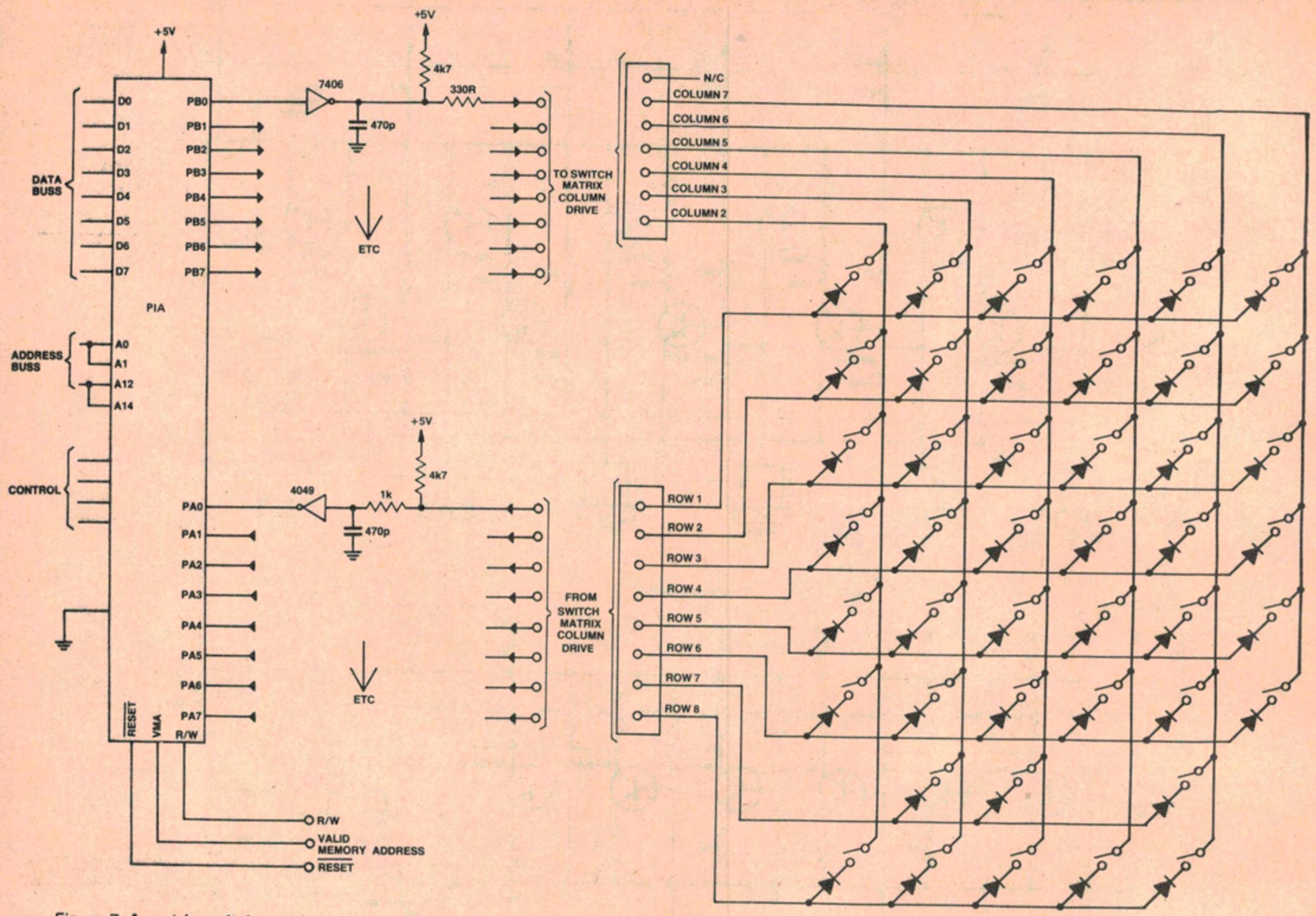


Figure 7. **A matrix switch sensing arrangement is sometimes used to activate deflector solenoids and provide scoring data to the microprocessor which then arranges the score display.**

Sound effects

In general, the introduction of microprocessor control has had little effect on the electro-mechanical devices in pinball machines. Except in one area. Early 'electronic' machines still used chimes as an audible announcement of scores. Typically three tones were used, one each for 10 point, 100 point and 1000 point scores. Inevitably electronics found its way into this domain.

The first step was to replace the mechanical chimes with three 555 timers driving something like an LM380 audio power stage. Further developments were the introduction of programmable counters and harmonic generation to add 'life' and flexibility to the system. Practically any frequency can be produced under program control with exponential fades and selectable harmonic content.

This is one area in which there is no standard practice. Each manufacturer has gone his own way in choosing between chips like the 76477 complex sound generator and a purely discrete system. In the more extravagant machines a complete microprocessor system is used exclusively to produce the weird and wonderful sounds. A 6802 processor, 512 bytes of ROM, a 6820 PIA and D/A converter allow enormous flexibility in sound generation and such a system is clearly the basis for the latest generation of 'talking' machines.

Prospects

What can we expect in the future? Most of the design work just described is around three to five years old. It is commonly known that at least one of the major US manufacturers will be releasing new hardware in their machines shortly. One smaller maker has opted for the Z80 system, even though this application involves control rather than data manipulation. Support circuitry for the Z80 is similar to that for the 6800.

There are obvious advantages in adopting the 'one processor/one job' approach, particularly for something like the F8 series with 'on board' RAM and ROM. It would be risky to predict what form the next generation of pinball machine electronics will take. Considering that 'leisure time' electronics is fast becoming a major part of the industry, we can expect to see some very sophisticated goodies inside the pintable before too long. ●

About the author

Neil Dunn began his electronics career as an apprentice mechanic in a small TV and radio repair shop. After completing his apprenticeship and passing the trade examinations he went to work in the electronics workshop of North Sydney Technical College and soon afterwards became a teacher of radio and television with the Department of Technical Education, a post he occupied for six years, teaching Radio Trades courses at all levels.

In 1973 he began working for Honeywell Information Systems as a technical instructor. There he became really involved in digital electronics for the first time, working on both hardware and software as a senior member of the technical support team. After four years or so he was itching to work on the actual design of microsystems, so when a vacancy arose at Electronic Control Systems of Chatswood, NSW he jumped in eagerly. The company was then manufacturing terminals based on the 8080 MPU and Neil was directly involved in designing a 32K RAM board, keyboard and interfaces for a typesetting terminal.

In May 1979 he began working for MFS & JE Heron, designing a complete microcomputer system and associated electronics for a pinball machine, a position he occupied until March of this year. He is now a freelance designer and writer.