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HOW TO PROGRAM READ-ONLY MEMORIES

An experimenter's guide to programmable ROM's—what they are and practical applications for them.

BY ROBERT D. PASCOE

PROGRAMMABLE read-only memories are unique among the digital integrated circuits readily available to experimenters. What makes it unique is that it is user programmable. *You* decide what you want the PROM to do and program it to do just that. The only "tools" you need are a pair of regulated power supplies, some switches, and a resistor. The programming procedure itself is outlined later on in this article.

The PROM is one member of the standard ROM family of memories. Once it is programmed, its memory is nonvolatile, which means that, if power is removed from and then reapplied to the PROM, the stored information remains intact. By contrast, a RAM (random-access memory) has a volatile memory; if power is interrupted, when it is again applied, whatever information was stored in the memory will be erased.

The ROM (and PROM) can be made from bipolar transistors, in which case it is called a bipolar ROM. It can also be made from metal oxide semiconductor devices, which makes it a MOS-ROM. Whichever type it is, the ROM is a digital device that "remembers" information on the standard binary format of 1's and 0's. The logic levels remembered by the bipolar ROM are the same as those used in TTL circuits, whereas the levels remembered by the MOS-ROM are determined by the supply voltage required by the device itself.

Organization. An important characteristic of the ROM is its organization. The ROM remembers quantities of binary "bits" that are organized into "words." Each word has a certain number of bits. For example, one type of ROM can remember 256 bits of information organized into 32 words of eight bits apiece (32 words × 8 bits = 256 bits).

Some of the more commonly available ROM's can remember 256, 1024, 2048, or 4096 bits in a single IC chip. With the various types of ROM's, the manufacturer determines how the total number of bits is organized in the chip.

The organization of the bits deter-

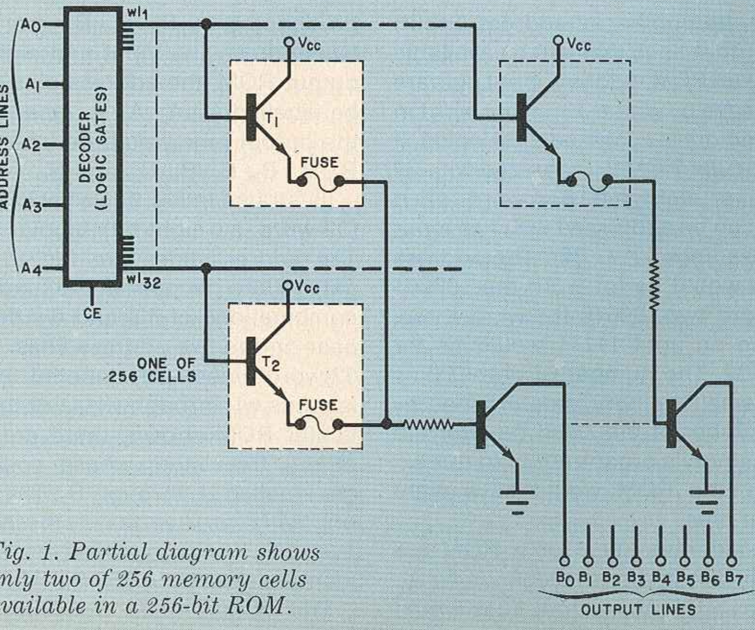

Fig. 1. Partial diagram shows only two of 256 memory cells available in a 256-bit ROM.

SOME APPLICATIONS FOR PROM's

THERE are countless applications for the ROM. Some of the more traditional ones use the ROM as lookup-table (trigonometry, logarithms, etc.) memories in calculators; as micro-instruction systems in computers; and character generators for displaying alphanumerics on a CRT screen. The following are examples of what you can do with an 8223 PROM:

Character Generator. A seven-segment display device can be used to create the numerals 0 through 9, a number of upper- and lower-case letters of the alphabet, and some mathematical punctuation—all with a single 8223 PROM chip. Because the display has only seven segments, it cannot form all 52 upper- and lower-case or even all 26 upper- or lower-case letters.

In Fig. A is shown the logic diagram for an alphanumeric/punctuation generator. Beside it is the "truth table" we used for generating the 32 possible characters. Note that the entire memory storage capability is "used up" in this truth table. (This truth table assumes a buffering transistor between the outputs of the 8223 and segments of the display. The display can be either an RCA 2100 incandescent or common-anode LED display. For common-cathode LED displays, all B_0 through B_7 logic levels must be reversed.)

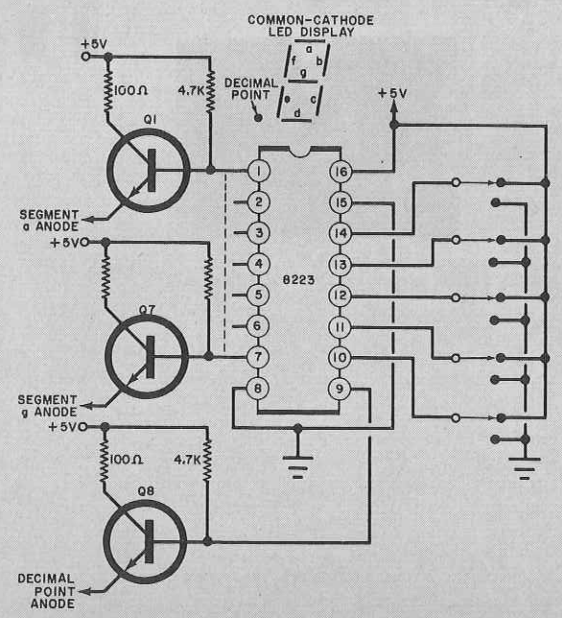

Fig. A. Once PROM is programmed according to truth table at right, it can generate numbers, letters, etc., on 7-segment display device.

All eight output lines from the 8223 PROM are used, with one output assigned to each segment of the display and a final one for the decimal point. To use up the entire storage capability of the PROM, the entire 00000 through 11111 series was used on the address lines (A_0 through A_4). We will discuss later how to perform the actual "programming" procedure for the PROM.

Figure Displayed	Address (A_4-A_0)	Outputs (B_7-B_0)	Segments on
0	00000	00111111	abcdef
1	00001	00000110	bc
2	00010	01011011	abdeg
3	00011	01001111	abcdg
4	00100	01100110	bcfg
5	00101	01101101	acdfg
6	00110	01111101	acdefg
7	00111	00000111	abc
8	01000	01111111	abcdefg
9	01001	01101111	abcdfg
.	01010	10000000	decimal point
-	01011	01000000	g
=	01100	01001000	dg
A	01101	01110111	abcefg
b	01110	01111100	cdefg
C	01111	00111001	adef
c	10000	01011000	deg
d	10001	01011110	bcdeg
E	10010	01111001	adefg
F	10011	01110001	aefg
G*	10100	00111101	acdef
H	10101	01110110	bcefg
h	10110	01110100	cefg
i*	10111	00010000	e
J	11000	00011110	bcde
L	11001	00111000	def
n*	11010	01010100	ceg
o	11011	01011100	cdeg
P	11100	01110011	abefg
r*	11101	01010000	eg
U	11110	00111110	bcdef
u	11111	00011100	cde

*These letters are only approximations, included only to use up the PROM's program capability.

An extension of the single-character generator is the word generator. Here, we have several PROM's and an equal number of displays, each programmed with identical information. Depending on the number of PROM's and displays desired, this system can be used to generate words, strings of numbers, identification and license numbers, etc. You simply set the address lines of each PROM to generate the character you want.

Model RR Track Patterns. The PROM can also help an HO model railroader remember track patterns for his train layout. As an example, suppose an HO train layout has eight track switches and 10 possible track configurations. A PROM can be used to remember the positions of the various switches for the 10 possible track patterns, as shown in Fig. B. The outputs of the PROM would be connected to the track switches through electronic switches (driver transistors). This ensures that the output voltage levels of the PROM are converted to the proper voltages and currents needed to move or position the track switches.

The PROM must be programmed with the appropriate binary codes. The words w_1 through w_{10} can then be the various track patterns that the train can have. The one-shot multivibrator's output is coupled to the CE input of the PROM so that the switches do not have voltage across their coils continuously. With the PROM remembering the various track positions for the eight switches, you need only select the pattern you wish and push a button to initiate the selection of that pattern.

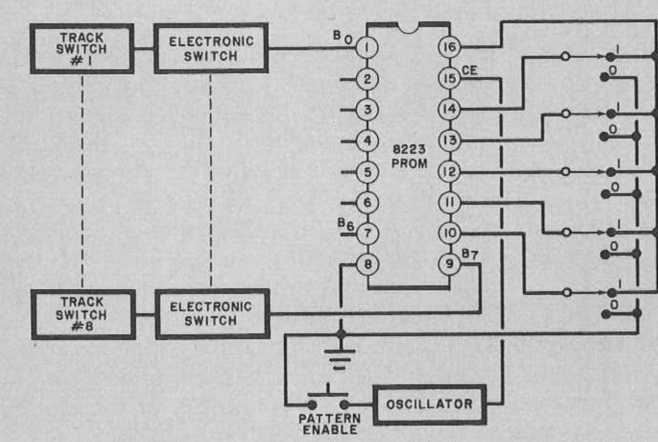

Fig. B. In model-railroad system, PROM would be programmed to control all possible combinations of switches on track.

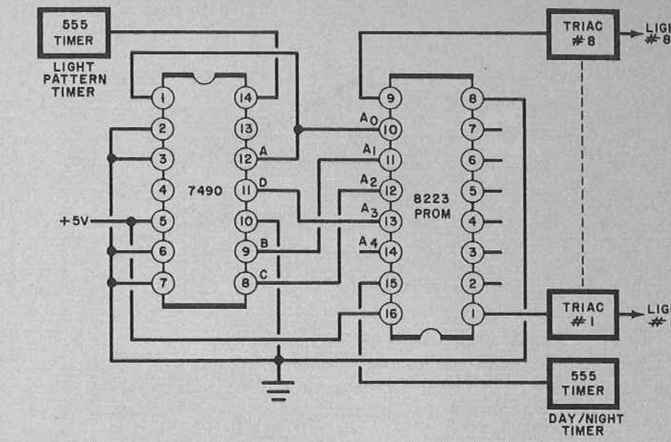

Fig. C. Clocked by timer circuit, 7490 counter delivers a 4-bit input to PROM, which controls triacs to turn lights on and off.

Intruder Deterrent. When you go away from home for a day or longer, you probably use mechanical timers to turn on and off house lights to make it appear that someone is home. A PROM can be used for this purpose and is much more effective in deterring intruders than are mechanical timers.

Shown in Fig. C is a system, built around a PROM, for turning on and off house lights in a certain sequence. Suppose that there are eight lights located throughout the house. The lights can be controlled by individual triacs, with the triacs controlled by the outputs from the PROM.

Assume that 10 light patterns are to be used in the evening hours. Word one can be a basement and a living room lights-on command, word two can be a living room and a kitchen lights-on command, and so on.

The various patterns of lights (words) can be selected by changing the address inputs, which are connected to a 7490 decade counter. A 555 timer can be used to change the outputs, of which there are a possible 10, of the 7490. This, in turn, changes the lighting sequence for the house. With this arrangement, various lights in the house can be changed every so often to give the appearance that someone is home and moving from room to room.

mines the number of address (input) and output lines that will be available in a given ROM. Address input pins are the means by which a specific word in the memory is accessed or selected. If a particular ROM is organized with 32 words of eight bits per word, each word can be addressed with five input address lines ($2^5 = 32$). The address 00000 would be for word one, 00001 for word two, 00010 for word three, and so on until 11111 would be for word 32. The number of output pins for a small memory is determined by the number of bits used per word in the memory's organization. In our example, the ROM would have eight output pins.

The address lines for a ROM are usually denoted by the legends A_0, A_1, A_2, etc., while the output lines would be denoted by B_0, B_1, B_2, etc. For a five-address-line input and eight-line output ROM, the address pins would be labelled A_0, A_1, A_2, A_3, and A_4, and the output pins would be labeled B_0, B_1, B_2, B_3, B_4, B_5, B_6, and B_7.

Illustrated in Fig. 1 is a basic 256-bit (32-word by eight-bit) bipolar ROM. The address lines are fed to logic gates that decode the 32 possible combinations of 1's and 0's that appear on the five address lines. These 32-word lines are denoted by the legends wl_1 through wl_{32}. For the particular ROM shown, there are eight output transistors whose collectors are labelled B_0 through B_7. The memory "cells" are denoted by the legends T_1 and T_2. There are 256 of these basic memory cells for a 256-bit ROM.

The output lines from the ROM would be either high (logic 1) or low (logic 0), depending on whether or not a conduction path exists between the memory cell and the output transistor in each line. As an example, if a 0 is to be stored at B_0 in word 32, the T_2 resistance link (fuse symbol) must be present. If, on the other hand, a 1 is to be stored at B_0 of word 32, the fuse must be electrically removed (blown) from the circuit.

Most ROM's have a pin labelled CE, for "chip enable," that permits the output to be isolated from the rest of the circuitry inside the IC. So, if a 1 is placed at CE (while the address is being changed), the outputs will be at the logic-1 level. The placement of this specific binary information into the ROM is called "programming." The means of programming is determined by the type of ROM. The two major types of ROM's are the custom-programmed and the field-programmable ROM.

With custom-programmed ROM's, the manufacturer places the binary information (links or no links) into the memory as specified by the user. Custom programming of ROM's can be very expensive when only small quantities are ordered. To reduce the high cost of small quantities of ROM's, manufacturers offer the field-programmable ROM or PROM.

The PROM is an ordinary ROM that has all of its on-chip fuses intact. A 256-bit PROM would have 256 of these fuses, one for each bit of memory. The user can program information into the PROM simply by blowing selected on-chip fuses. The fuses are blown open by passing a specific amount of current through them for a specified period of time. (The Signetics 8223 is an example of a 256-bit PROM. It is readily available from a number of surplus-parts suppliers for about $4.50. This PROM is organized into 32 words of eight bits per word.)

Erasable PROM's. ROM's are usually thought of as having permanent binary information programmed into their memories. Once information is programmed into an ordinary ROM, it cannot be altered. Recently, however, a new type of PROM—the erasable PROM—has become available. This type of PROM permits information stored semi-permanently to be erased and new information to be reprogrammed in.

One type of erasable PROM, the 2048-bit MM5203, is made by National Semiconductor Corp. It can be erased by concentrated shortwave ultraviolet light. (It is available, surplus, for about $24.) The MM5203 is housed in a 16-pin dual in-line package (DIP) with a quartz top that is transparent to shortwave UV light. The 2048 bits are organized as either 256 words of eight bits per word or 512 words of four bits per word.

The advantage of the erasable PROM, as opposed to the nonerasable PROM, is that it can be used over and over again for different programs. The unwanted information is simply erased by directing UV light through the IC's quartz "window" and reprogramming as desired.

Another type of erasable PROM

PREPARING A PROGRAMMING AND ADDRESSING TRUTH TABLE FOR PROM'S

Because the PROM is a logic element, programming and addressing it must conform to the rules of logic. To do this, a truth table must be drawn up for the programming procedure. This same truth table is also used for addressing the ROM after programming has taken place so that stored information can be retrieved.

There are two approaches you can use when working up your truth table. The first is an arbitrary table, used mainly for demonstration purposes. Since you would key in the address codes by manually setting switches, you can use any address system that suits your fancy. The truth table accompanying the diagram in Fig. A is an example of the arbitrary approach.

For more practical applications, address code selection would be under the control of the digital system in which the PROM is to be used. In this case, the programming truth table for both input and output codes must conform to those required by the system. A typical example is a BCD-to-7-segment decoder.

Let us assume a 7490 decade counter's encoded output is to be used to drive a seven-segment LED display. All decoding can be accomplished with a PROM. The PROM will then feed inverter/buffer transistors, which in turn will power the display's segments. The truth table, with the 7490's DCBA output lines feeding the 8223's $A_3A_2A_1A_0$ address lines respectively, would be:

	A_4	A_3	A_2	A_1	A_0	B_7	B_6	B_5	B_4	B_3	B_2	B_1	B_0
NO.		D	C	B	A		g	f	e	d	c	b	a
0	X	0	0	0	0	X	0	1	1	1	1	1	1
1	X	0	0	0	1	X	0	0	0	0	1	1	0
2	X	0	0	1	0	X	1	0	1	1	0	1	1
3	X	0	0	1	1	X	1	0	0	1	1	1	1
4	X	0	1	0	0	X	1	1	0	0	1	1	0
5	X	0	1	0	1	X	1	1	0	1	1	0	1
6	X	0	1	1	0	X	1	1	1	1	1	0	1
7	X	0	1	1	1	X	0	0	0	0	1	1	1
8	X	1	0	0	0	X	1	1	1	1	1	1	1
9	X	1	0	0	1	X	1	1	0	1	1	1	1

The DCBA in the heading represents the outputs from the 7490, while the gfedcba represents the display segments controlled. The X's are don't-care states, since there is no input to the A_4 input nor output termination for the B_7 output lines of the 8223 PROM.

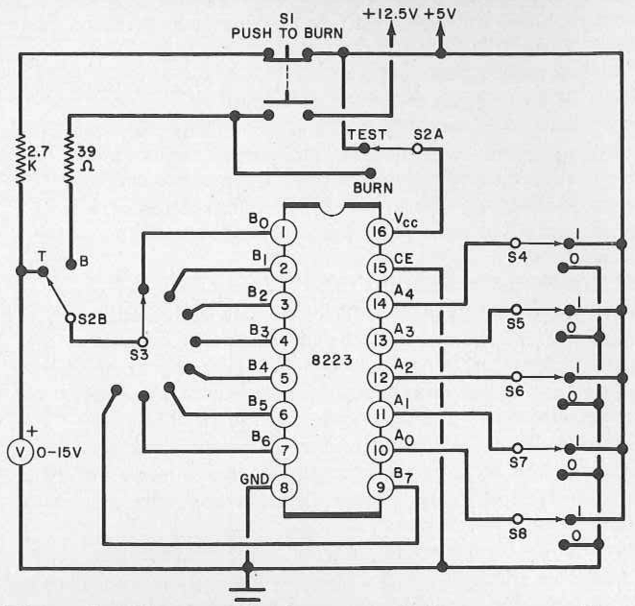

Fig. 2. In this programming setup, both power supplies must be regulated. Once PROM is programmed, its memory can be checked as described in the text.

—this one not so readily available to experimenters—is the Nitron Company's NC7010 EAROM. This device can be erased electrically in one second. It can be erased and reprogrammed up to a million times. The NC7010 is organized as 512 words of two bits per word.

How to Program a PROM. The 8223 PROM used in the applications described is shipped with all of its outputs at a logic-0 level. This means that all of its on-chip fuses are intact. If a logic 1 is to be written into the PROM's memory, the fuses must be blown. The procedure for blowing selected fuses is called programming. It can be performed with the circuit shown in Fig. 2. The +5- and +12.5-volt power supplies must be regulated. Switch *S1* is a two-circuit pushbutton switch, with one set of contacts normally open and the second set normally closed. Switch *S2* is a dpdt slide or toggle switch, while switch *S3* must be a *non*-shorting rotary switch with eight or more positions.

After wiring together the Fig. 2 circuit, program the PROM as follows:

1. Set *S2* to the BURN position. (Note: *Never* operate *S1* when *S2* is set to BURN.)
2. Feed the proper logic-1 (+5-V) and logic-0 (0-V or ground) code for word one onto address lines A_0 through A_4 via *S4* through *S8*.
3. Set *S3* to the first PROM output line position in which a fuse is to be blown according to your programming truth table.
4. Depress *S1* for about a half second and release. This action, in blowing the fuse, develops considerable localized on-chip heat; so, **do not depress *S1* for longer than a full second**.
5. Allow several seconds of cooling down time for the chip.
6. Set *S3* to the next output line in which a fuse is to be blown.
7. Repeat steps 4 and 5 for each output line in which a fuse is to be blown.
8. Set *S4* through *S8* for the logic required for word two.
9. Repeat steps 3 through 7.
10. Continue to address the PROM for each succeeding word, repeating steps 3 through 7 as you proceed from word to word, until you have completed programming the PROM.

The schematic diagram shown in Fig. 2 depicts a program and test circuit. As you finish steps 3 through 7 for each word, set *S2* to TEST (do *not* change the address code yet) and, observing the meter, check the PROM's outputs by cycling through *S3*'s positions. Logic 0 will be indicated by the pointer swinging to near the scale's zero index, while logic 1 will be indicated by about a +5-volt reading. Once you have verified that the program has "taken" for a given word, set up the circuit for programming into the PROM's memory the next word that you want.

After making sure that the PROM is properly programmed, affix some identifying code on its case and truth table and file away the latter in a safe place where it will not get lost. ◈

HOME EMERGENCY LIGHT for "BLACKOUTS"

- *Automatic "on" when ac power fails*
- *Full-wave battery-charging circuit*
- *Doubles as lantern flashlight*
- *Compact, neat design*

BY WILLIAM OLDACRE

WHEN a power blackout occurs, one is likely to get caught in the dark without ready access to a flashlight or candle. Here is a hand emergency light to solve the problem, minimizing possible injury and fear due to darkness.

This emergency light goes on *automatically* whenever ac power is interrupted for one second or more, providing several hours of light before a recharge is needed. (The 1-second delay is built in to prevent flickering.) In addition, the system includes a battery charger which maintains full charge on ordinary nickel-cadmium batteries. It can also double as a portable flashlight and is designed into a neat, small package.

This home safety device is simple to build, requiring easy-to-get parts and modification of an inexpensive lantern-type flashlight.

How It Works. The schematic of the emergency light is shown in Fig. 1. Transformer *T1*, *RECT1* (a full-wave bridge rectifier), and filter capacitor *C1* form a low-voltage dc power supply. When line voltage is applied to the circuit, *LED1* glows. Current through *LED1* is limited by *R1*. The power supply provides charging current for battery *B1*, two NiCd cells. Diode *D1* prevents the battery from discharging back through the LED. Charging current is limited by either *R3* or *R4*. When switch *S1* is in the SLOW position, *R3* allows 33 mA to flow into the battery. When *S1* is placed in the FAST position, *R4* provides 100 mA, which charges *B1* more quickly.

The dc voltage also energizes relay *K1*. Since the relay coil is energized under normal (line voltage-on) conditions, it might tend to get very warm. To keep the coil cool, resistor *R2* is placed in series with it, lowering the amount of continuous current flow. The path between the battery and the light bulb (*I1*) is controlled by the relay contacts. Under line-on conditions, no current can flow through the bulb.

When the line power drops out, however, the relay coil is de-energized, and the contacts complete the circuit between the battery and the light bulb. The bulb automatically lights up, providing emergency illumination. To prevent the emergency light from flashing on and off whenever the line voltage drops for a fraction of a second (for example, when your refrigerator compressor kicks in), we take advantage of the fact that it takes about one second for the voltage across *C1* to decay to the point where the relay drops out. The exponential properties of the RC circuit smooth out any instantaneous variation in line voltage.

The flashlight is a self-contained unit which connects to the power supply through a three-conductor power plug-jack combination. When independent flashlight operation is desired, switch *S2* takes over the relay's switching operations by pro-