Elementary Electronics

A Combination Lock

By Ross Tester

We have had a number of requests to describe an electronic version of a combination lock. While most readers are interested in this purely as a novelty exercise, there is no reason why some of the ideas which it involves should not form the basis for a practical unit.

The combination lock has been around for a long time. Most of us would have seen movies of "expert" safecrackers with their ears to the safe, listening as the tumblers clicked into place, and then dramatically opening the door to reveal the inner treasures.

Maybe the tumblers are not all that easy to hear in reality, a fact which movie makers would doubtless ignore. Nevertheless, a lock which is completely silent in operation, and which can be built from readily available electronic components, makes an interesting project.

We plan to present a lock such as this. As well as the features mentioned above, it has the added advantage of an alarm function which would sound at the first wrong move. Also, the combination is relatively easy to change — unlike the mechanical variety.

While presented basically as a beginner's exercise, the project could have more serious applications. Suitably engineered it could form the basis of a genuine security lock, and we will have more to say about the actual lock mechanism later on.

At a less serious level it could form the basis of a game of chance at a typical charity fair. Contestants could be offered so many tries for, say, 10c and anyone fortunate enough to "crack" the combination and open the safe would receive the prize it contained. Considering the odds, the organisers could afford to be fairly generous in regard to the prize.

Let us look at the broad concepts of such a lock. Basically, we need a device which will allow a mechanical device to activate when, and only when, the information given it is correct in every respect. If any of the information is incorrect, the device should be able to warn of this fact.

A very simple system of logic circuits is able to do this. If the term logic is new to our younger readers, it is the field which embraces number systems and control using electronics. Naturally, computers fall into this class. In fact, some of the things in the electronic combination lock will be found in every computer.

These are the so-called "gates". As the name implies, a gate is a two state device — it can be only open or shut. The state of the gate depends on two things — the type of gate it is, and the information fed to it.

There are three main types of gates, namely AND, OR, & NOT. A refinement of the first two are the NOT OR, commonly called the NOR, and the NOT AND, commonly called the NAND.

As we said before, gates have two possible states. These states are known by many names, including on-off, true-false, and so on. The usual way of showing them is by the use of the figures 0 and 1. 0 corresponds to off or false, and 1 corresponds to on or true.

Figure 1 shows simple circuits used to demonstrate gates, together with their logic symbols. Figure 1a is an AND gate. As can be seen from the circuit, the lamp will light only if switch 1 AND switch 2 AND switch 3 are closed. Figure 1b, on the other hand, shows that the lamp will light if switch 1 OR switch 2 OR switch 3 is closed.

In other words, an AND gate requires all inputs to be at 1 before the output will be at 1. Alternatively if any of the inputs to an OR gate are at 1 the output will be at 1.

We are not concerned with the other types of gates for this project. In passing, however, we might mention that a NOT gate merely complements an input. In other words, if the input to a NOT gate is 1, the output will be at 0, and vice versa. NAND and NOR gates are derived from the NOT gate.

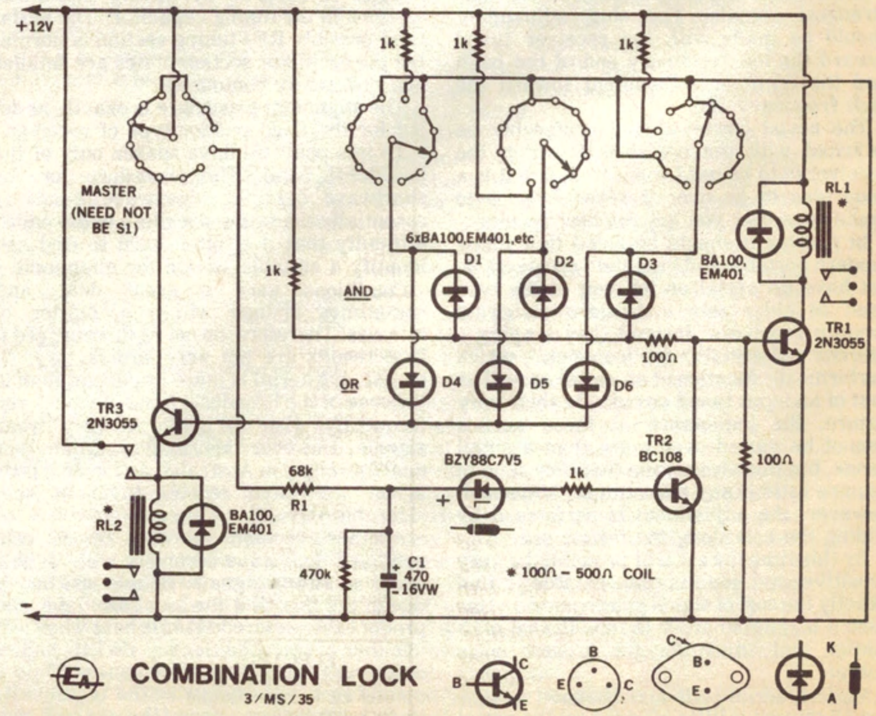
If all inputs to a NAND gate are at 1, the output will be at 0, and vice versa. Similarly, for a NOR gate, if any input is at 1, the output will be at 0.

We will be using both the AND and OR gates in our alarm. The AND application will become obvious immediately. The OR application we will describe a little later.

The simplest concept of an AND gate lock is an extension of figure 1a, where a number of switches are connected in series and, by reason of this arrangement, in themselves constitute the AND gate. In place of the lamp we can use an electrically operated lock, a relay to control such a lock, or a power transistor to control a relay etc. Each arrangement would have its particular advantages. (Figure 2.)

If we use, say, four 12 position switches, with a random position selected on each switch, we have over 20,000 possible combinations, other than the right one.

In certain applications, such an arrangement can be very useful. For example, it can be used, not to operate a



Circuit of the electronic combination system. If an actual lock is not required, the supply voltage may be increased somewhat to allow higher resistance relays to be used.

lock, but to disable an alarm system to permit legitimate entry. In such a situation, a would-be intruder has only one chance to get the combination right. If he fails the alarm will sound and he gets no second chance.

However, where such a circuit is used to operate a lock directly, the would-be intruder can have as many chances as he likes, the penalty for failure being nothing but wasted time. If he could work undisturbed, he would have a good chance of finding the combination by systematic trial and error.

The circuit which we have worked out below should be impossible to defeat. We say "should be", because nothing like this is absolutely 100% safe. However, the odds of someone cracking this combination are virtually infinite. It would be easier to win the Opera House Lottery, play four of a kind, and back every winner at Randwick — all on the same day!

As well as a combination, the lock incorporates two other safety factors. If the wrong dial is moved first, an alarm will sound — so it is not enough to learn the combination. Secondly, even if the right dial is correctly set at the first attempt — which is very unlikely — the user is given only a short period in which to set all the other dials. If he takes longer than, say, 10 seconds, the unlocking mechanism is bypassed, and there is no way the lock can be made to open.

The period of setting time is best determined by the user. Anything from a few seconds to a few minutes is possible for this delay.

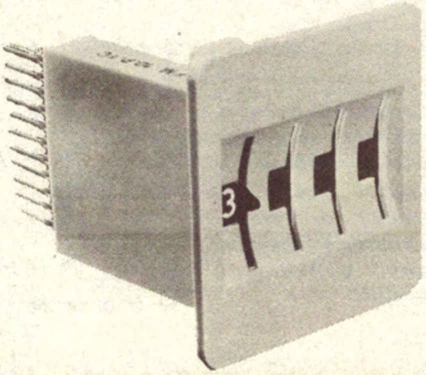
PARTS LIST

TRANSISTORS etc
2 2N3055 or similar
1 BC108
8 EM401 diodes
1 BZY88/ C7V5 zener diode
RESISTORS (½ W)
1 470k
1 68k
5 1k
2 100 ohms
CAPACITORS
1 470uF 16VW electrolytic
MISCELLANEOUS
1 Relay, 100 to 500 ohm coil,
1 set normally open contacts
1 Relay, 100 to 500 ohm coil,
2 sets normally open contacts
4 Rotary or thumbwheel switches, see text
Suitable alarm (if required)
Suitable lock (if required)
Tagstrip, hookup wire, solder etc.
ADDITIONAL PARTS FOR POWER SUPPLY (optional)
1 power transformer, 240V to 12V 1A. (A&R2155, 6978 etc)
5 EM401 diodes
1 470uF 25VW electrolytic
2 6V Lantern batteries (Eveready 509 etc)

Resistor wattage ratings and capacitor voltage ratings are those used for our prototype. Components with higher ratings may generally be used providing they are physically compatible. Components with lower ratings may also be used in some cases, providing the ratings are not exceeded.

If the owner should accidentally take too long to complete the sequence he will, of course be locked out also, but we have arranged matters so that the circuit will restore itself after a certain time, which can be selected by the user.

Now we can examine the circuit in more detail. The extreme left hand ("master") switch is wired differently from the other three. Once this switch is set the alarm is disabled, because the power for the alarm relay (RL2) and transistor (TR3) is supplied via the wiper and contacts of this switch. Once this is broken by setting the wiper to the correct position, the alarm is disabled.



The Philips thumbwheel switch. One unit only is shown on a four unit facade.

Incidentally, while we have shown the master switch in a particular position, for reasons of circuit convenience, the actual position which it occupies relative to the other three, should be chosen by the constructor. Then he, and only he, will know which knob to operate first. Thus the position of this switch becomes a part of the total combination.

The other three switches are wired with their moving arms connected to an AND gate made up of three diodes, D1, D2, and D3. The combination number is connected to the 12V positive rail and the remaining contacts to the negative rail.

At this point readers may wonder why we have used diodes to provide the AND gate, rather than simply using the switches themselves, as in the same manner shown in the example in figure 1a. The answer is that, while such an arrangement would be quite practical as far as this part of the circuit was concerned, it would prejudice the use of the additional protective circuitry we have already mentioned.

The operation of the diode AND gate is quite simple, and it will help the reader if he understands its operation. As shown in the circuit, it consists of three diodes with their anodes joined. This junction is the output of the AND gate. The three cathodes are the three separate inputs to the gate. The output connects to the positive rail via a current limiting resistor, and also connects to the base of TR1.

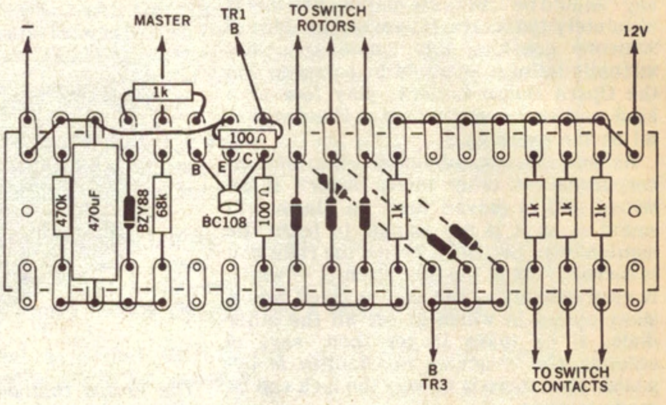
In normal use (that is, with the switches set off their combination number) the cathodes of the three diodes are at negative rail potential. Therefore, they are forward biased and they conduct. Their anodes are only slightly positive with respect to the negative rail (the voltage across the diode), and the output is regarded as being in the 0 state.

As each switch is set to its combination number, the cathode of the associated diode is switched from the negative rail to the positive. Therefore each diode ceases to be forward biased, and stops conducting. When the last switch is set, no diodes are conducting. The voltage at the output of the gate (anodes) rises substantially towards the positive rail voltage, and this shift constitutes the change from 0 to 1.

The increase in voltage is enough to turn on TR1, thus pulling in the relay. We used a 2N3055 power transistor in this project, rather than a BC108/relay combination which we have used in earlier projects. The main reason was that a number of readers have informed us that relays which pull in at low currents are relatively hard to come by. This is rectified by using a transistor which can handle more current.

The master switch circuitry has another function besides controlling the alarm. It also incorporates a time delay circuit, consisting of a resistor (R1), capacitor (C1) and a zener diode. It functions as follows: The resistor restricts the rate of current flow and the rate at which the capacitor charges. As the capacitor charges, the voltage across it rises until it reaches a point where the zener diode conducts.

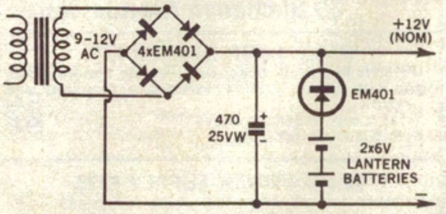
This turns on TR2 (BC108), which "steals" the bias which would otherwise have allowed the power transistor to turn on and pull in the relay. Therefore, the lock cannot be opened after this time delay has occurred. If the legitimate user is caught by this trap, he has to wait until the capacitor discharges through its parallel resistor until he can try again.



Component layout is not critical but that shown here is a logical one. The leads to relays, switches etc may be any convenient length.

The alarm circuit consists of TR3 (2N3055), relay RL2, three diodes D4, D5, and D6, plus a few minor components. TR3 is connected between the positive rail, via the master switch, and the negative rail, with RL2 in the emitter circuit. The base of TR3 connects via a suitable limiting resistor to the output of an OR gate made up from the three diodes.

These three diodes are connected to the three combination switches in such a manner that, if the moving arm of any switch is set on, or passes over, its combination number, the positive rail voltage is applied to the diode, which becomes forward biased, and so to the base of TR3. This turns TR3 on, the relay closes, and the appropriate set of contacts operates the alarm. A second set of contacts between the positive rail and the base of TR3 by-passes both the switch and TR3, thus keeping the bell ringing despite any manipulation of the switches.



Basic circuit for a mains power supply with automatic battery standby.

Note that only one diode needs to be forward biased in order to turn on TR3. This can be either D4 or D5 or D6; hence the term OR gate.

Now that we have explained the electronics of the combination lock, we can have a closer look at the mechanical aspects. Naturally enough, the switch mechanism represents the most important part of the device. We understand that a number of manufacturers market switches specifically intended for purposes such as ours. These are known as "thumbwheel" switches, and are operated by turning a numbered wheel which is mounted edge-on through a facade. It is a simple matter to operate these, and select the correct number very quickly.

We obtained one of these switches from the Philips organisation, and used it to formulate our original ideas. However, they have one major drawback — a four section switch would cost well over twenty dollars. Therefore, they could be seriously contemplated only in a commercial installation — such as that for a factory, office, etc. Here, the high initial cost would be more than offset by the reliability and dependability of the devices.

The type number of the Philips thumbwheel switch is 4311 027 82320. These switches also require a facade for mounting, which should be ordered at the same time as the switch.

For those who are more interested in building the combination lock as a novelty, we recommend conventional rotary switches, single pole — 12 position. These can be a miniature type, such as the Jabel model.

Ideally, these switches should have non-shorting contacts (ie, break-before-make) to avoid complications when switching between contacts at different voltage levels. Unfortunately, the more readily available and lowest cost types all tend to use shoring contacts (make-before-break) so we have gone to a good deal of trouble to design the circuit in which complications arising from their use are virtually eliminated.

Electrically operated locks may be new to most readers, but they are readily available. The well known Yale company market several models under the trade mark "Yale Elettra". A typical price would be around twenty dollars.

The bolt is normally spring loaded in the locked position, and is withdrawn when power is applied, and only for as long as it is applied. They are available for 12V operation and require a current of between 800mA and 1A.

This information was supplied by the Australian importers, Glen Carr & Partners Pty Ltd, Quirk Rd, Balgowlah, NSW, 2093. They should normally be available from the larger hardware and builders' supply stores. If difficulty is experienced, the importers should be contacted directly.

The power supply required for the whole system depends on a number of factors. The basic circuit, as shown, can be operated from a relatively simple supply such as a pair of lantern batteries. In the

Elementary Electronics Ideas Worth Trying

Emergency Ammeter

The writer was recently faced with the need to check the behaviour of his car's electrical system, in particular whether the alternator was capable of carrying all the load which could be imposed on it — headlights, mobile radio gear, etc. — even when the engine was only idling.

As no ammeter was available, either in the car or as a separate item, this presented a problem. The final solution is so simple, it may appeal to others.

A multimeter, set to the 0-1mA range (also 100mV in most meters), was connected between the chassis terminal of the battery and the chassis proper or, in other words, directly across the lead from battery to chassis. While the resistance of this strap is low, it was reasoned that there would still be a small voltage developed across it when several amps were flowing through it.

Switching on the headlamps gave a deflection of about three minor divisions (6mV) — not much, but enough.

Then the engine was started and run at idling speed. The pointer swung back past zero, indicating a charge condition. Reversing the meter connections sent the pointer up the scale a couple of divisions, even with all auxiliary circuits switched on, indicating that the alternator was not only supplying all these, but charging the battery at a significant rate also.

While there is no suggestion that this is a substitute for an ammeter, it is a quick and easy way of checking the system's behaviour.

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locked position there is a steady drain of about 12mA and in either the unlock or alarm position the drain will depend mainly on the resistance of the relays used in these circuits. Assuming typical relays of about 500 ohms the operate drain for either condition would be 25mA.

Power for the associated devices, such as the alarm or power operated lock, presents more of a problem. A heavy duty alarm may require 1A or more and need to operate for a reasonable period if it is to be effective. As already stated, the lock will require a similar current, but with a shorter duty cycle.

This kind of power can be supplied by dry batteries, and the two lantern batteries already mentioned may be adequate in some cases. However, these would be right on the lower limit.

Mains power is an alternative, but has some objections. One is that an unauthorised person may attempt to beat the system by cutting off the power. This will, in fact prevent the lock from operating, but it will also disable the alarm, which may be undesirable in some circumstances. Another objection is that a power failure may prevent legitimate entry, although some locks have a mechanical override using a conventional key.

A good compromise appears to be mains operation with battery standby. This is quite easy to arrange and has a high order of reliability. As shown in the circuit, the mains supply consists of a transformer and rectifier delivering a little more than 12V. The standby battery is permanently connected, but isolated from the load by means of a diode, which is reversed biased so long as the mains supply voltage is higher than the battery voltage. If the mains supply fails the diode is forward biased and the battery takes over without any break.

Adjustment of the time delay circuitry is simple. The 68K series resistor gives a time delay of around thirty seconds. To shorten the delay, one of two changes can be made. The 68K resistor can be replaced with a lower value — a 22K should give around ten seconds delay. Alternatively, the zener diode could be replaced with one of lower voltage. A lower voltage zener does not require the capacitor to charge as long to reach the zener point.

Using the lock is very simple. However, always make sure the master is the last switch un-set, otherwise the alarm will sound. Also, it must always be the first switch set, for the same reason. Remember the time delay, too. If the correct combination is set, and the lock does not operate, un-set all switches (the master last) and wait for about thirty seconds. This gives the capacitor time to discharge. Then, the setting can be commenced again.