

[54] **ELECTRONIC LOCK**

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[22] Filed: **Dec. 23, 1971**

[21] Appl. No.: **211,544**

[52] U.S. Cl.**340/147 MD, 317/134, 340/274**

[51] Int. Cl.**G08b 13/08**

[58] Field of Search**340/147 R, 147 MD, 164 R;
317/134**

[57] **ABSTRACT**

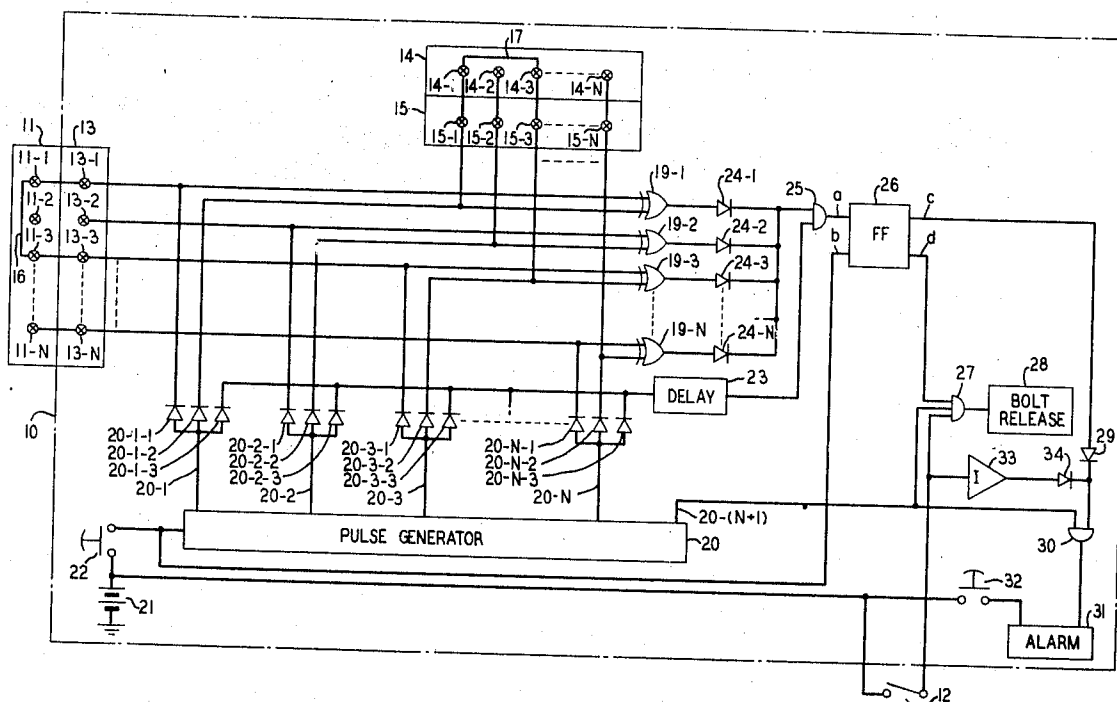
An electronic lock in which the key combination necessary for opening it is determined by an easily replaceable plug whose terminals have been jumpered or strapped in an arbitrary arrangement. The key for the lock is a second plug. When strapping in the second plug is identical to that in the first plug, insertion thereof permits the lock to be opened; if the strapping does not match, the lock cannot be opened. Options include initiation of an alarm if a key with incorrect strapping is inserted, and remote disablement of the lock.

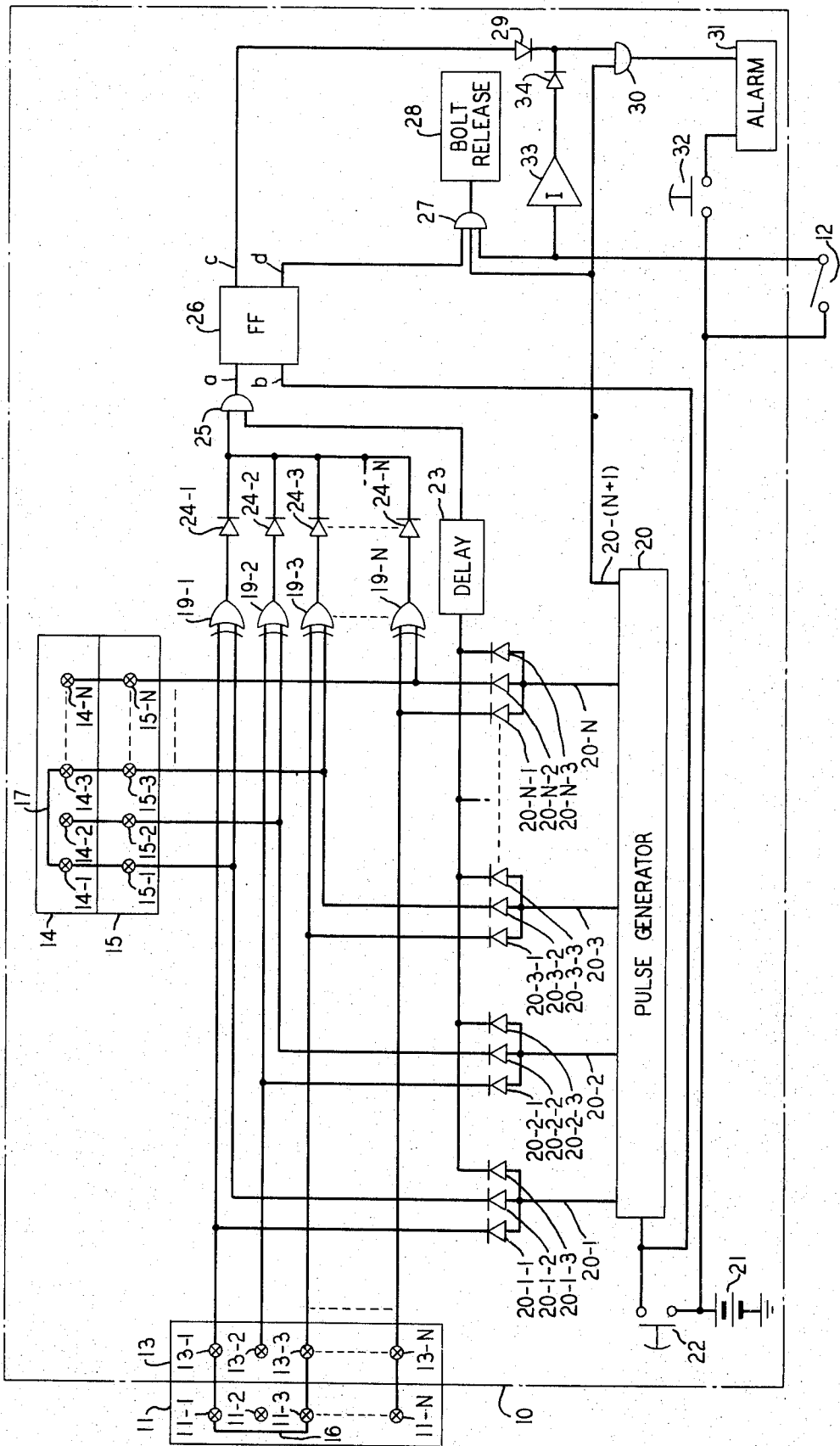
[56] **References Cited**

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9 Claims, 1 Drawing Figure





ELECTRONIC LOCK**GOVERNMENT CONTRACT**

The invention herein claimed was made in the course of or under a contract with the Department of the Army.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

This invention relates to electronic locks.

2. Description of the Prior Art

The most often used form of lock includes mechanical elements which must be physically operated in a predetermined manner to release the lock. These elements may be operated upon by either a metal key or a dial in a so-called combination lock. To the best of applicant's knowledge, the more secure or pick-proof lock of this form is the combination lock. A three-turn, 50-position combination lock, for example, offers 125,000 (i.e., 50^3) possible combinations.

A combination lock requires exact positioning for each turn and consequently presents a problem in that several attempts may be required before it is correctly operated. This is especially a problem when operating under pressure. Furthermore, this problem becomes more severe when increasing the number of turns and/or positions in order to increase the degree of security.

Another problem with known mechanical combination locks is that one must know both the old and the new combinations when resetting such a lock to open for a new combination. If one does not wish to or cannot reset his own lock, a compromise occurs because the person resetting the lock must know the new combination.

A much less used form of lock utilizes electronic circuits which must be electrically operated in a predetermined manner to release the lock. The attractiveness of such locks has increased because the size, cost and reliability characteristics of many electronic circuits have been improved with the advent of integrated circuits.

SUMMARY OF THE INVENTION

An object of the invention is to provide a high degree of security in an electronic lock.

Another object is to keep to a minimum the time required for an authorized person to open the lock.

Another object is to permit a person to change the opening combination without disclosing to him either the old or new combinations.

Still another object is to be able to easily and rapidly change the opening combination.

These and other objects of the invention are achieved through the use of AND gates, EXCLUSIVE OR gates, OR gates, a flip-flop, a pulse generator, switches, plugs, and receptacles. The various terminals of the plugs are strapped together so that identical random strapping appears in both plugs. One of these plugs determines the key combination necessary for opening the lock while the other plug comprises the key. When the key-plug is inserted in the lock and a switch is activated, the pulse generator applies pulses in a sequential manner to corresponding terminals of the two plugs. The EXCLUSIVE OR gates, one of the OR gates, and the flip-flop function to produce an output

indicative of the correspondence or noncorrespondence of the strapping in the key-plug to the other plug. When correspondence occurs, the last of the sequential pulses gates the flip-flop output to operate a bolt release. If desired, a remotely controlled switch may be added to disable the last-mentioned gating function, thus permitting control from a master station. Furthermore, an alarm may be added. With the alarm addition, the last of the sequential pulses gates the noncorrespondence output of the flip-flop to operate the alarm. Finally, with the addition of the remotely controlled switch and alarm, the last of the sequential pulses may be gated to operate the alarm whenever the switch is disabled. The alarm will sound, therefore, whenever anyone — including someone with the correct key — is attempting to open the lock when it has been remotely disabled.

These and other objects and features of the invention will become apparent from a study of the following detailed description of an embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWING

A block diagram of an embodiment of the invention is disclosed in the drawing.

DESCRIPTION OF THE DISCLOSED EMBODIMENT

The embodiment disclosed in the drawing comprises a lock mechanism 10, a plug 11 (which is used as a key) and a remotely located enabling switch 12. Included within the lock mechanism 10 is a receptacle 13 for receiving plug 11 and a second plug and receptacle identified as 14 and 15, respectively. Each of these plug-receptacle combinations have N terminals. A jumper 16 is connected between terminals 11-1 and 11-3 of plug 11 while a jumper 17 is similarly connected between terminals 14-1 and 14-3 of plug 14. Although not illustrated, other jumpers are connected in a random manner between pairs of terminals in the first N terminals of plug 11 while similar jumpers exist in plug 14 so that the first N terminals of both plugs are interconnected in an identical manner. A jumper, for example, may exist between terminals 11-5 and 11-8 while still another jumper may exist between terminals 11-8 and 11-(N-1). In this case, jumpers would also exist between terminals 14-5 and 14-8 and 14-8 and 14-(N-1).

Terminals 13-1 through 13-N are connected to a plurality of EXCLUSIVE OR gates 19-1 through 19-N, respectively. Terminals 15-1 through 15-N are similarly connected to EXCLUSIVE OR gates 19-1 through 19-N. Each of these EXCLUSIVE OR gates produces a logic ONE output only when its inputs are dissimilar — that is, only when one input is a logic ONE and the other is a logic ZERO. In the present disclosure a logic ONE is taken to be a positive pulse or potential while a logic ZERO is taken to be a nonpulse or zero potential. Such techniques and circuits for performing them are well known to those skilled in the art.

Also included within the lock mechanism 10 is a pulse generator 20 having (N+1) output leads identified as 20-1 through 20-(N+1). When potential from a source 21 is applied to generator 20 by the momentary closure of an activating switch 22, generator

20 produces positive potential pulses in a sequential manner on output leads 20-1 through 20-(N+1). The pulse on lead 20-1 is fed through a diode 20-1-1 to the junction between terminal 13-1 and EXCLUSIVE OR gate 19-1. The same pulse is fed through a diode 20-1-2 to the junction between terminal 15-1 and EXCLUSIVE OR gate 19-1 and through a diode 20-1-3 to a delay circuit 23. In a similar manner the pulse on lead 20-2 is fed through a diode 20-2-1 to the junction between terminal 13-2 and EXCLUSIVE OR gate 19-2, through a diode 20-2-2 to the junction between terminal 15-2 and EXCLUSIVE OR gate 19-2 and through a diode 20-2-3 to the delay circuit 23. Pulses on the remainder of the first N output leads of generator 20 are similarly fed through diodes to the remaining junctions and delay circuit 23. These diodes operate to provide isolation so that positive potential pulses appearing at any of the junctions or at the input to delay circuit 23 are not coupled to any of the other junctions by way of these feed paths.

Positive potential pulse outputs of EXCLUSIVE OR gates 19-1 through 19-N are coupled through diodes 24-1 through 24-N, respectively, to one input terminal of an AND gate 25. These diodes function as an OR gate so that when one or more of the EXCLUSIVE OR gates 19-1 through 19-N produces a pulse, that pulse is coupled to AND gate 25. The remaining input of AND gate 25 is connected to the output terminal of delay circuit 23. The output from delay circuit 23 enables AND gate 25 only after all transients in the other input of AND gate 25 have terminated.

Operation of the apparatus described thus far is now presented.

Plug 11 is the key to the lock and must be inserted as shown before the lock can be made to open. Once inserted, activating switch 22 is closed and a sequence of pulses appears on output leads 20-1 through 20-(N+1) of generator 20. The pulse appearing on output lead 20-1 appears at both input terminals of EXCLUSIVE OR gate 19-1 with the result that this gate produces a nonpulse output. This same pulse passes by way of jumpers 16 and 17 to terminals 13-3 and 15-3, respectively, and thence to EXCLUSIVE OR gate 19-3. Because its two inputs are alike, this OR gate produces a nonpulse output. The inputs to the remaining EXCLUSIVE OR gates are all nonpulses and consequently their outputs are also nonpulses. These outputs from EXCLUSIVE OR gates 19-1 through 19-N result in a nonpulse being applied to one input terminal of AND gate 25. Delay circuit 23 causes the remaining input of AND gate 25 to receive a slightly delayed version (to permit the decay of transients from the EXCLUSIVE OR gates) of the pulse on lead 20-1. AND gate 25 produces a nonpulse output because of the absence of a pulse on the other input terminal of the gate.

A pulse appearing on output lead 20-2 is applied to both inputs of EXCLUSIVE OR gate 19-2 with the result that a nonpulse appears at its output. Because of the absence of any jumpers interconnecting leads 11-2 and 14-2 to other terminals, the pulse appearing on lead 20-2 is not applied to any of the other EXCLUSIVE OR gates and consequently their outputs are all nonpulses. As all of the EXCLUSIVE OR gates produce nonpulse outputs, a nonpulse is again applied to one of the input terminals of AND gate 25. Delay

circuit 23 causes a delayed version of the pulse on lead 20-2 to be applied to the other input of AND gate 25. A nonpulse output is again produced by AND gate 25.

Keeping in mind that corresponding jumpers interconnect the first N terminals of plugs 11 and 14, it is believed readily apparent, from the above discussion, that subsequent pulses on leads 20-3 through 20-N result in nonpulse outputs from AND gate 25.

Now consider the operation when a wrong key — i.e., a plug 11 with jumpers which do not correspond to those in plug 14 — is inserted into lock mechanism 10. For example, assume jumpers 16 to be missing. In this case, EXCLUSIVE OR gate 19-3 produces a pulse output in response to a pulse on lead 20-1, while EXCLUSIVE OR gate 19-1 also produces a pulse output in response to a pulse on lead 20-3. These EXCLUSIVE OR gate pulse outputs along with the pulse outputs from delay circuit 23 cause AND gate 25 to produce pulse outputs which indicate the use of the wrong key.

The remaining elements of lock mechanism 10 include a flip-flop 26 having an input terminal *a* connected to AND gate 25 and an input terminal *b* connecting to activating switch 22. The output terminals of the flip-flop are identified as *c* and *d*. A positive potential or pulse applied to input terminal *a* causes the output on terminal *c* to be a positive potential while the output on terminal *d* is a zero potential. A positive potential or pulse applied to terminal *b* — by the momentary closure of switch 22 — causes the above-mentioned outputs on leads *c* and *d* to reverse.

Lock mechanism 10 also includes an AND gate 27 which has three input terminals. These terminals are connected to lead *d* of flip-flop 26, lead 20-(N+1) of generator 20 and remotely located enabling switch 12. Enabling switch 12 applies potential from source 21 as a logic ONE to one input terminal of AND gate 27. Operation of switch 22 places flip-flop 26 in a state to apply a positive potential as a logic ONE to another input terminal of AND gate 27. Because the correct plug 11 has been used, the state of the flip-flop 26 remains the same for all of the pulses appearing on leads 20-1 through 20-N. A pulse appearing on lead 20-(N+1) provides a logic ONE on the last input terminal of AND gate 27 and a pulse output is produced. This output is applied to a bolt release mechanism 28 which releases the locking bolt.

As explained earlier, use of an incorrect plug 11 causes flip-flop 26 (in response to pulses on leads 20-1 through 20-N) to change state so that its output leads *c* and *d* are at positive and zero potential levels, respectively. In this case, AND gate 27 does not produce a pulse output and the lock is not released.

Output terminal *c* of flip-flop 26 is connected by way of a diode 29 to a first input terminal of an AND gate 30. The remaining input terminal of AND gate 30 is connected to output lead 20-(N+1) of generator 20. The output of AND gate 30 is in turn applied to an alarm 31. Once activated, the alarm remains activated until a resetting voltage is applied to another input thereto by the closure of a reset switch 32.

Lock mechanism 10 further includes an inverter 33 and a diode 34 connected in series in that order between remotely located enabling switch 12 and the aforementioned first input terminal of AND gate 30. With switch 12 in its disabled state, inverter 33 applies

a positive potential to the first input terminal of AND gate 30. Operation of switch 22 causes a pulse to appear on lead 20-(N+1), which is effective to activate alarm 31. This occurs even when the correct plug 11 has been inserted. This feature permits the lock to be disabled from a master location.

If the above-described control feature is not desired, switch 12, one of the input terminals of AND gate 27, inverter 33, AND gate 30, and diodes 29 and 34 may be eliminated with diode 29 and AND gate 30 being replaced by a through connection. On the other hand, if the alarm feature is not desired, inverter 33, diodes 29 and 34, AND gate 30, alarm 31, and switch 32 may be eliminated.

In summary, operation of switch 22 assures that flip-flop 26 at least initially applies a positive voltage to one of the inputs of AND gate 27. It further starts generator 20 so that a sequence of testing pulses are produced on leads 20-1 through 20-N, following which a pulse is applied to a second input terminal of AND gate 27. Plug 11 supplies a set of paths which are compared with paths in plug 14. When an unfavorable comparison occurs, the positive voltage applied to AND gate 27 by flip-flop 26 is removed while a positive voltage is applied to AND gate 30 so that the alarm sounds when a pulse appears on lead 20-(N+1). When a favorable comparison occurs, the state of flip-flop 26 does not change. Under these conditions, however, switch 12 must be closed before the pulse appears on lead 20-(N+1) in order to activate bolt release 28. When switch 12 is not so closed, bolt release 28 will not be activated while alarm 31 will be.

Changing of the combination is achieved by merely replacing plug 14 with another plug having a different jumper or strapping arrangement. For security purposes, the jumper or strapping arrangements in plugs 11 and 14 may be encased in a potting compound such as ceramic. Changing of the combination may therefore be performed by someone who does not need to know the strapping arrangement. Furthermore, the user of the key plug does not need to know the strapping arrangement in order to use the plug.

In accordance with the invention, jumpers or strapping may be present between any pair of terminals, among triplets, quadruplets, or other groupings of terminals, as well as in all possible different combinations of strapping groups. If the number of such terminals available for strapping is N, and the number of terminals strapped together in a group is r, then the number of different combinations available for a key with a single strapping set is

$$\sum_{r=2}^N C(N,r) = \sum_{r=2}^N \frac{N!}{(N-r)!r!}$$

where C(N,r) is read as the number of combinations of N things taken r at a time. Summation begins with 2 because a terminal must be strapped to at least one other terminal to have significance.

When two mutually exclusive sets of strappings appear on the plugs, the number of available combinations increases to

$$\sum_{r=2}^N C(N,r) + \frac{\sum_{r=2}^{N-2} \sum_{s=2}^{N-r} C(N,r)C(N-r,s)}{2}$$

providing that $(r+s) \leq N$.

Each time the number of terminals is increased by two, the number of generations of strappings — that is, the number of mutually exclusive and separate concurrent strapping arrangements — is increased by one. The total sum of the distinct combinations available from N terminals may be expressed as S_N . A formula for its calculation is as follows:

$$S_N = \sum_{r=2}^N C(N,r) + \sum_{r=2}^{N-2} \sum_{s=2}^{N-r} \frac{C(N,r) \cdot C(N-r,s)}{2!} + \sum_{r=2}^{N-4} \sum_{s=2}^{N-(2+r)} \sum_{t=2}^{N-(r+s)} \frac{C(N,r) \cdot C[(N-r),s] \cdot C[N-(r+s),t]}{3!} + \dots$$

This series is limited in its number of terms by the constraints that $N \geq r+s+t+\dots$ and that all terms $r, s, t, \text{et cetera} \geq 2$.

The value of S_N grows at an extremely rapid rate. This is illustrated in the following table:

N number of terminals	S_N number of combinations
2	1
3	4
4	14
5	51
6	202
7	876
8	4,034
9	18,891
10	92,784
12	4,055,265
15	Approx. 10^9

What is claimed is:

1. An electronic lock comprising:

bolt releasing means responsive to an electrical input to move from a locked position to an unlocked position;

a plurality of EXCLUSIVE OR gates, each having first and second input terminals and an output terminal;

a first plurality of shorting leads interconnecting at least some of said first input terminals in a predetermined combination;

means including a second plurality of shorting leads and connectable to said second input terminals to interconnect said second input terminals in a combination corresponding exactly to that in which said first input terminals are connected;

means to apply pulses sequentially to said EXCLUSIVE OR gates to pulse simultaneously both of the input terminals of each gate being pulsed; and

means to apply said electrical input to said bolt releasing means in response to the nonoccurrence of any outputs from said gates after said pulses have been applied thereto.

2. An electronic lock comprising:

bolt releasing means responsive to an electrical input to move from a locked position to an unlocked position;

a plurality of EXCLUSIVE OR gates, each having first and second input terminals and an output terminal;

first and second receptacle means each having a plurality of terminals equal to said plurality of EXCLUSIVE OR gates with the terminals of said first receptacle connected to said first input terminals, respectively, and with the terminals of said second receptacle connected to said second input terminals respectively,

first and second plugs each having a plurality of terminals corresponding to said first and second receptacle terminals for engagement therewith,

a first plurality of shorting leads interconnecting at least some of said first plug terminals in a predetermined combination,

a second plurality of shorting leads interconnecting said second plug terminals in a combination corresponding exactly to that in which said first plug terminals are connected;

said first plug being inserted in said first receptacle to determine the lock combination and said second plug being insertable in said second receptacle as the key for the lock;

pulse producing means connected to said EXCLUSIVE OR gates to apply pulses sequentially thereto to pulse simultaneously both of the input terminals of each gate being pulsed and, furthermore, to produce a control pulse immediately thereafter, and

means connected between said EXCLUSIVE OR gates, said bolt releasing means and said pulse producing means to apply said electrical input to said bolt releasing means in response to said control pulse when said gates do not produce any output in response to said pulses.

3. An electronic lock in accordance with claim 2 which further comprises

means operable for disabling said last-mentioned means.

4. An electronic lock in accordance with claim 2 which further comprises

an alarm mechanism, and

means to activate said alarm mechanism in response to the occurrence of an output from any of said gates after said pulses have been applied.

5. An electronic lock in accordance with claim 3 which further comprises

an alarm mechanism,

means to activate said alarm mechanism in response to the occurrence of an output from any of said gates after said pulses have been applied, and

means to activate said alarm mechanism in response to said disabling means having been operated and said pulses having been applied to said gates.

6. An electronic lock comprising:

bolt releasing means responsive to an electrical input to move from a locked position to an unlocked position;

a plurality of N EXCLUSIVE OR gates where N is an integer and each of said gates has first and second

input terminals and an output terminal;

first and second receptacle means each having N terminals with the terminals of said first receptacle connected to said first input terminals, respectively, and with the terminals of said second receptacle connected to said second input terminals, respectively,

first and second plugs each having N terminals and mateable with said receptacles, respectively,

a first plurality of shorting leads interconnecting at least some of said first plug terminals in a predetermined combination,

a second plurality of shorting leads interconnecting said second plug terminals in a combination corresponding exactly to that in which said first plug terminals are connected;

said first plug being inserted in said first receptacle to determine the lock combination and said second plug being insertable in said second receptacle as the key for the lock;

pulse producing means having (N+1) output terminals on which pulses appear in a sequential manner,

means connecting the first N of said pulse producing means terminals to said gates, respectively, to pulse simultaneously both of the input terminals of each gate being pulsed,

a flip-flop circuit having two input and two output terminals,

means connecting one of said flip-flop circuit input terminals to said gate output terminals whereby said flip-flop circuit is responsive to a pulse output from any one of said gates to place said flip-flop circuit in a first state when not already in that state,

an AND gate having input terminals connected to said (N+1) output terminal and to one of said flip-flop circuit output terminals respectively, to produce an output from said AND gate in response to said flip-flop being in said first state and a pulse occurring on said (N+1) terminal, and

means connecting said AND gate to said bolt releasing means to apply said AND gate output to said bolt releasing means as said electrical input.

7. An electronic lock in accordance with claim 6 which further comprises

means operable for disabling said AND gate.

8. An electronic lock in accordance with claim 6 which further comprises

an alarm mechanism, and

an AND gate having a first input terminal connected to the remaining output terminal of said flip-flop circuit, a second input terminal connected to said (N+1) terminal and an output terminal connected to said alarm mechanism.

9. An electronic lock in accordance with claim 8 which further comprises

means operable for disabling both of said AND gates.

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