

[54] **REMOTELY POWERED TRANSPONDER**

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[58] Field of Search **343/6.5 R, 6.5 LL,**
343/6.5 SS, 6.8 R, 6.8 LC

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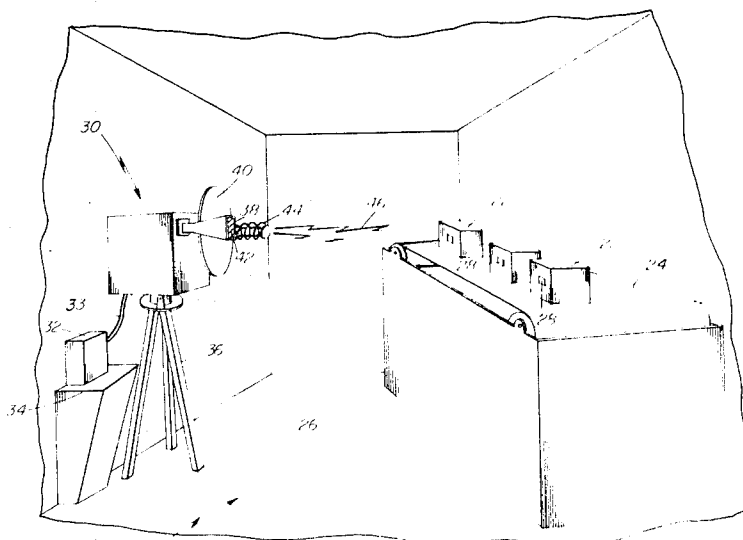
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[57] **ABSTRACT**

A transponder having a circuit for the extraction of power from an incident interrogating beam of electromagnetic energy, the extracted power being utilized to operate a digital coding circuit. The transponder further comprises an oscillator circuit for developing a train of pulses of electromagnetic energy with successive pulses occurring in a coded format in accordance with a digital code imparted by the digital coding circuit. The transponder is of sufficiently small size to be affixed in the form of a tag to automobiles, personnel, containers and other objects to be identified. The electronic tag communicates with an interrogation system.

27 Claims, 12 Drawing Figures



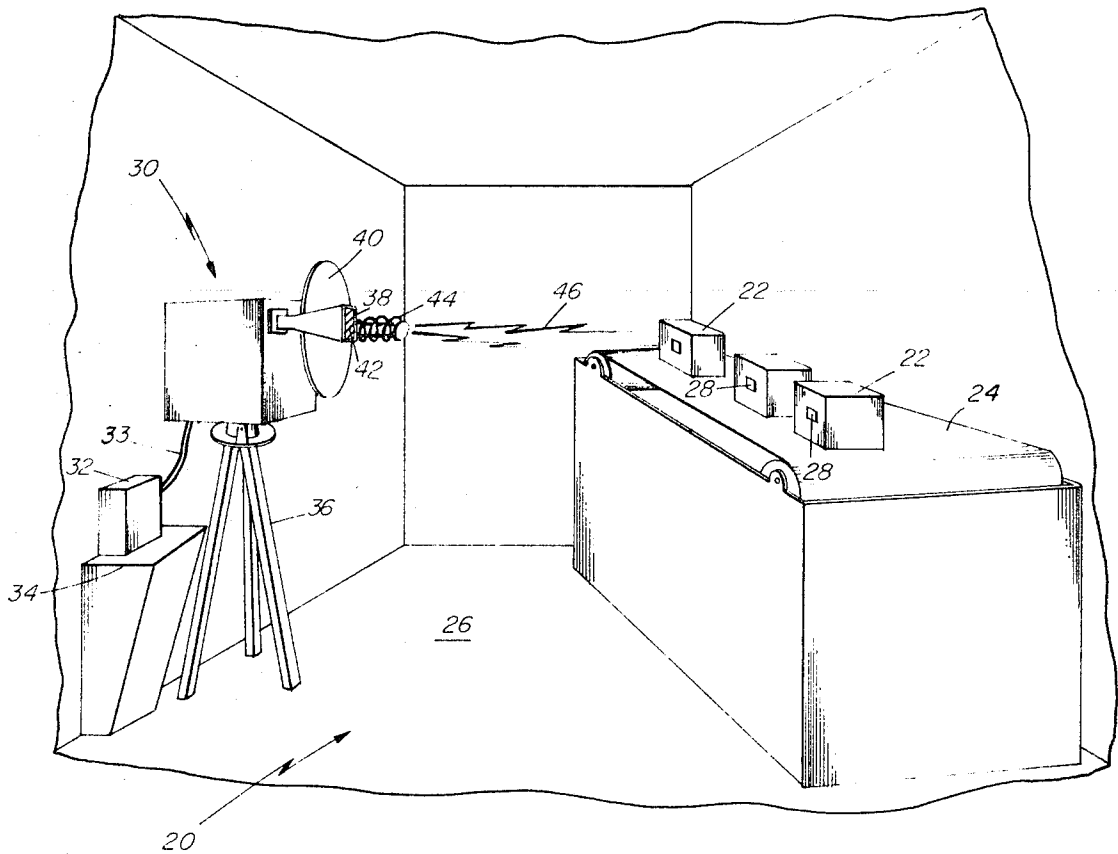


FIG. 1

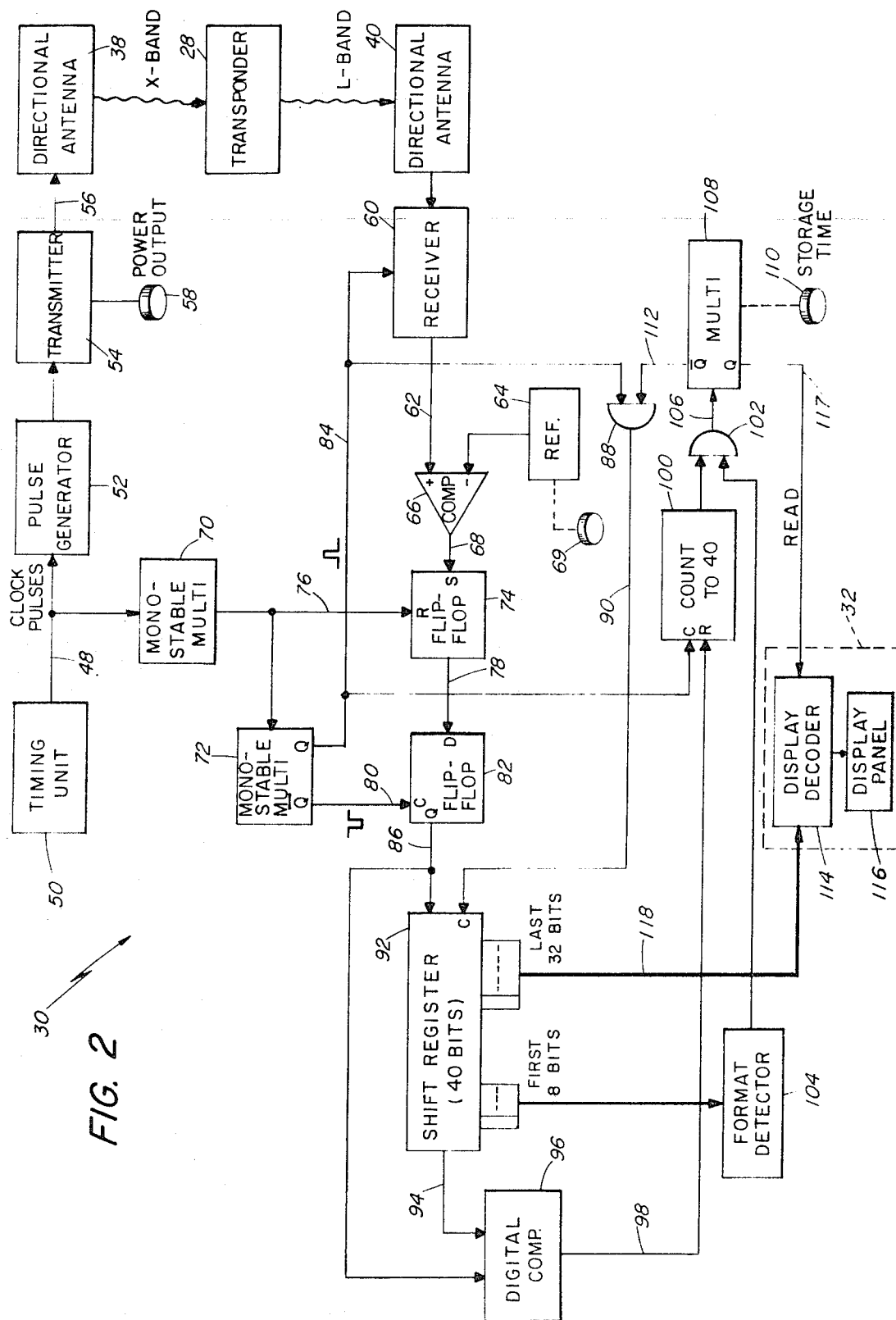
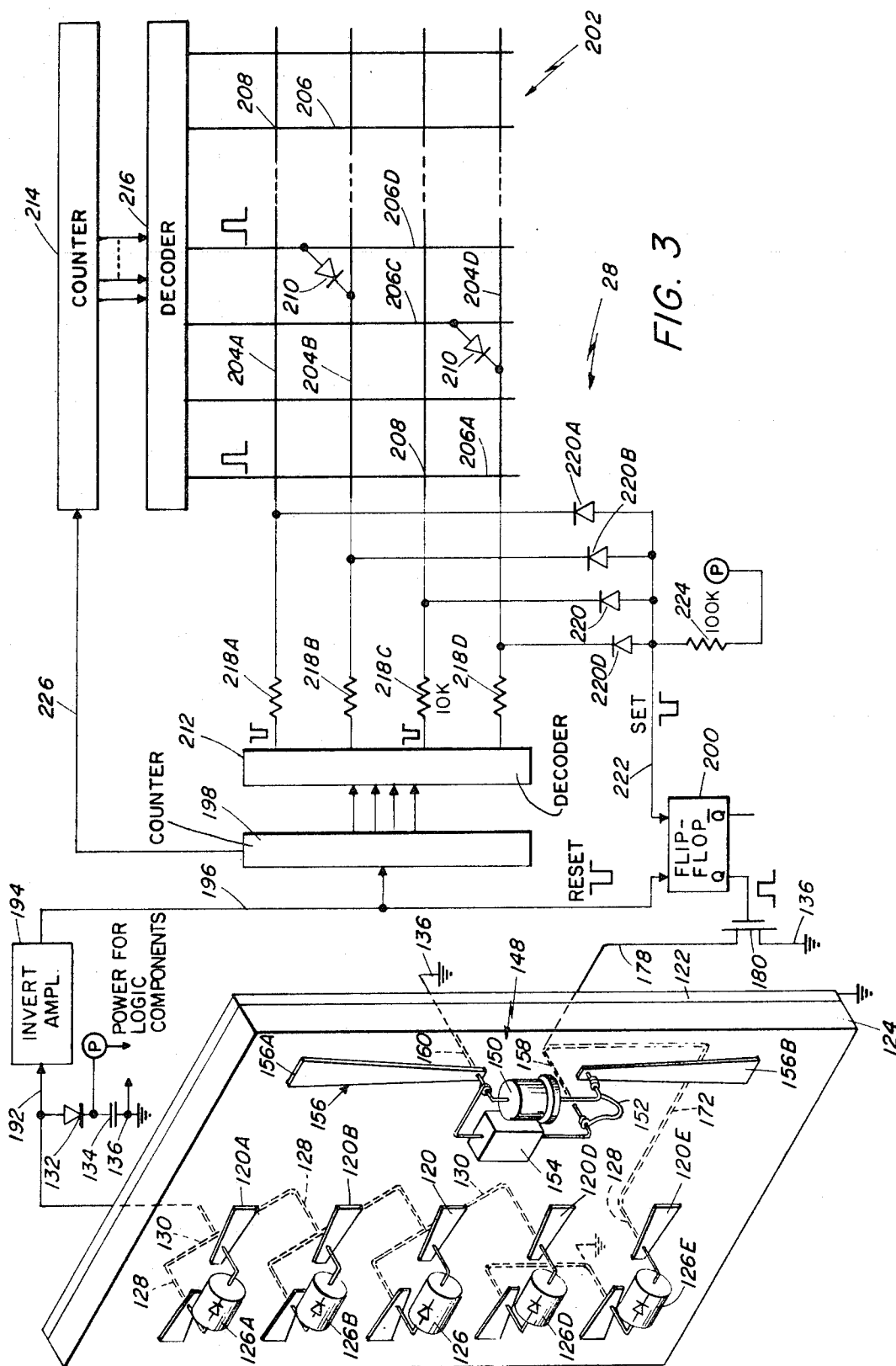
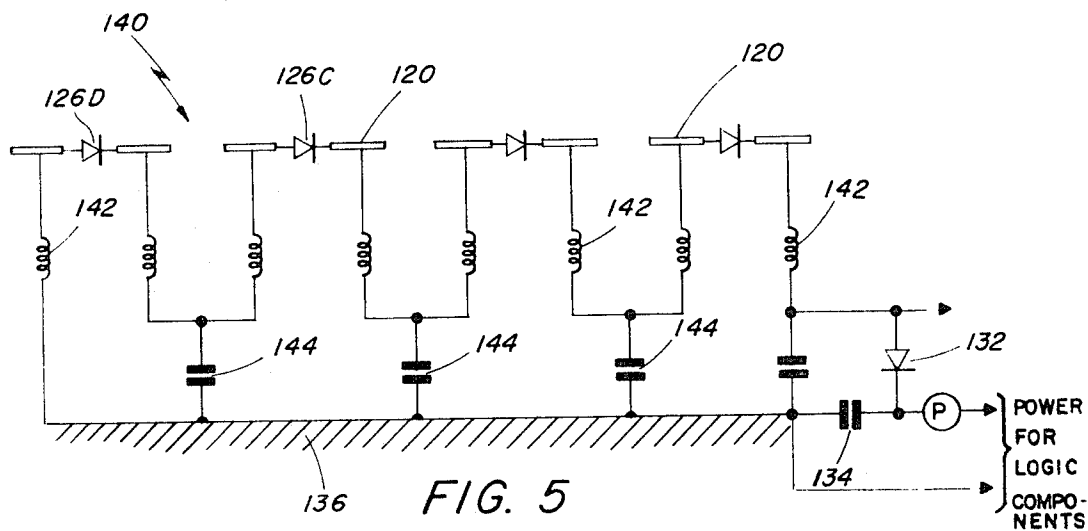
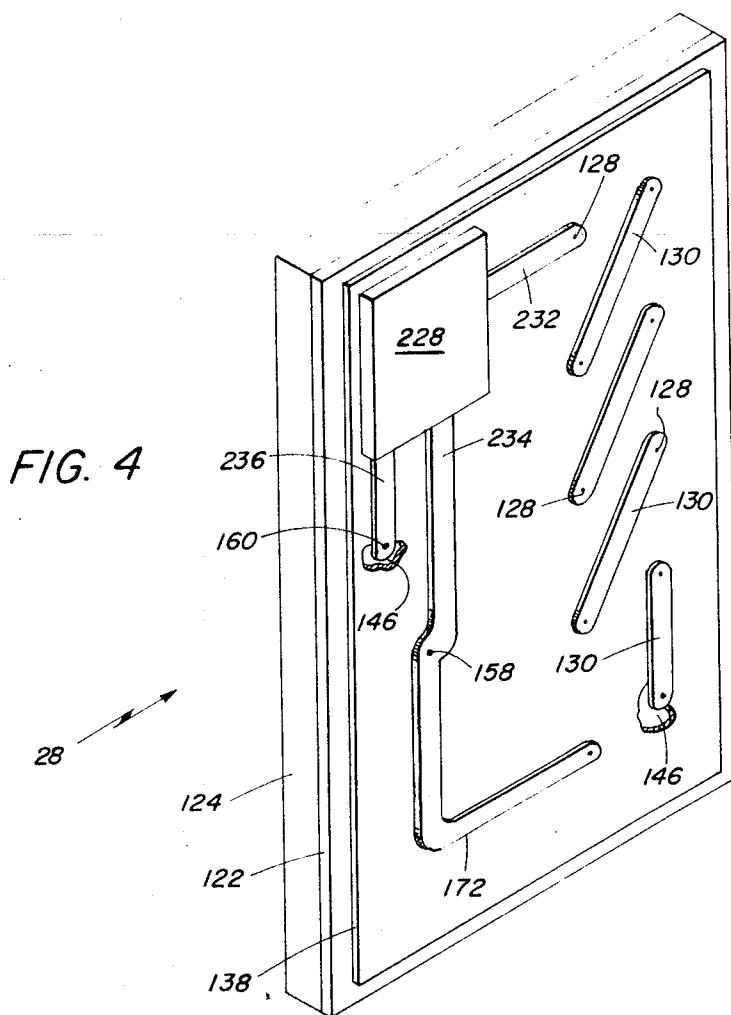


FIG. 2





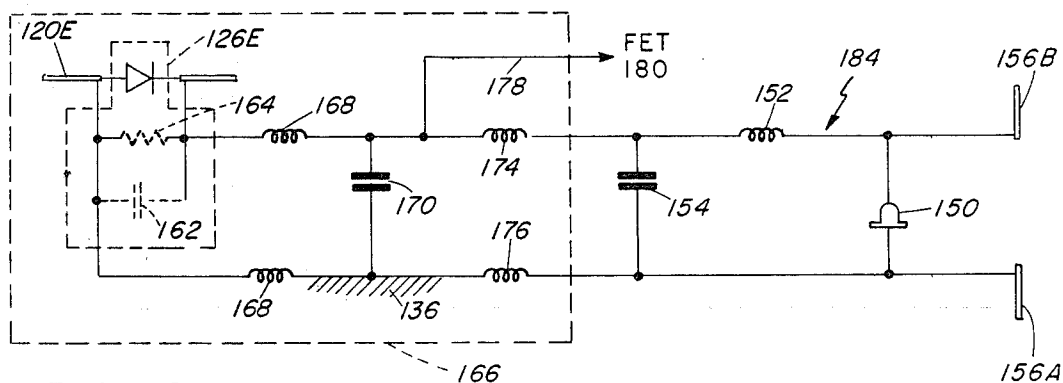


FIG. 6

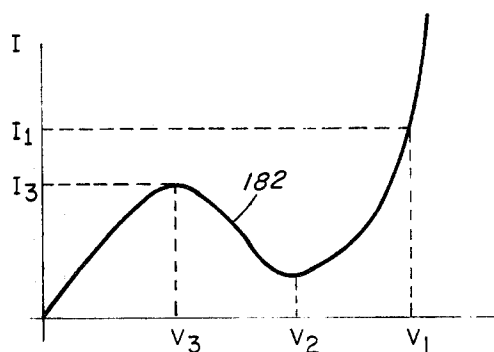


FIG. 7

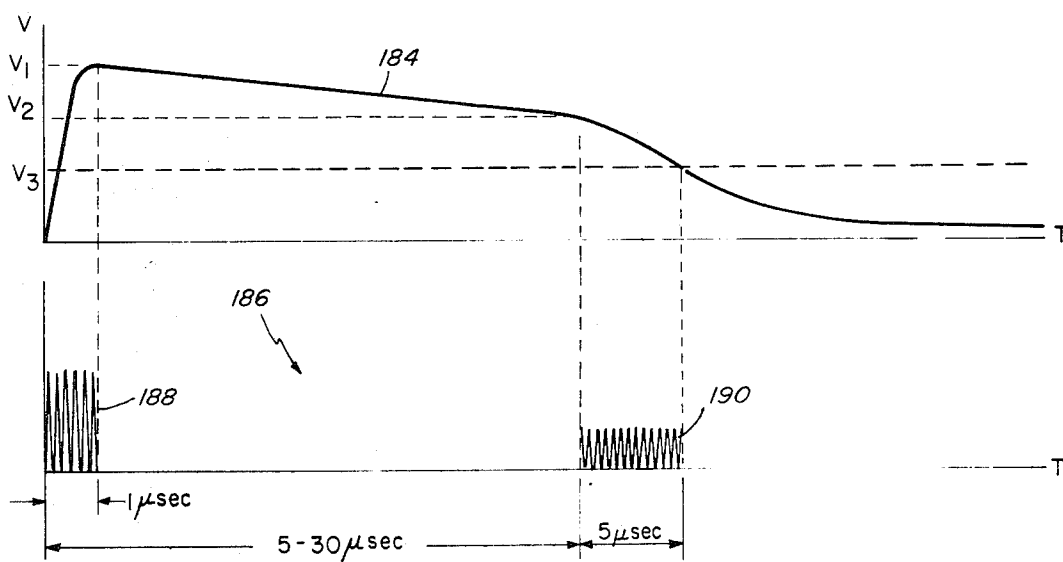


FIG. 8

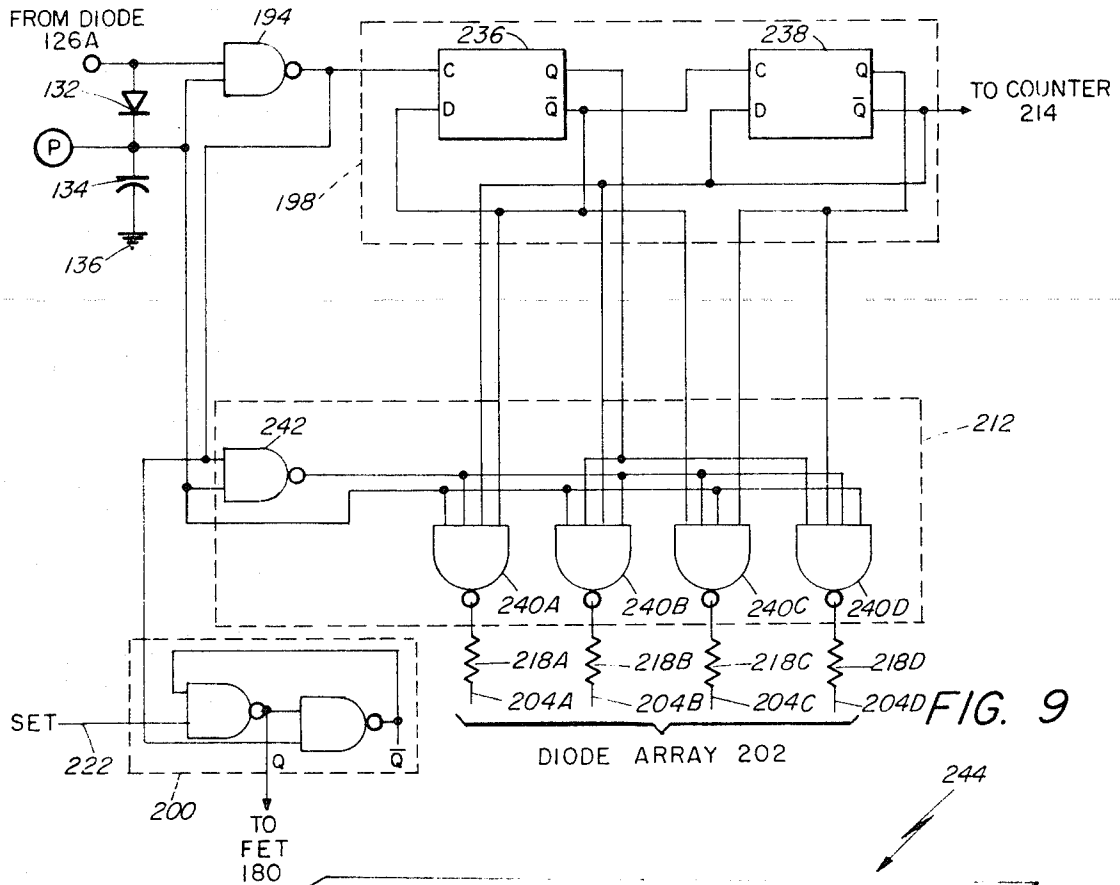
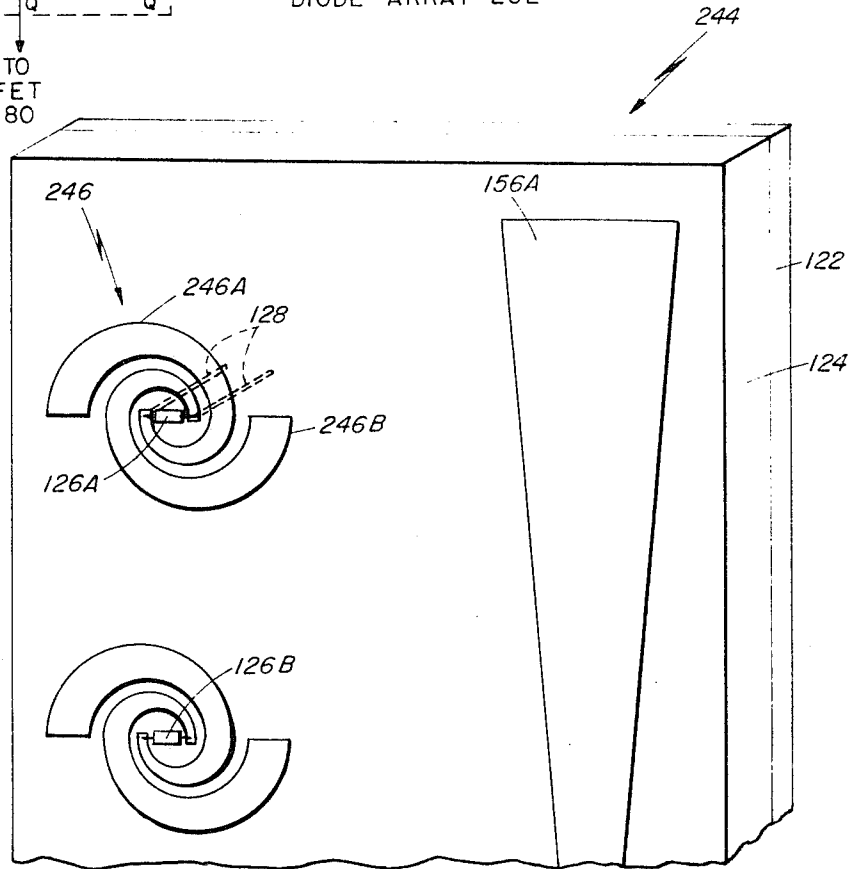
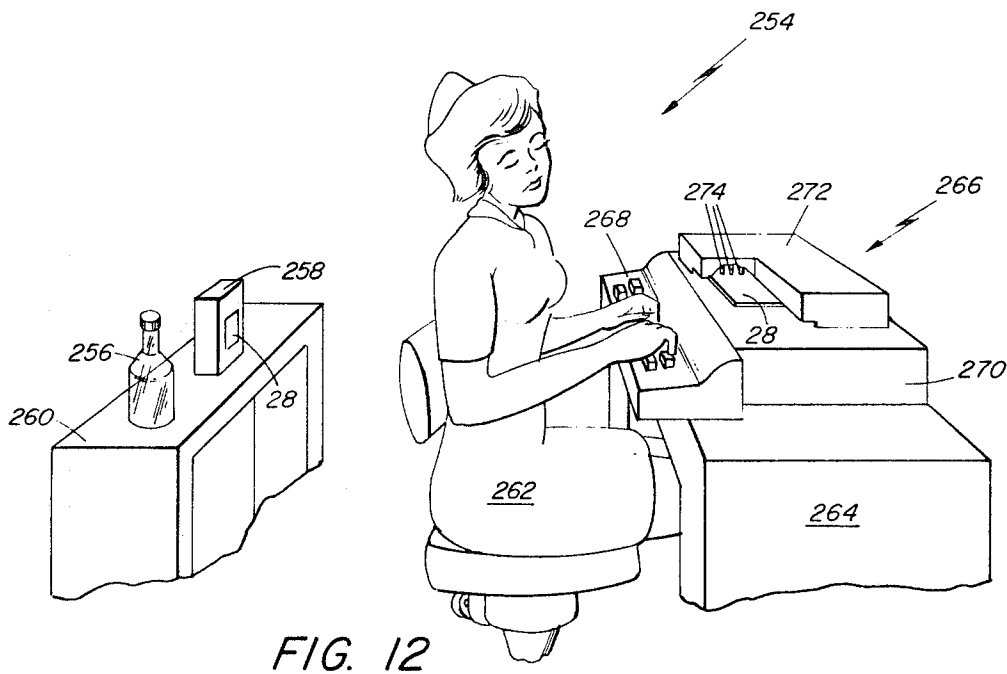
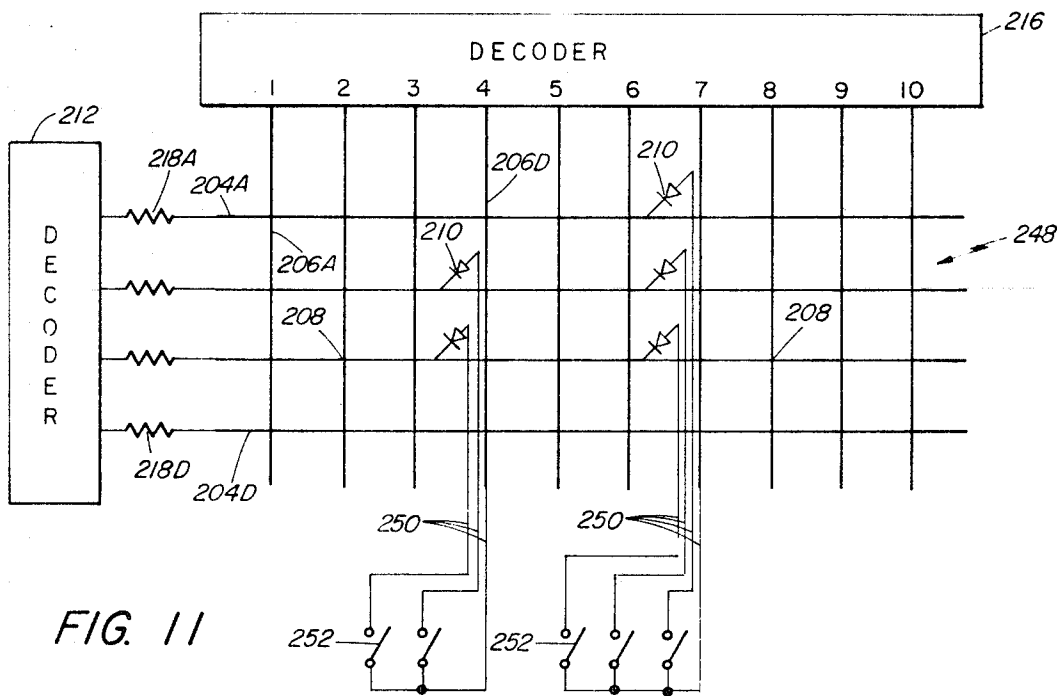


FIG. 9

FIG. 10





REMOTELY POWERED TRANSPONDER

BACKGROUND OF THE INVENTION

Various forms of transponders having no internal source of power have been utilized in the past. Typically, these transponders have utilized a tuned circuit responsive to incident radiation and extracting energy therefrom for momentarily storing such energy either within the tuned circuit itself, as by means of mechanical strains in a piezoelectric crystal, or by means of a detector having a storage capacitor. Such transponders are inherently limited in the amount of information that they can supply in a response to an interrogating signal. For example, such a transponder may utilize a thermally sensitive element in its tuned circuit for retransmitting a pulse of electromagnetic energy at a frequency slightly offset from that of the interrogating frequency such that the amount of frequency offset is related to the temperature as sensed by the thermally sensitive element. Or, alternatively, such transponders may comprise a tuned circuit responsive to some harmonic or subcarrier frequency of the interrogating signal for responding with a pulse of electromagnetic energy at that frequency.

A problem exists in that in many applications today, such as in the identification of automobiles in a car rental system, or in the identification of packages moving along a conveyer belt, or in the identification of medicine contained in bottles in a hospital, as well as numerous other similar type situations requiring identity of an object as well as information about the object, it is frequently desirable to provide a substantial amount of data in a manner which is suitable for rapid display and for entry into a computer. For example, in an automobile rental system it is desirable to know the identity of the car, the mileage, the amount of gasoline, the expected date of return and similar matters; all of this to be extracted in the relatively short interval of time that is required for the automobile to pass by a gate of the parking lot. Similar comments apply to the storage of medicine in a bottle in a hospital wherein it is desirable to know the identity of the medicine and the patient for whom it has been prepared, the attending physician, the patient's location in the hospital, the date and similar matters; all this data to be provided by a momentary scan of the bottle of medicine to insure effective operation of hospital administrative procedures.

SUMMARY OF THE INVENTION

The aforementioned deficiencies in the informational capacity of transponders energized from the energy of an interrogating signal are overcome by a transponder and interrogator in accordance with the present invention in which the transponder utilizes a succession of serially connected antenna elements, each of which is electrically connected with a rectifying device, preferably a microwave diode, for developing a source of power having a voltage substantially higher than that provided by a single radiating element. A low voltage oscillator circuit, such as a tunnel diode relaxation oscillator, is energized by successive pulses of an interrogating electromagnetic beam incident upon one of the aforementioned antenna elements, an in response thereto, provides a succession of pulses of electromagnetic energy via a separate antenna. For example, the interrogating beam may be at an X-band microwave

frequency while the response is provided at L-band. The transponder further incorporates a preset memory system, preferably an array of conductors arranged in a matrix with preselected crosspoints coupled by diodes, the conductors being energized via counters in response to a counting of the interrogating pulses, and the output of the memory being utilized to activate (or inhibit) the oscillator circuit to provide a succession of the radiant energy pulses in a digitally coded format for transmission of the message stored in the memory. The transponder is of sufficiently small physical size to be attached to an object in the form of a tag.

The interrogator incorporates means for identifying a preset sequence of pulses to establish that a transponder is present as well as to identify the beginning of the message. In addition the interrogator further checks each pulse with the pulse arriving one message interval earlier to further identify the presence of a valid message. The message is stored, as by a shift register having parallel outputs, to provide ready access to a display or computer.

BRIEF DESCRIPTION OF THE DRAWINGS

The aforementioned features and other advantages of the invention are explained in the following description taken in connection with the accompanying drawings wherein:

FIG. 1 is a description of a cargo identification system in which packages tagged with transponders pass before an interrogator in accordance with the invention for identification of the individual packages;

FIG. 2 is a block diagram of the interrogator of the invention including a communication link with the transponder of the invention;

FIG. 3 is a diagrammatic view, partially schematic and partially structural, of the transponder of the invention;

FIG. 4 is a detailed view of the back side of the transponder showing interconnections between the antenna elements;

FIG. 5 is a schematic diagram of the interconnection of antenna elements of the transponder;

FIG. 6 is an oscillator circuit of the transponder for transmitting a response to the interrogator;

FIG. 7 shows the current-voltage relationship for a tunnel diode of the oscillator circuit;

FIG. 8 is a graph of the tunnel diode voltage, and further indicates the interval of oscillation;

FIG. 9 is a schematic diagram of a counter and decoder utilized in the coding circuit of the transponder for coding the response with data stored within the transponder;

FIG. 10 is a dimetric view of an alternative antenna arrangement for the transponder utilizing spiral antenna elements;

FIG. 11 is a schematic diagram for switchably altering the cross-point connections in the memory system of the transponder; and

FIG. 12 shows a means for automatically imprinting a message in the memory system of the transponder.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a pictorial view of a package identification system 20 in which individual packages 22 are transported along a conveyer belt 25 in a shipping room 26. The individual packages

are identified, in accordance with the invention, by means of transponders 28 each of which has the form of a tag which is affixed to a package 22. An interrogator 30 interrogates each transponder 28 as the packages 22 pass by the interrogator 30. A message, relating to the contents of an individual package 22 and stored within the transponder 28, is transmitted back to the interrogator 30 and appears on a display 32 connected by electrical cable 33 to the interrogator 30 and conveniently mounted on a shelf 34 for easy viewing by personnel of the shipping room 26. The interrogator 30 is shown mounted on a tripod 36 so that it may be readily positioned to interrogate the individual packages 22 as they pass along the conveyer belt 24.

The interrogator 30 is equipped with a directional transmitting antenna 38 and a directional receiving antenna 40 so that electromagnetic energy may be directed towards a single transponder 28 even when the packages 22 are closely spaced. The interrogator 30 is equipped with a threshold circuit, to be described hereinafter, whereby the interrogator 30 is adjusted for the intensity of radiation transmitted back from a transponder 28 to the receiving antenna 40 for improved discrimination between the transmissions of transponders 28 on closely spaced packages 22. The intensity of the power transmitted by the transmitting antenna 38 is also adjustable, in a manner to be described, so that a transponder 28 is radiated with an optimum intensity independently of the distance between the interrogator 30 and the conveyer belt 24.

To provide isolation between the transmitting antenna 38 and the receiving antenna 40, it is convenient to transmit and receive on separate frequencies. Thus, in the preferred embodiment the transmitting antenna 38 operates at X-band (approximately 9.4 GHz) and the receiving antenna 40 operates at L-band (approximately 1.2 GHz); circular or linear polarization may be utilized. Alternative antenna configurations for the transponders 28 adapted for linear or circular polarizations will be disclosed hereinafter. As shown in FIG. 1, the horn of the transmitting antenna 38 is equipped with diagonal vanes to provide circular polarization, and the receiving antenna 40 includes a helical radiating element for reception of circularly polarized radiation. The beam of radiation from the transmitting antenna 38 is indicated by rays 46. While the linear polarization has the advantage of providing a simpler antenna configuration within the transponder 28, the circular polarization is advantageous in that there is no requirement that the transponder 28 be positioned in a preferred direction to intercept the polarized radiation.

The radiant energy signal transmitted from a transponder 28 to the interrogator 30 consists of a digitally coded pulse train, to be described hereinafter, which conveys the message stored within the transponder 28 to the interrogator 30. The digital code includes a sequence of digits which identify the presence of a valid signal radiated by a transponder 28, as well as indicating the beginning and end of the digitally coded message. The remaining digits of the coded pulse-train signal are utilized to convey the message itself. Thus, as each transponder 28 moves into the rays 46 and, in response thereto, begins retransmitting to the interrogator 30, the interrogator 30 processes the received pulse-train signal, in a manner to be described, and stores the message for a few moments as it is displayed on the display 32. The interrogator 30 then again processes the re-

ceived pulse-train signal and, if the transponder 28 is still within the rays 46, this information is displayed for a few more moments on a display 32; however, if the transponder 28 on the next package 22 has moved into the rays 46, then the message in that transponder is displayed on the display 32.

While the transponder to be described herein is responsive to incident electromagnetic energy, it is understood that a similar type transponder may be provided which is responsive to incident acoustic energy. For example, a beam of pulses of radiant acoustic energy incident upon a piezoelectric crystal is converted by the crystal to pulses of electrical energy which may then be processed in the same manner as will be disclosed hereinafter with reference to the transponder responsive to the incident electromagnetic energy.

Referring now to FIG. 2, there is shown a block diagram of the interrogator including the X-band and L-band transmission links with the transponder 28. The signal transmitted by the transmitting antenna 38 to the transponder 28 is a pulse modulated X-band carrier signal in which the succession of pulses occur respectively in response to clock pulses on line 48 from a timing unit 50. In response to each of the clock pulses on line 48 a pulse generator 52 generates a pulse having a width on the order of one microsecond which is then applied to a transmitter 54. The transmitter 54 is a well known X-band source of electromagnetic energy which is modulated by the pulses of pulse generator 52 to provide a succession of X-band pulses along line 56 to the directional antenna 38. The transmitter 54 is equipped with a power output control 58 for adjusting the power of the signal on line 56 in a well known manner such as by adjusting an attenuator (not shown) within the transmitter 54. The repetition rate of the clock pulses on line 48 is high enough to accommodate the data rate in the transmission of the message from the transponder 28 to the interrogator 30; for example, a repetition rate of 4 KHz is utilized in the preferred embodiment.

The transponder 28 transmits along the L-band link to the receiving antenna 40 a pulse train signal in which each pulse corresponds to one of the transmitted pulses from the transmitting antenna 38. The coding of the transponder output signal, as well as described hereinafter, is accomplished by deleting certain pulses in each sequence of pulses in accordance with a digital format in which the presence of a pulse corresponds to a logic 1 and the absence of a pulse corresponds to a logic 0. Since the transponder 28 has its own oscillator circuit for generating pulses of microwave energy, the pulses in the L-band link have a pulse width independent of the pulse width of pulses in the X-band link, and furthermore the occurrence of the pulses in the L-band link is delayed from that of the pulses in the X-band link. However, the pulse repetition frequency of pulses in the L-band link is equal to that of pulses in the X-band link.

The pulses of microwave energy in the L-band link incident upon the receiving antenna 40 are received by a receiver 60 which amplifies, filters and demodulates these pulses in a well known manner to provide a pulse signal on line 62. The bandwidth of the receiver 60 is provided in accordance with well known procedures for passing the major spectral components of the pulses and attenuating noise in the spectral region outside the spectrum of the pulses.

The pulse signal on line 62 is compared to a reference signal 64 by means of a comparator 66 which provides an output sequence of pulses on line 68 corresponding to the sequence of pulses on line 62 when the amplitude of the pulses on line 62 is greater than that of the reference signal 64. The reference signal 64 is adjusted by control 69 (a potentiometer, not shown, may be utilized to provide the reference signal) in accordance with the anticipated amplitude of signals received at the interrogator 30, of FIG. 1, from a transponder 28 directly in front of the receiving antenna 40. This value of the reference signal 64 is larger than a signal which would be received from a second transponder 28 substantially off the axis of the receiving antenna 40. While it is doubtful that a transponder 28 located substantially off the axis of the transmitting and receiving antennas 38 and 40 would receive sufficiently intense radiant energy to be activated to retransmit the coded message, the use of the comparator 66 provides an additional safeguard such that only one transponder 28 is interrogated at a given time.

It is desirable to render the interrogator 30 nonresponsive to received signals during those instance of time when transmitted pulses appear on line 56, thereby insuring that there is no interference between transmitted and received signals. This function is accomplished by means of multivibrators 70, 72, and flip-flop 74. The multivibrator 70 is triggered by the clock pulses on line 58 so that the flip-flop 74 receives a reset signal corresponding to each of the clock pulses 48.

As has been noted, the transponder 28 does not transmit immediately upon reception of the X-band signal, but transmits after a small delay which, as will be seen, is in the range of 5-30 microseconds depending on the intensity of the incident X-band radiation. Furthermore, in view of the short range between the interrogator 30 and the transponder 28 as is evidenced by the arrangement of the shipping room 26 of FIG. 1, the propagation delay of signals on the X-band and L-band links are normally well under 100 nanoseconds so that the only delay that need be considered is that provided by the transponder 28 itself. Accordingly, the multivibrator 70 is monostable for providing a delay somewhat less than the delay in response time of the transponder 28, for example 3 microseconds, this delay being accomplished by triggering the multivibrator 72 and the flip-flop 74 on the trailing edge of the pulse signal on line 76 provided by the multivibrator 70. Thus, the flip-flop 74 is reset immediately before the arrival of a pulse signal on line 68, and is then set by a pulse on line 68 if such pulse has not been deleted as part of the digital coding. Accordingly, there appears on line 78 a voltage provided by flip-flop 74 corresponding to a logic state of 1 if a pulse has arrived on line 68, while the voltage on line 78 remains at a value corresponding to a logic state of 0 in the event that the pulse on line 68 has been deleted in accordance with the digital coding of the message of the transponder 28. Thus, with respect to the digital word appearing on line 68, logical states of 1 appearing on line 78 are in correspondence with the logical states of 1 appearing on lines 68, and logical states of 0 appearing on line 78 correspond to the logical states of 0 appearing on line 68.

Multivibrator 72, a monostable multivibrator which is similarly triggered by the trailing edge of the pulse on line 76, provides in response to each of these triggerings a clock pulse signal on line 80 for flip-flop 82 as

well as an optional gating signal on line 84 for the receiver 60. The clock pulse on line 80 is a negative going pulse provided by the Q output of the multivibrator 72, while the gating signal on line 84 is a positive pulse provided by the Q output of the multivibrator 72. As has been mentioned above, it is desirable to render the interrogator 30 nonresponsive to signals which may be incident upon the receiving antenna 40 except at such times as when a pulse may be received from the transponder 28. The multivibrator 72 provides a pulse width somewhat larger than the width of pulses appearing on line 62 and, accordingly, the signal on line 84 is well suited for gating the receiver 60 to render it responsive to incoming signals at such times as a pulse is expected from transponder 28. Gated receivers are well known and need not be further described. In the preferred embodiment of the invention the pulse width of the multivibrator 72 is approximately 40 microseconds since, as will appear presently, the pulse width of pulses generated by the transponder 28 is typically 5 microseconds.

The flip-flop 82 is of the form known as a D-edge flip-flop which functions in a manner analogous to a one bit shift register such that a pulse signal appearing at terminal D is momentarily stored and then presented at terminal Q on line 86 in response to the pulses on line 80 applied to the clock input terminal of the flip-flop 82. Thus, when the signal voltage on line 80 is of a high value, a signal at the terminal D is stored in the flip-flop 82; and when the signal voltage on line 80 is of a low value, the voltage at terminal Q of flip-flop 82 assumes a high or a low value corresponding to the high or low value of the signal stored in the flip-flop 82. As was mentioned above, the voltage on line 78 is either of a low value corresponding to the logic state of 0 in response to a reset condition of the flip-flop 74, or alternatively, the voltage on line 78 is of a high value corresponding to a logic state of 1 in response to a set condition of flip-flop 74. It is noted that a set condition of flip-flop 74 is retained from the instant of reception of a pulse signal on line 68 until after the generation of the next clock pulse on line 48. By way of summary it is seen, therefore, that a pulse signal on line 68 appears as a voltage level on line 78 which persists for approximately the interpulse spacing of the clock pulses on line 48, and furthermore, the voltage level on line 78 reappears on line 86 after a delay of approximately the interpulse period of the clock pulses on line 48.

The pulse signal on line 84 is also applied via AND gate 88 to serve as clock pulses on line 90 for clocking shift register 92. In response to successive clock pulses on line 90, the shift register 92 accepts successive inputs of the voltages appearing on line 86, that is, the high voltage on line 86 being stored in shift register 92 as logic 1 and the low voltage appearing on line 86 being stored in shift register 92 as logic 0. In the preferred embodiment of the invention, the message of the transponder 28 has a word length of 40 bits of which the first 8 bits form a sequence of 0's and 1's which is unique in the message, that is, this particular sequence is not found anywhere else in the message word. The last 32 bits of the message word represent the actual data content of the message. Accordingly, each bit of the message word is seen to repeat once every 40 bits, or, equivalently, once for every 40 pulses transmitted on the L-band link from the transponder 28.

In the processing of the message by the interrogator 30, two tests are performed. A random digit test is performed to determine that all digits in the shift register are valid digits and are not due to spurious signals which might be received by the receiving antenna 40, such as for example, when the transponder 28 on the moving package 22 of FIG. 1 is at considerable distance from the receiving antenna 40 and has not yet moved into the beam width of the receiving antenna 40. The second test performed by the interrogator 30 is an examination of the first eight bits stored in the shift register 92 to determine that these first eight bits do form the unique sequence for identifying the presence of a transponder 28 as well as establishing that the 40 bits are arranged in the shift register 92 such that the first bit of the message word is positioned at one end of the shift register 92 while the last bit of the message word is positioned at the opposite end of the shift register 92.

The first test, namely the random digit test, is performed in the following manner. In response to the clocking of the shift register 92 by the clock pulse signal on line 90, the shift register 92 becomes filled with successive samples of the signal on line 86 and, thereafter the first bits to be stored in the shift register 92 are cast off via line 94 into a digital comparator 96 which compares the successive logic states of signals appearing on line 94 with the logic states of signals appearing on line 86. Since the length of the shift register 92 is equal to the length of a message word, the logic state of a signal sample on line 86 should be equal to the logic state of the corresponding signal sample on line 94 since that signal sample appeared exactly 40 bits, or 1 message word length, earlier on line 86. The digital comparator 96 provides an output signal on line 98 having a logic state of 0 in response to an equality of logic states on the lines 86 and 94, namely, a 0 and a 0 or a 1 and a 1; and the digital comparator 96 provides a signal on line 98 having a logic state of 1 in response to differing logic states appearing on lines 86 and 94, namely, a 0 and a 1 or a 1 and a 0.

A counter 100 counts the pulses on line 84, these pulses being applied to the clock input terminal of the counter 100. The counter 100 counts to a count of 40 and remains at a count of 40 until it is reset to a count of 0 by a pulse signal on line 98 having a logic state of 1; the counter 100 may also be reset at any time prior to its reaching a count of 40 by the signal on line 98. When the counter 100 reaches a count of 40 it provides a positive pulse to AND gate 102. The counter 100 can reach the count of 40 only when a total of 40 successive bits on line 86 agree with the preceding set of 40 successive bits which occur on line 94, since, in the event that any one of these bits fails to agree with the corresponding bit, the digital comparator 96 provides a logic state of 1 on line 98 which resets the counter 100 to 0.

A format detector 104 is responsive to the first 8 bits of the message word stored in the shift register 92 and, if but only if these first 8 bits have the proper values and are in the proper sequence or format, the format detector 104 applies a positive pulse to the AND gate 102. The format detector 104 may comprise, by way of example, a multiple input AND gate in which certain ones of its inputs are inverted. In the preferred embodiment of the invention, the first 8 bits are arranged in the sequence 01111100 in which case the first, seventh and eighth inputs to the AND gate are preceded by in-

verters so that when all of the bits are correct, 8 positive pulses appear at the inputs to the AND gate with the result that a positive pulse appears at the output of the AND gate.

In response to the positive pulse signals of the counter 100 and the format detector 104, the AND gate 102 applies a positive pulse on line 106 to multivibrator 108. The multivibrator 108 is a monostable multivibrator providing a negative going pulse at the $\bar{Q}$ output and a positive going pulse on the Q output, these pulses having a pulse width which is variable and is preset in a well known manner by means of a control 110 connecting with the multivibrator 108. For example, the control 110 may adjust the value of a resistance within the multivibrator 108 to effect a change in the pulse width. The $\bar{Q}$ output on line 112 normally presents a voltage of a high value to the AND gate 88 so that the aforementioned pulses on line 90 appear in response to pulses on line 84. In response to the signal on line 106 the voltage on line 112 assumes a low value which terminates the presence of clock pulses on line 90 during the duration of the negative pulse on line 112. As has already been noted, the presence of a pulse on line 106 indicates that all digits of a message word are properly positioned within the shift register 92 and, accordingly, the cessation of clock pulses on line 90 permits the message word to remain stored in the shift register 92 for an interval of time as has been set by the control 110. Upon the termination of the negative pulse on line 112, clock pulses again appear on line 90 and the foregoing procedure is repeated to admit a new message word into the shift register 92. With reference to FIG. 1, if the transponder 28 has not moved away from the receiving antenna 40, then the new message word will be the same as the preceding message word. However, if the transponder 28 has moved away from the receiving antenna 40, and the transponder 28 on the next package 22 has moved in front of the receiving antenna 40, then the new message word to be stored in the shift register 92 may differ from the preceding message word stored in the shift register 92.

The display 32, seen in both FIGS. 1 and 2, comprises a decoder 114 and a display panel 116. The decoder 114, in response to a READ signal on line 117 from the Q output of the multivibrator 108, accepts the last 32 bits on 32 parallel conductors indicated by line 118 and decodes this digital signal in a well known manner to activate the alphanumeric symbols on the display panel 116 as represented by the various bits on line 118 so that the message stored within the shift register 92 appears on the display panel 116. The message displayed on the panel 116 is updated upon successive applications of the READ signal to the decoder 114. The electrical conductors represented by lines 117 and 118 are contained within the electrical cable 33 of FIG. 1. It is also readily apparent that, with reference to FIG. 2, the display 32 could be replaced by a computer (not shown) with the data on the parallel conductors of line 118 being entered into a buffer storage register of the computer in response to the READ signal on line 117.

While the digital comparator 96 and the counter 100 have been utilized in the preferred embodiment for testing the contents of the shift register 92, it is understood that other well known methods may also be utilized, particularly the well-known parity check in which one, two or more bits of the message word may be reserved for parity checks.

Referring now to FIG. 3, there is shown a view, partially diagrammatic, of the transponder 28. A series of five dipole antenna elements 120, some of which are further identified by suffixes 120A-E, are spaced apart from an electrically conducting reflecting plate 122 by a slab 124 of low loss insulating material to be described hereinafter. The dipole elements 120 may be conveniently formed by utilizing a slab 124 which is initially copper clad, and then etching away the excess copper to leave copper strips substantially as shown in the drawings which serve as the dipole elements 120. Diodes 126, some of which are further identified by suffixes 126A-E, interconnect the respective portions of each dipole element 120. Conducting wires 128, preferably thin wires having a relatively large inductance such as No. 40 gauge wire, pass through the slab 124 for connection with the anode and cathode terminals of the diodes 126. The wires 128 are interconnected by metallic strips 130 to be described in further detail with reference to FIG. 4, to provide electrical connection between the terminals of the diodes 126 and the corresponding portions of the dipole elements 120 so that the dipole elements 120A-D are connected in series. Thus, for example, the anode of diode 126A is connected to the cathode of diode 126B. The anode of diode 126D is grounded at the reflecting plate 122 while the cathode of the diode 126A connects via diode 132 with capacitor 134. One terminal of capacitor 134 is grounded at ground 136 to complete a series circuit with the dipole elements 120A-D.

The reflecting plate 122 serves as a shield in the event that the transponder 28 is mounted on a metallic object and thereby preserves the radiation characteristics of the array of dipole elements 120. The dipole elements 120A-E are spaced from the reflecting plate 122 by a distance of one-quarter of the wavelength of the X-band radiation within the material of the slab 124 to maximize the intensity of the electric field incident upon the dipole elements 120A-E. In the event that the reflecting plate 122 is not required for shielding purposes, as when the transponder 28 is mounted on a nonconducting object, the reflecting plate 122 may be dispensed with and the slab 124 need be thick enough only to provide sufficient strength for supporting the dipole elements 120A-E in their relative positions. For example, the dipole elements 120A-E could be mounted within an automobile window in which case the slab 124 would be provided for by the glass of the window. In those instances where the reflecting plate 122 is utilized, it is desirable to minimize the required depth of the slab 124 to minimize the thickness of the transponder 28, this being accomplished by utilizing a material of high dielectric constant. For example, in the preferred embodiment the slab 124 has been made of a ceramic material formed of a two phase mixture of Zn_2TiO_4 and TiO_2 which provides a dielectric constant of approximately 26. Such a ceramic material is described more fully in a patent application entitled "Microwave Dielectrics" by Dennis W. Ready et al., filed on Apr. 1, 1971 and having Ser. No. 130,356. Alternatively, a low dielectric material such as Teflon (polytetrafluoroethylene) may be utilized, but the thickness of the transponder 28 will be greater. In view of the novel feature of the combination of the dipole elements 120 and the diodes 126 such that a single antenna structure performs the dual functions of receiving incident radia-

tion and rectifying it, the structure has been referred to as a "rectenna."

Due to the connections of the diodes 126 to each of the dipole elements 120, the current waveform induced in the wires 128 has the form of a rectified sine wave. The direct component (DC) of this current waveform is extracted by means of a low pass filter which attenuates the alternating components of the signal, the low pass filter being composed of the inductances of the wires 128 and the capacitances between the metallic strips 130 and the reflecting plate 122.

This low pass filter is better seen by referring to FIGS. 3, 4 and 5. FIG. 4 is an isometric view of the back side of the transponder 28 showing the metallic strips 130 separated from the reflecting plate 122 by a thin film 138 of insulating material, for example Mylar film, available as a pressure sensitive adhesive tape which is readily applied to the back side of the reflecting plate 122. Similarly, the metallic strips 130 can be formed by utilizing commercially available metallized pressure sensitive adhesive tape which is readily applied over the film 138. As seen in FIG. 4, the metallic strips 130 interconnect the wires 128 of which the ends are visible in FIG. 4. The widths of the metallic strips 130 may be selected to provide the desired capacitance between the metallic strips and the reflecting plate 122. The metallic strips 130 have been shown in the Figure as being relatively narrow in order to better indicate the connections between the wires 128, however, they may be widened and also elongated beyond their points of contact with the wires 128 so that a substantial region of the back side of the transponder 28 may be utilized to provide capacity for the low pass filter.

FIG. 5 shows a schematic representation of the low pass filter, here identified by numeral 140, in which the inductances of the wires 128 are represented by inductors 142 and the capacitances between the metallic strips 130 and the reflecting plate 122 is represented by capacitors 144. Also shown connected to the filter 140 is the diode 132 and capacitor 134 described earlier with reference to FIG. 3. The dipole antenna elements 120 are indicated schematically by heavy lines connecting with the terminals of the diodes 126. The interconnection of the anode of diode 126D via inductor 142 to ground 136 is accomplished, as seen in FIG. 4, by removing a portion of the film 138 to expose a region 146 of the reflecting plate 122 for making electrical contact between the metallic strip 130 and the reflecting plate 122.

In the preferred embodiment the diodes 126 are microwave diodes, type 1N82A, and the serial interconnection of the four diodes 126A-D provides 5 volts at a distance of 30 feet from the interrogator 30 with the transponder 28 being illuminated with a peak power intensity of 10 milliwatts per square centimeter. A total of 15 volts can be obtained from the serially connected diodes 126A-D at a distance of 5 feet. The transmitting antenna 38 of the interrogator 30 has a 26 db (decibels) gain and the receiving antenna 40 has a 20 db gain. The beam width provided by the array of dipole elements 120 is relatively broad, the beam having the form of a cone of 90° beam width with the axis of the cone being perpendicular to the plane of the reflecting plate 122. It is desirable to maintain these spacings between neighboring dipole elements, such as the elements 120A-B, greater than one-half wave length to reduce mutual coupling between these dipole elements,

a spacing of approximately one wave length having been successfully used in the preferred embodiment. The radiators of the dipole elements 120 may be either of rectangular shape or, as seen in FIG. 3, be provided with a slight taper for an improved impedance match. The diode leads, themselves, of the diodes 126 have been found to function effectively as dipole elements 120. The wires 128 are perpendicular to the reflecting plate 122 so as to minimize interaction direction with the electromagnetic fields incident upon the array of dipole elements 120. The interrogator 30 of the preferred embodiment has utilized a 2 kilowatt peak power transmitter.

As shown in FIG. 3, the transponder 28 further comprises an oscillator 148 composed of a tunnel diode 150, an inductor 152 formed of a fractional turn of wire and having an inductance of substantially less than one microhenry, a capacitor 154 having a value of 0.02 microfarads for storing energy provided by an incident pulse of electromagnetic radiation, and a dipole antenna 156 composed of a pair of radiators 156A and 156B. The dipole antenna 156 has an overall length, in the preferred embodiment, of approximately 2 inches which is substantially smaller than the wave length, 25 centimeters, of radiation radiated by the antenna 156. Thus, the dipole antenna 156 approximates a point source with an almost omnidirectional radiation pattern. Each of the radiators 156A-B may have a tapered form as shown in the Figure, or other form in which the outer extremity is larger than the inner extremity to provide a more favorable impedance match. A wire 158 is mounted perpendicularly to the reflecting plate 122 and passes through the slab 124 to connect with the junction of the inductor 152 and the capacitor 154. A second wire 160 is positioned perpendicularly to the reflecting plate 122 and grounded thereto, and passes through the slab 124 to contact the junction of the radiator 156A, the tunnel diode 150 and the capacitor 154. A source of power to be described hereinafter is applied to the oscillator 148 such that the power supply voltage is impressed between the wire 158 and ground 136.

Referring now to FIGS. 3, 6, 7 and 8, power for the oscillator 148 is provided by the diode 126E in a manner analogous to the aforementioned operation of the serially connected diodes 126A-D. As seen in FIG. 6, the diode 126E comprises a well known stray capacitance and resistance represented by dotted lines and indicated by the numerals 162 and 164 respectively. The power supply portion of the circuit of FIG. 6 is indicated by numeral 166 and is seen comprising, in addition to the diode 126E, the dipole antenna element 120E, and filtering elements analogous to those of FIG. 5. The filtering elements of FIG. 6 are a pair of inductors 168 representing respectively the inductance of each of the wires 128 (of FIG. 3) connecting with the diode 126E, a capacitor 170 representing the capacitance between the metallic strip 172 (seen also in FIG. 4) and the reflecting plate 122, and inductors 174 and 176 representing respectively the inductances of the wires 158 and 160 (of FIG. 3). In addition, FIG. 6 shows an interconnection along line 178 to an insulated gate field effect transistor, hereinafter referred to as FET 180, to be described hereinafter.

The oscillator 148 is a relaxation type oscillator utilizing a nonlinear active element such as the tunnel diode 150 and the inductor 152. For example, a tunnel

diode type IN3713 may be utilized. A typical current-voltage graph for a tunnel diode is shown in FIG. 7 wherein V1 represents the voltage to which the capacitor 154 is initially charged by the power supply 166 in response to a pulse of radiation incident upon the dipole element 120E. The operation of the oscillator 148 is as follows: After the charging of the capacitor 154, current flows from the capacitor 154 through the inductor 152 and the tunnel diode 150 thereby slowly discharging the capacitor 154 and reducing its voltage to a value of V2 whereupon well known relaxation oscillations begin and continue during a further discharging of the capacitor 154 until the voltage across the tunnel diode 150 reaches a value of V3.

The upper graph 184 of FIG. 8 represents the voltage across the tunnel diode 150 as a function of time. The lower graph 186 shows two pulses of radiant energy, 188 and 190, which represent respectively the pulse of radiant energy incident upon the dipole element 120E of FIGS. 3 and 6, and the pulse of radiation emanating from the radiators 156A-B of FIGS. 3 and 6. The pulse 188 which energizes the oscillator 148 is seen having a duration of approximately 1 microsecond while the pulse 190 generated by the oscillator 148 is seen having a duration of approximately 5 microseconds. There is a time delay of approximately 5 to 30 microseconds between the leading edge of the pulse 188 and the leading edge of the pulse 190, this delay being the interval of time during which the voltage across the tunnel diode 150 drops from a value of V1 to the value of V2. The value of V1 depends on the intensity of the radiation incident upon the dipole antenna element 120E, while the value of V2 is dependent on the characteristics of the tunnel diode 150. Thus the interval of time during which the voltage across the tunnel diode 150 drops from the value of V1 to the value V2 similarly depends on the intensity of the incident radiation, or, with reference to FIG. 1, on the distance between the interrogator 30 and the transponder 28. This interval between the leading edges of the pulses 188 and 190 is the same interval of time which was mentioned earlier with reference to the interrogator 30 of FIG. 2 with respect to the delay provided by the multivibrator 70.

As seen in the graph 184 of FIG. 8, the voltage across the tunnel diode 150 continues to drop towards zero even after the termination of the oscillations at the value of V3. The stray resistance 164 of the diode 126E provides via the wires 128, 158 and 160 a direct path to ground 136 which discharges the capacitor 154 so that there is essentially no residual charge left on the capacitor 154 when the next pulse 188 of graph 186 arrives. This insures that only one pulse 190 is produced by the oscillator 148 for each pulse 188 of radiation incident upon the transponder 28.

Returning to FIG. 3, pulses of energy appearing on line 192 in response to the radiation incident upon the dipole elements 120A-D are applied via an inverting amplifier 194 along line 196 to a counter 198 and a flip-flop 200. It is noted that as the transponder 28 is first illuminated with incident radiation, the pulses appearing on line 192 are of a relatively low value until such time as the capacitor 134 becomes charged to its full voltage. Since the capacitor 134 is a relatively large size, 0.1 microfarads being utilized in the preferred embodiment, a number of pulses of reduced amplitude appear on line 192 as the capacitor 134 is charged to its full voltage and, thereafter, the pulses on line 192 have

the requisite magnitude of from 5 to 15 volts (depending on the intensity of the incident radiation as was noted hereinbefore), this being adequate to operate the counter 198 and the flip-flop 200.

A diode matrix array 202 having a well known form comprises a set of row conductors 204 and a set of column conductors 206 having cross points 208 some of which are interconnected by diode 210. Only a portion of the diode array 202 is shown in FIG. 3. Any number of row conductors 204 and column conductors 206 may be utilized, the number depending on the amount of storage capacity desired for the storage of the message word. In the preferred embodiment, four row conductors 204 are utilized and 10 column conductors 206 are utilized. Accordingly, the counter 198 of the preferred embodiment is a 2 bit counter for activating the four row conductors 204 by means of a decoder 212. In response to each of the counts from the counter 198 the decoder 212, in a well known fashion, energizes successive ones of the row conductors 204. In a similar manner a counter 214 and a decoder 216 having a capacity of 10 energize the 10 column conductors. The counters 198 and 214, the decoders 212 and 216, as well as the flip-flop 200 and the inverting amplifier 194 are each energized with power received from the energy storage capacitor 134 between terminal P and ground 136. The counter 214 is activated by the last bit of the counter 198 so that the count of counter 214 is altered once each time the counter 198 reaches a count of 4. Both the counters 198 and 214 reset themselves to 0 after reaching their maximum count.

For ease of reference, the row conductors 204 will be further identified by suffixes such as the row conductor 204A and the column conductors will be further identified by suffixes such as the column conductor 206A. Each of the row conductors 204 is energized via resistors 218, some of which are further identified by suffixes such as resistor 218A, which connect with respective terminals of the decoder 212. Each row conductor 204 connects with a diode 220, some of which are further identified by suffixes such as diode 220A. The anodes of the four diodes 220 connect via line 222 to flip-flop 200, the signal on line 222 serving as the SET signal for the flip-flop 200. A resistor 224 is connected between line 222 and terminal P of capacitor 134.

The Q output of flip-flop 200 is connected to the gate terminal of the FET 180 such that when the flip-flop has been set by a signal on line 222, a voltage of sufficient magnitude is applied to the gate of the FET 180 to place it in a state of conduction. When the flip-flop 200 is reset by the signal on line 196, the voltage at the Q terminal of the flip-flop 200 is of a sufficiently low value such that the FET 180 is in a state of nonconduction. For example, during a reset condition the flip-flop 200 provides a voltage at the Q terminal on the order of a few tenths of a volt which is sufficient to maintain the FET 180 in a state of nonconduction. And during a set condition, the flip-flop 200 provides at its Q terminal a voltage of 5 volts or more (depending on the magnitude of the voltage stored by capacitor 134) which is sufficient to maintain the FET 180 in a state of conduction. By way of example of components that may be utilized, the preferred embodiment utilizes as FET 180 an FET of the Radio Corporation of America (RCA) having a part number CD4016E. The counter 214 and decoder 216 are sold as a single unit by RCA having the part number CD4017E.

In operation, therefore, the transponder 28 provides a digitally coded train of pulses in response to an incident radiant energy pulse train in the following manner. When the counter 198 registers a count of 1, the decoder 212 in response to the count of 1 applies a logic state of 0 to the resistor 218A, the logic state of 0 being a voltage of value less than 1 volt. The row conductor 204A may or may not be at this low voltage depending upon interconnections with the column conductors 206 as will be described hereinafter. When the counter 198 attains the count of 2, the decoder 212 applies a logic state of 0 to the resistor 218B and restores the row conductor 204A to a logic state of 1, this being a relatively high voltage of approximately 5 volts or greater. The procedure repeats itself for counts of 3 and 4 by the counter 198 so that at a count of 4 the logic state of 0 is applied to resistor 218D. Since the counter 198 is modulo-4, upon receipt of the next pulse on line 196, the counter 198 reverts to the state representing a count of 1 in which case the logic state of 0 is again applied to the resistor 218A.

When the counter 198 recycles from the count of 4 to the count of 1, it applies a pulse along line 226 to the counter 214 which, in response thereto, increases its count by count of 1 with the result that the decoder 216 applies a signal to the next column conductor 206 in a manner analogous to the operation of the decoder 212. It should be noted that the decoder 216 applies logic states of 1 to the column conductor 206 corresponding to the count of the counter 214 while the decoder 212 applies logic states of 0 to the resistor 218 corresponding to the count of the counter 198.

For example, assuming that at some point in time the column conductor 206C is energized with a high voltage while a low voltage is applied to the resistor 218B. There is no connection between the column conductor 206C and the row conductor 204B at their cross point 208 so that a low voltage is applied to the cathode of diode 220B. The value of a resistor 218 is much smaller than the value of the resistor 224, for example, values of 10,000 and 100,000 ohms being used respectively in the preferred embodiment and being indicated in FIG. 3 by the legends 10K and 100K. Thus the application of the low voltage to the cathode of the diode 220B results in a low voltage appearing on line 222 which places the flip-flop 220 in a SET condition.

In response to the next pulse to appear on line 196, the counter 198 advances to a count of 3, but the low voltage remains on the line 222 since there is no connection between the column conductor 206C and the next row conductor. However when the counter 198 reaches a count of 4 and the low voltage is applied to resistor 218D, it is noted that there is a diode 210 at the cross point 208 for providing a conducting path between the column conductors 206C and the row conductor 204D with the result that the row conductor 204D remains at the high voltage (except for a fractional volt drop across the diode 210) with a voltage drop appearing across the resistor 218D, this voltage drop being equal to the difference in voltages between the high voltage on line 204D and the low voltage being applied to the terminal of the resistor 218D next to the decoder 212. Thus it is seen that a high voltage is applied to the cathode of each of the diodes 220 with the result that a high voltage appears on line 222 thus terminating the SET signal to the flip-flop 200.

Continuing now, in response to the next pulse on line 196, the counter 198 transmits a pulse along line 226 and reverts to a count of 1. In response to the pulse on line 226 the counter 214 advances one count, and in response thereto the decoder 216 energizes the next column conductor 206D with a high voltage while applying a low voltage to the other column conductors 206. The decoder 212 in response to the count of 1 at the counter 198 applies a low voltage to the resistor 218A while a high voltage is being applied to each of the other resistors 218. Since there is no connection at the cross point 208 between the column conductor 206D and the row conductor 204A, a low voltage appears at the cathode of the diode 220A while high voltages appear at the cathodes of the other diodes 220 with the result that the low voltage appears on line 222 for setting the flip-flop 200. In response to the next pulse to appear on line 196, the decoder 212 applies the low voltage to the resistor 218B with the result that current flows through the diode 210 at the cross point 208 between the column conductor 206D and the row conductor 204B. As a result of the current flow from the decoder 216 along the column conductor 206D through the diode 210 and the resistor 218B, the row conductor 204B is at a high voltage (as is each of the other row conductors 204) with the result that a high voltage appears on the line 222 which terminates the setting of the flip-flop 200.

It is noted that a RESET pulse appears on line 196, as has been mentioned hereinbefore, for each pulse of radiant energy incident upon the diode antenna elements 120. However, with respect to the signal on line 222, a SET signal may, or may not, appear in response to each pulse on line 196 depending on the positioning of diodes at the cross points 208. If this SET signal does appear, it appears a fraction of a microsecond after the RESET signal and is retained throughout the interpulse period between successive ones of the pulses 196 so that the flip-flop 200 is then placed in a SET condition. As a practical matter in the selection of the cross points 208 which are to be provided with diodes 210, it is convenient to purchase commercially a diode matrix array and then to apply sufficiently large currents simultaneously to a row and a column conductor to burn out the diode at their cross point. By burning out the unwanted diodes the diode matrix array 202 attains its desired format.

The FET 180 of FIG. 3 shorts out the capacitor 154 in response to each setting of the flip-flop 200. As seen in FIG. 8, there is an approximately 5-30 microsecond interval between the arrival of a pulse on line 196 and the oscillation by the oscillator 148 so that there is ample time for the FET 180 to short out the capacitor 154 prior to the inception of an oscillation. Thus it is seen that for each pulse on line 196 an oscillation is produced by the oscillator 148 unless a SET signal appears on line 222. As a result, in response to a continuous succession of pulses of radiant energy incident upon the dipole antenna elements 120, there is an intermittent succession of pulses of radiant energy transmitted by the dipole antenna 156, the presence and absence of transmissions by the dipole antenna 156 being governed by the positions of diodes 210 in the diode matrix array 202. The occurrences and the absences of transmissions by the dipole antenna 156 constitutes the digital coding of the pulse train signal provided by the transponder 28 in response to the succession of radiant

energy pulses incident thereupon. The extraction of information from the digitally coded signal has been described hereinbefore with reference to FIG. 2.

The digital electronics portion of the transponder 28, namely, the diode 132, the capacitor 134, the inverting amplifier 194, the FET 180, the flip-flop 200, and the counters, decoders and diode matrix array with its interconnections to the flip-flop 200 may be fabricated utilizing a large scale integration (LSI) package of sufficiently small size to be placed on the back side of the transponder 28 as seen by the emplacement of package 228 of the LSI circuitry. Connections from the package 228 are provided by metallic strips 230, 232 and 234, the metallic strip 232 being the interconnection between diode 126A and diode 132 of FIG. 3, the metallic strip 234 being the interconnection shown schematically by line 178 in FIG. 3, and the metallic strip 236 being a ground connection, such as the grounding of one terminal of a capacitor 134, to an exposed region 146 of the reflecting plate 122. It is also noted that the average power dissipated by the circuitry of the transponder 28 is approximately 100 microwatts, and the average power transmitted by the dipole antenna 156 is 2 microwatts in the preferred embodiment of the invention.

Referring now to FIG. 9 there is shown a detailed schematic diagram of the counter 198 and the decoder 212 of FIG. 3. The counter 198 comprises two flip-flops 236 and 238, each being a D-edge flip-flop. In the preferred embodiment the flip-flops 236 and 238 are within an integrated circuit by RCA type No. CD4013E. The decoder 212 comprises four multiple input AND gates 240A-D to which the two flip-flops 236 and 238 are interconnected as shown in the drawing. Also shown in the drawing is a NAND gate which serves as the inverting amplifier 194 as well as a second NAND gate 242 which again inverts the output of the inverting amplifier 194 and applies this to the four NAND gates 240A-D. The flip-flop 200 comprises a pair of NAND gates interconnected as shown in the drawing. Also seen in the drawing are the diodes 132 (type 1N4606 being utilized in the preferred embodiment), capacitor 134, resistors 218A-D and the row conductors 204 for the diode array 202, all of which have been described with reference to FIG. 3. In the preferred embodiment, the inverting amplifier 194, the NAND gate 242 and the NAND gates of the flip-flop 200 are included within an integrated circuit, RCA type CD4011E. The four NAND gates 240A-D are integrated circuits, RCA type CD4012E. The diode array 202 is an integrated circuit, Harris Intertype diode array, type RM1-0410-5.

Referring now to FIG. 10 there is shown a partial view of an alternative embodiment of the transponder 28 of FIG. 3, here designated by the numeral 244. The transponder 244 comprises the same slab 124, reflecting plate 122, the dipole antenna 156 of which only the radiator 156A is seen in the Figure, and the diodes 126 of which only diodes 126A and 126B are seen in the Figure. However, a double leaved spiral antenna element 246 having leaves 246A-B is utilized in lieu of the dipole elements 120 of FIG. 3. The spiral antenna element 246 is responsive to both circularly and linearly polarized radiation so that the transponder 244 may be mounted on an object, such as the packages 22 of FIG. 1, in a variety of orientations while still being responsive to the radiation transmitted by the interrogator 30.

The diodes 126 are connected by wires 128 in the same manner as shown for the transponder 28 of FIG. 3. One leaf 246A connects with the anode of the diode 126 while the other leaf 246B connects with the cathode of the diode 126. The spiral antenna elements 246 may be fabricated in a manner similar to that utilized for the transponder 28 of FIG. 3, namely, by bonding a copper sheet to the front face of the slab 124 and etching away the unwanted portions of the copper.

Referring now to FIG. 11, there is shown an alternative embodiment of the diode array 202 of FIG. 3, here designated by numeral 248. The diode array 248 utilizes the same row conductors 204, the same column conductors 206, and the same diodes 210 as does the diode array 202. However, the diode array 248 is provided with additional leads 250 whereby the anode of each diode 210 can be connected by a switch 252, external to the diode array 248, to a column conductor 206 to provide a conducting path at a cross point 208 via the diode 210 between the column conductor 206 and the row conductor 204. By simply opening and closing selected ones of the switches 252, any desired message can be stored in the diode array 248. In this respect, the diode array 248 can be regarded as a read-only memory in which the stored message can be readily altered as desired. This is particularly useful in the situation where the transponder 28 and interrogator 30 are to be utilized in an automobile rental system wherein an automobile passing through the entrance of a parking lot must identify its serial number, mileage, destination and similar matters.

Referring now to FIG. 12, there is shown a hospital nurses station 254 in which containers of medicine 256 and 258 are placed on a shelf 260 within easy reach of a nurse 262. The nurse 262 is seated at a desk 264 on which is placed an encoder unit 266 which encodes the stored message within the diode array 202 of the transponder 28, seen nested within the encoder unit 266. Here, the row conductors 204 and the column conductors 206 of FIG. 3 have been extended towards the edges of the transponder 28 so that electrical contact can be made with selected ones of the row conductors 204 and the column conductors 206 for applying a surge currents which burn out selected diodes 210 for encoding the message to be stored within the diode array 202. The encoder unit 266 comprises a keyboard 268, a well known logic unit 270 which selects the particular row conductor 204 and column conductor 206 which correspond to a particular key of the keyboard, and a current supply 272 for injecting the surge current between the selected row conductor 204 and column conductor 206. As seen in the Figure, the current supply 272 is partially cut away to disclose probes 274 which contact the transponder 28 at the extremities of the row conductors 204. A similar set of probes, not seen in the Figure, makes contact with the column conductors 206 of the transponder 28.

In operation, therefore, a pair of probes 274 one for a row conductor 204 and one for a column conductor 206 are energized with current from the current supply 272 in accordance with signals provided by the logic unit 270 in response to the depressing of a key on the keyboard 268. The transponder 28 after having been encoded with information such as a patient's name, the type of medicine, and the times of administering the medication, is then affixed to a medicine container such as the medicine container 258. The transponder

28 may have an adhesive backing to facilitate attachment to the medicine container 258 or, may simply be held in place by pressure sensitive adhesive tape. The same procedure would be utilized in the laboratory of the hospital in the preparation of blood transfusions in which case the encoded message would include data such as the blood type. Prior to the administering of the medicine or the blood transfusion, the container would be placed in front of an interrogator, such as the interrogator 30 of FIG. 1, and a display would verify the contents of the container while an optional connection with a computer would provide an entry for inventory control to indicate the amount of medicine or blood remaining in stock.

It is understood that the above described embodiments of the invention are illustrative only and that modifications thereof will occur to those skilled in the art. Accordingly, it is desired that this invention is not to be limited to the embodiments disclosed herein but is to be limited only as defined by the appended claims.

What is claimed is:

1. In combination:

means for extracting power from an incident radiant signal comprising a succession of pulses; and
means energized by said extracted power for generating a train of pulses coded in a digital format, said coded pulse generating means comprising means for gating pulses of said train of pulses in synchronism with the individual pulses of said succession of pulses of said radiant signal.

2. The combination according to claim 1 further comprising means responsive to said coded pulse train for displaying information provided by said coded pulse train.

3. The combination according to claim 1 further comprising:

a source of said radiant signal, said radiant signal comprising a succession of pulses of radiant energy;
means for receiving said coded pulse train; and
means synchronized to transmissions of said radiant energy pulses for correlating at least a portion of said coded pulse train with a reference code.

4. In combination:

means responsive to an incident radiant signal for extracting power from said radiant signal;
means energized by said extracted power for generating a train of pulses coded in a digital format, said power extracting means comprising:
a plurality of antenna elements;
a plurality of serially connected diodes, each of said diodes being coupled to respective ones of said antenna elements; and
means for storing power extracted by said diodes from a signal incident upon said antenna elements.

5. The combination according to claim 1 wherein said generating means includes means for varying said code.

6. The combination according to claim 1 wherein said radiant signal comprises a train of first pulses, and said coded signal comprises a train of second pulses, the occurrences of predetermined ones of said second pulses being deleted from said train of second pulses in accordance with said code.

7. In combination:

a radiating element;

diode means coupled to said radiating element for extracting power from radiation incident upon said radiating element;

counting means energized from said power for counting successive pulsations in said power;

an oscillator circuit for providing a radiant energy signal; and

logic means responsive to the count of said counter for activating said oscillator circuit.

8. The combination according to claim 7 wherein said logic means comprises a matrix conductor array having preselected cross points coupled during one condition of relative polarities of conductors at a cross point and decoupled during an alternate condition of relative polarities of conductors at said cross point, said conductors being energized respectively by said counting means in accordance with the count of said counter.

9. The combination according to claim 8 wherein said oscillator circuit comprises:

an energy storage unit;

a reactive impedance element; and

a nonlinear active element cooperating with said reactive impedance element to provide a relaxation type oscillation, the energy for said relaxation oscillations being supplied by said energy storage unit, said relaxation oscillations being delayed in time from a charging of said energy storage unit until current drained via said nonlinear active element has reduced the voltage of said energy storage unit to a value suitable for initiating said relaxation oscillations.

10. The combination according to claim 9 wherein said counting means comprises a first counter and a second counter, said first counter and said second counter each having a decoder for decoding the counts of said first counter and said second counter, each of said decoders energizing respective groups of conductors of said matrix conductor array.

11. The combination according to claim 10 wherein said nonlinear active element is a tunnel diode.

12. The combination according to claim 11 wherein said oscillator circuit further comprises an antenna for transmitting said radiant energy signal of said oscillator circuit at a frequency different from the frequency of said radiation incident upon said radiating element.

13. A message communication system comprising:

means for generating an interrogating signal, said interrogating signal comprising a succession of pulses;

means for applying a stored message to an object;

means energized solely by power from said interrogating signal for transmitting said stored message from said object, said transmitting means comprising means for gating said transmitted message in synchronism with individual pulses of said succession of pulses of said interrogating signal to provide gated portions of said transmitted message which correspond to respective ones of said pulses of said succession of pulses; and

means for receiving said transmitted message, said receiving means including means synchronized with individual pulses of said succession of pulses of said interrogating signal for performing a correlation on said received message.

14. A message communication system comprising:

means for generating an interrogating signal, said interrogating signal comprising a succession of pulses;

means for applying a stored message to an object;

means energized solely by power from said interrogating signal for transmitting said stored message from said object, said transmitting means comprising means for synchronizing successive portions of said transmitted message with said interrogating signal; and

means for receiving said transmitted message.

15. The system according to claim 14 wherein said message applying means includes a memory storage array in which bits of data are individually stored.

16. The system according to claim 15 wherein said bits of stored data may be individually varied.

17. The system according to claim 16 wherein said message applying means comprises means attached to said object for varying said bits of stored data.

18. The system according to claim 17 wherein said transmitting means comprises means for extracting energy from said interrogating signal and storing such energy, and means for reradiating a portion of such energy as a signal modulated with said bits of data to accomplish said transmission of said stored message.

19. A transponder for communicating a message comprising:

means responsive to a succession of pulses of incident radiant energy for providing a unidirectional voltage therefrom;

means for storing energy of a direct component of said unidirectional voltage;

means for reradiating a portion of said stored energy;

means for counting pulses of said succession of pulses of incident energy;

means for storing a message, said storing means including means responsive to the count of said counting means for extracting information from said stored message; and

means for modulating a signal of said reradiated energy with said information of said stored signal.

20. A transponder for communicating a message comprising:

means responsive to incident radiant energy for providing a unidirectional voltage therefrom;

means for storing energy of a different component of said unidirectional voltage;

means for reradiating a portion of said stored energy;

means for storing a message;

means for modulating a signal of said reradiated energy with information of said stored signal, and wherein said unidirectional voltage means comprises:

an array of radiators for intercepting said incident radiation and providing an electric field therefrom;

means for providing a ground plane, said radiators being spaced apart from each other and being uniformly spaced from said ground plane;

conducting elements serially interconnecting pairs of said radiators, said conducting elements extending from said radiators towards said ground plane, a first part of individual ones of said conducting elements being parallel to said ground plane to provide predetermined values of capacitance for filtering energy of said electric field; and

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rectifier means coupled between pairs of said radiators and responsive to said electric field for providing said unidirectional voltage.

21. The transponder according to claim 20 wherein a second part of individual ones of said conducting elements of said unidirectional voltage means are configured for providing inductances, said capacitances and said inductances serving as a filter for extracting said direct component of said unidirectional voltage.

22. The transponder according to claim 21 wherein said message storage means comprises a first and a second set of conductor elements of which a preselected conductor element of said first set communicates with a plurality of preselected conductor elements of said second set.

23. The transponder according to claim 23 further comprising switching means interconnecting with said message storage means for altering said communications between conductor elements of said first and said second sets of conductor elements.

24. A transponder for communicating a message comprising:

means responsive to incident radiant energy for providing a unidirectional voltage therefrom, said unidirectional voltage means comprising an array of radiators for intercepting said incident radiation and providing an electric field therefrom, and rectifier means responsive to said electric field for providing said unidirectional voltage;

means for storing energy of a direct component of said unidirectional voltage, said energy storage means including a filter for extracting said direct component of said unidirectional voltage;

means for reradiating a portion of said stored energy;

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means for storing a message, said message storage means comprising a first and a second set of conductor elements in which a preselected conductor element of said first set communicates with a plurality of preselected conductor elements of said second set, said message storage means further comprising means coupled to said first set of conductor elements for counting successive quanta of said incident radiant energy;

means coupled to said reradiating means for modulating a signal of said reradiated energy with information of said stored message; and

switching means interconnecting with said message storage means for altering said communications between conductor elements of said first and said second set of conductor elements.

25. The transponder according to claim 24 wherein said modulating means is responsive to currents communicated between a pair of said conductor elements of which one element of said pair is of said first set and the other element of said pair is of said second set of conductor elements, different pairs of said conductor elements being activated in accordance with the count of said counting means.

26. The transponder according to claim 25 wherein said modulating means modulates said signal of reradiated energy with the portion of the information of said stored signal corresponding to the pair of conductor elements activated by said counting means at each count of said counting means.

27. The transponder according to claim 26 wherein said modulation of said signal of said reradiated energy is a pulse code modulation.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,745,569 Dated July 10, 1973

Inventor(s) George A. Works et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 65, "an" should be -- and --.

Column 6, line 3, "Q" should be -- $\bar{Q}$ --.

Column 15, line 36, "fract 1 on" should be -- fraction --

Column 15, line 40, "coss" should be -- cross --.

Column 21, line 16, Claim 23, "23" (second occurrence) should be "22".

Signed and sealed this 6th day of August 1974.

(SEAL)

Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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