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(54) RFID COMMUNICATION SYSTEM AND METHOD OF OPERATION

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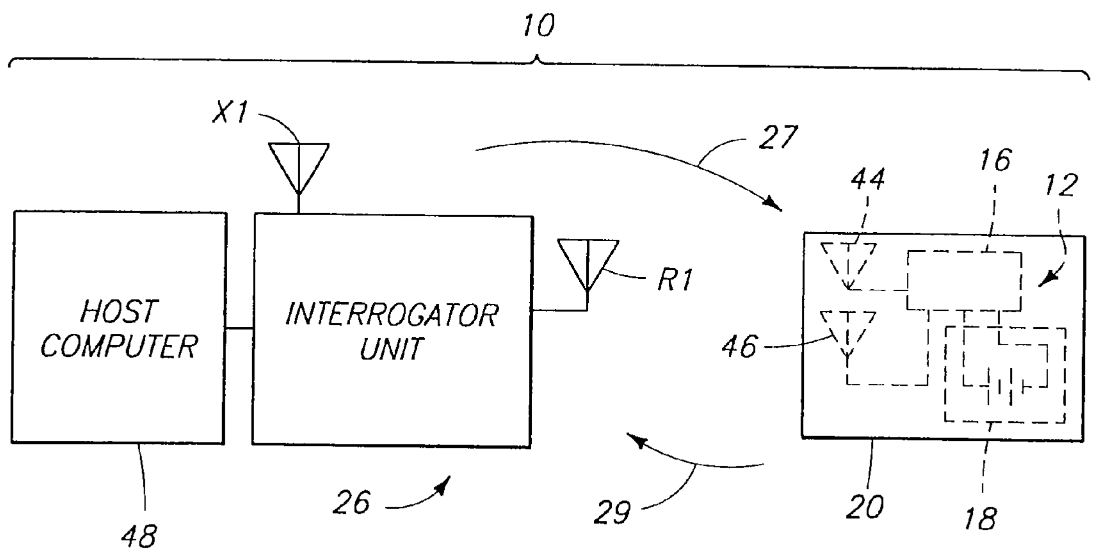
(57) **ABSTRACT**

A radio frequency identification (RFID) system enabling backscatter communication between a reader and a tag. A baseband data signal is encoded, and it may be selectively inverted and used to modulate a carrier using amplitude modulation, phase modulation, or both amplitude and phase modulation. A reply received from the tag in response to a command from the reader may include an identification code associated with an object to which the tag is affixed.



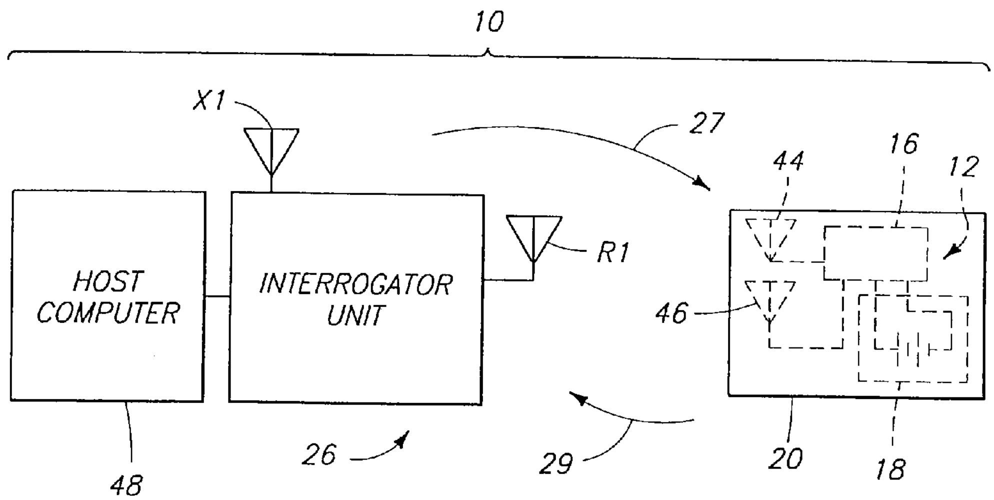


Fig. 1

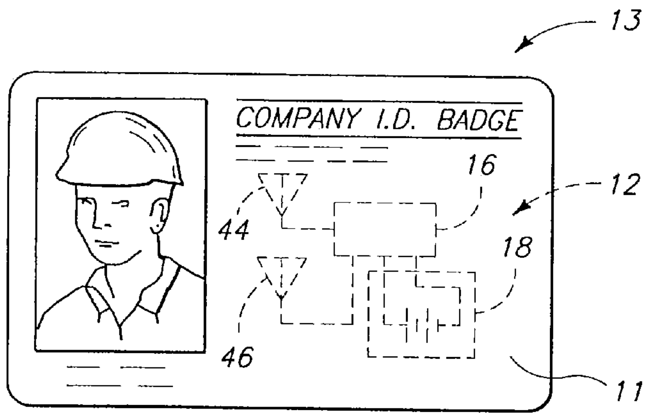
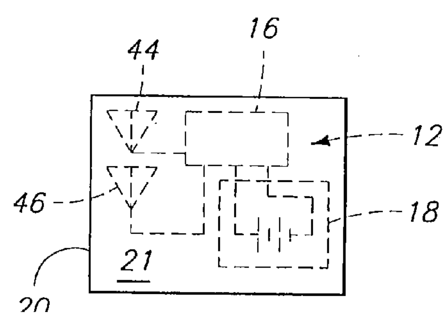


Fig. 2

Fig. 3



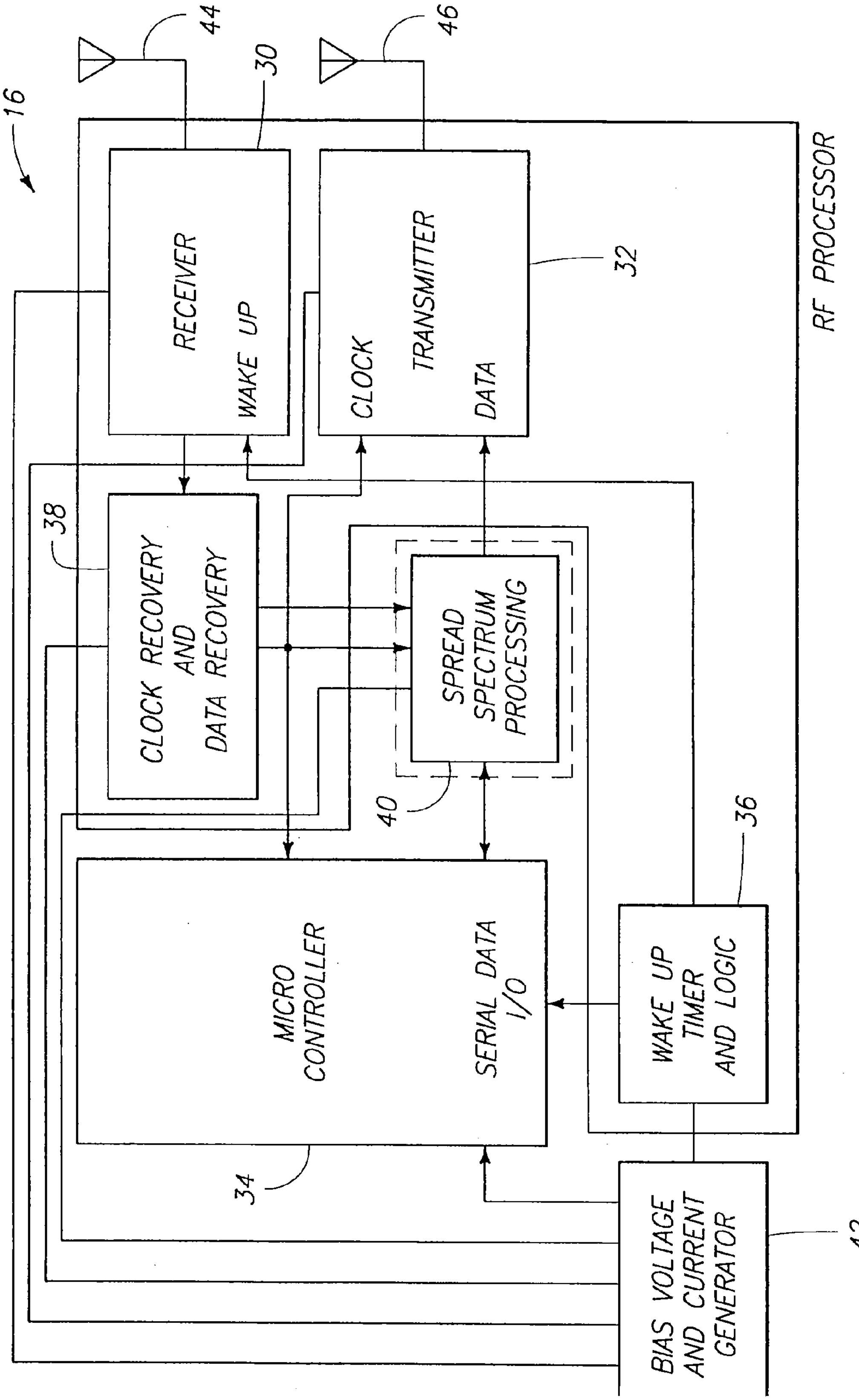
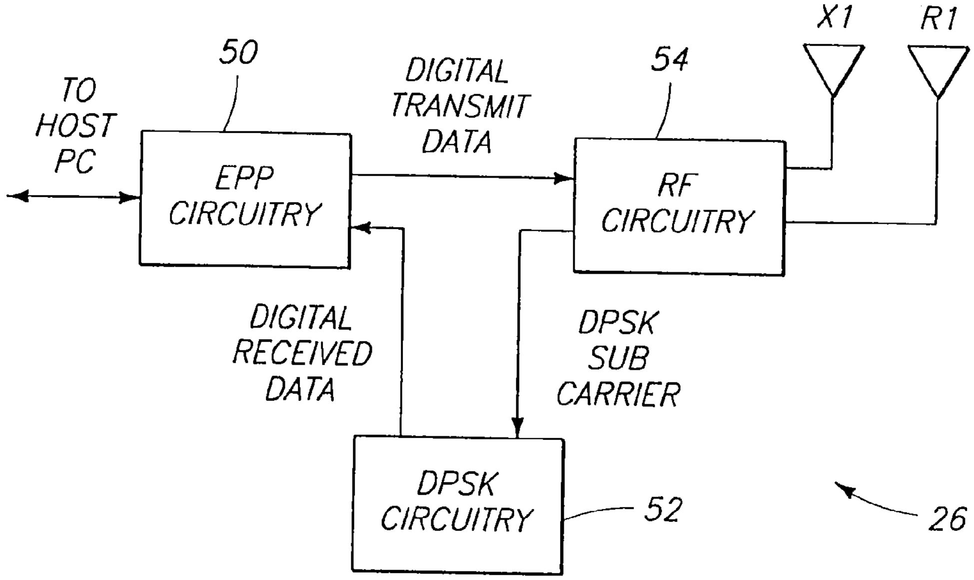
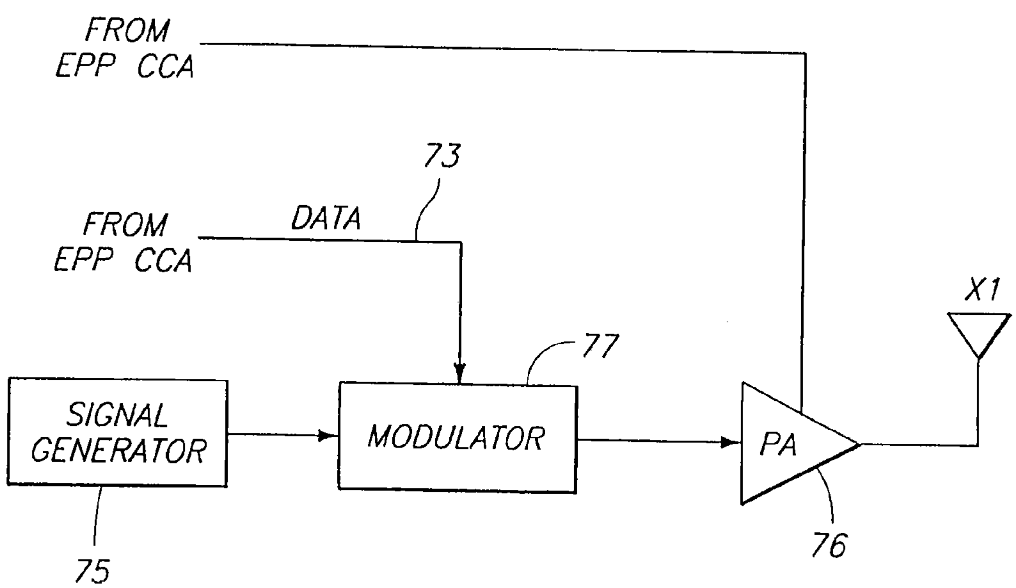

16
44
46
30
RECEIVER
WAKE UP
CLOCK
TRANSMITTER
DATA
32
RF PROCESSOR
38
CLOCK RECOVERY
AND
DATA RECOVERY
SPREAD
SPECTRUM
PROCESSING
40
36
MICRO
CONTROLLER
SERIAL DATA
I/O
WAKE UP
TIMER
AND LOGIC
34
BIAS VOLTAGE
AND CURRENT
GENERATOR
42

FIG. 2



TO
HOST
PC
50
EPP
CIRCUITRY
DIGITAL
TRANSMIT
DATA
54
RF
CIRCUITRY
X1
R1
DIGITAL
RECEIVED
DATA
DPSK
SUB
CARRIER
DPSK
CIRCUITRY
52
26

FIG. 5



FROM
EPP CCA
FROM
EPP CCA
DATA
73
77
X1
SIGNAL
GENERATOR
MODULATOR
PA
75
76

FIG. 6

54

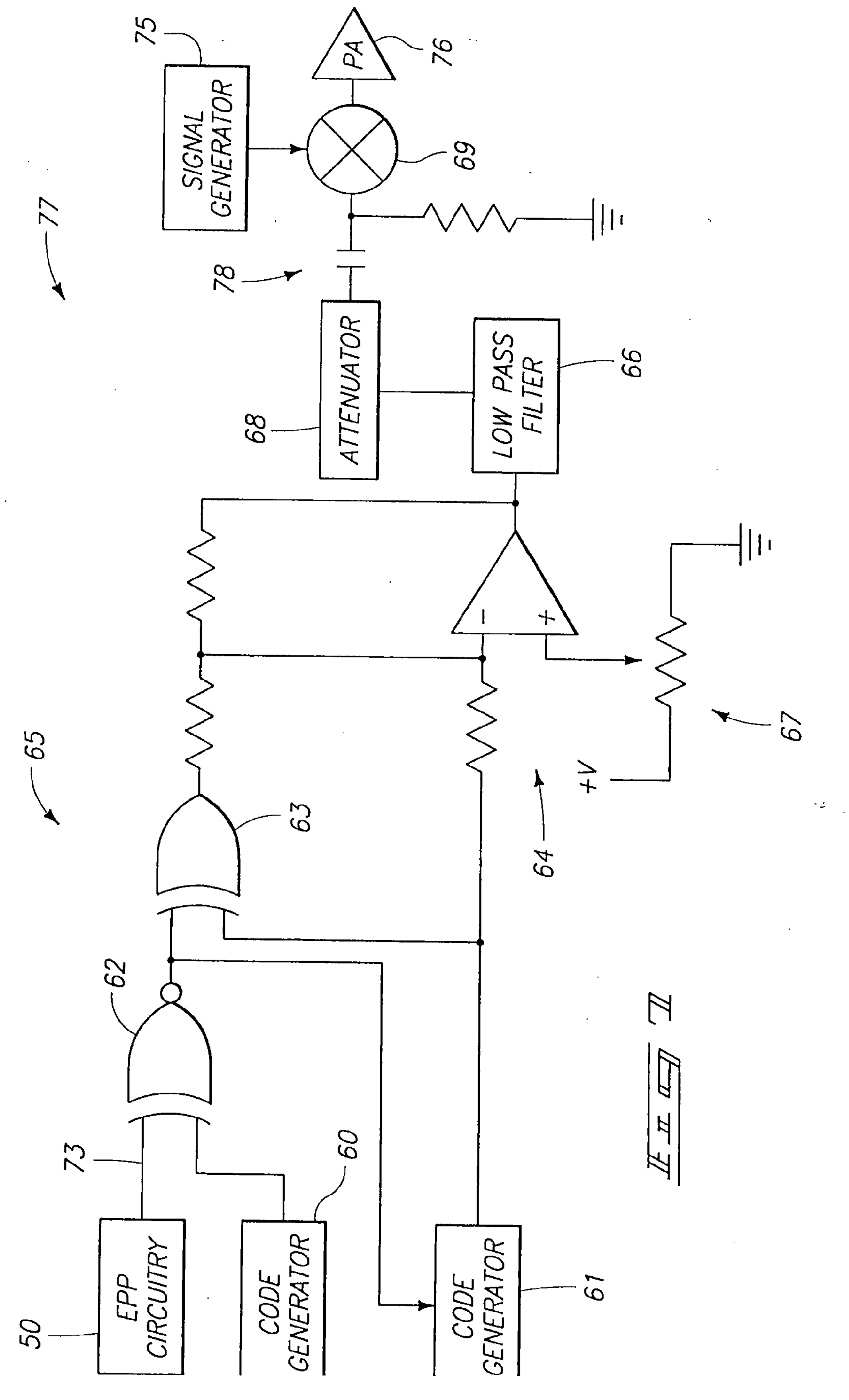

SIGNAL GENERATOR
PA
ATTENUATOR
LOW PASS FILTER
EPP CIRCUITRY
CODE GENERATOR
CODE GENERATOR
+V
75
76
69
77
78
68
66
65
63
64
67
62
73
60
50
61

FIG. 7

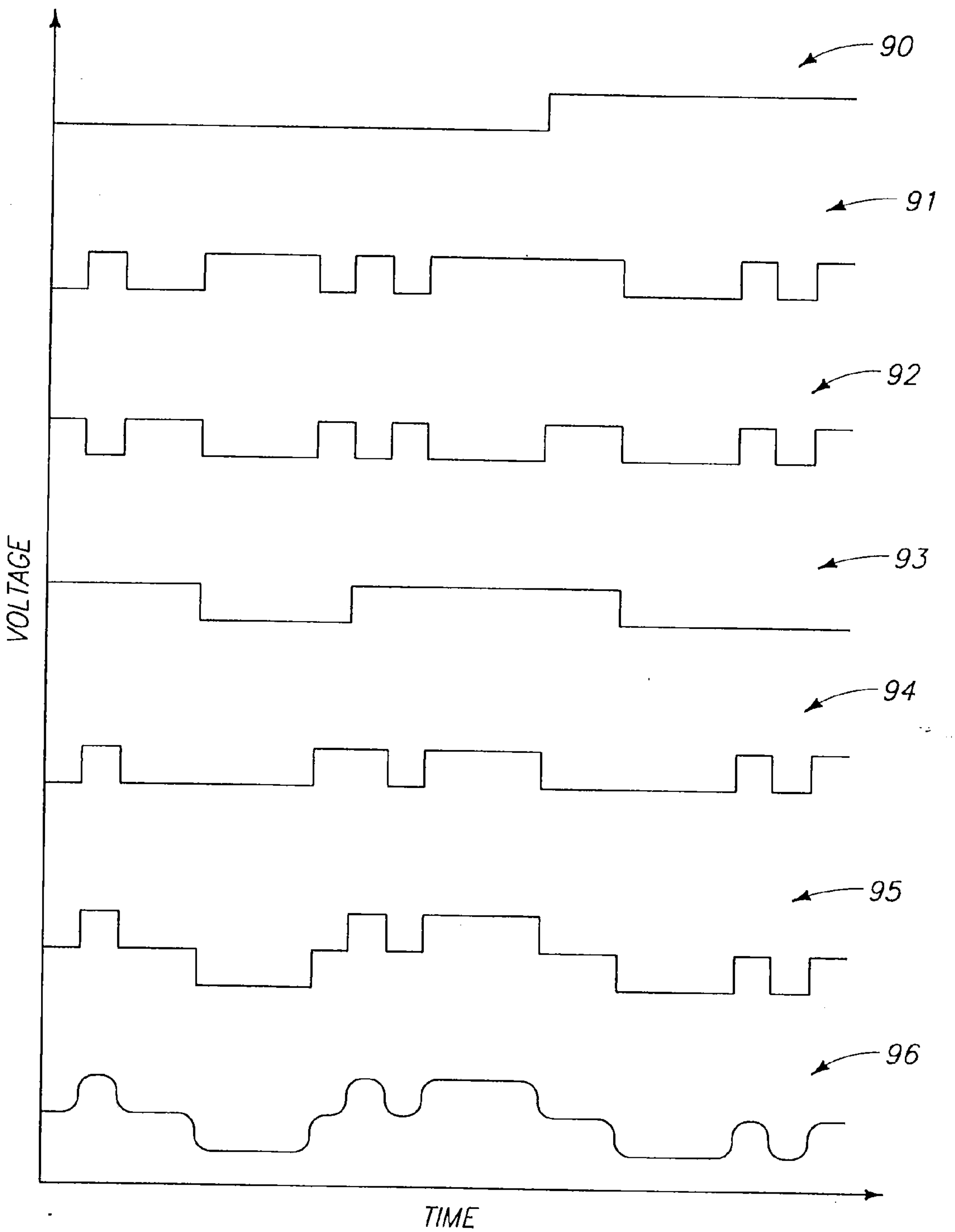


Fig 8

RFID COMMUNICATION SYSTEM AND METHOD OF OPERATION

RELATED PATENT DATA

[0001] This patent is a continuation of U.S. patent application Ser. No. 09/961,113, filed Sep. 20, 2001, entitled "Backscatter Interrogators, Communication Systems and Backscatter Communication Methods," naming David K. Ovard and Roy Greeff as inventors, which is a continuation of U.S. patent application Ser. No. 09/066,610 (now U.S. Pat. No. 6,459,726), filed Apr. 24, 1998; the disclosures of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to backscatter interrogators, communication systems and backscatter communication methods.

BACKGROUND OF THE INVENTION

[0003] Backscatter communication systems are known in the art. In a backscatter system, one transponder, such as an interrogator, sends out a command to a remote communications device. After the interrogator transmits the command, and is expecting a response, the interrogator switches to a CW mode (continuous wave mode). In the continuous wave mode, the interrogator does not transmit any information. Instead, the interrogator just transmits radiation at a certain frequency. In other words, the signal transmitted by the interrogator is not modulated. After a remote communications device receives a command from the interrogator, the remote communications device processes the command. The remote communications device of the backscatter system modulates the continuous wave by switching between absorbing RF radiation and reflecting RF radiation. For example, the remote communications device alternately reflects or does not reflect the signal from the interrogator to send its reply. Two halves of a dipole antenna can be either shorted together or isolated from each other to modulate the continuous wave.

[0004] One example of a backscatter system is described in commonly assigned U.S. patent application Ser. No. 08/705,043, filed Aug. 29, 1996, and incorporated herein by reference. Another example of a backscatter system is described in U.S. Pat. No. 5,649,296 to MacLellan et al. which is also incorporated herein by reference.

[0005] One application for backscatter communications is in wireless electronic identification systems, such as those including radio frequency identification devices. Of course, other applications for backscatter communications exist as well. Most presently available radio frequency identification devices utilize a magnetic coupling system. An identification device is usually provided with a unique identification code in order to distinguish between a number of different devices. Typically, the devices are entirely passive (have no power supply), which results in a small and portable package. However, such identification systems are only capable of operation over a relatively short range, limited by the size of a magnetic field used to supply power to the devices and to communicate with the devices.

[0006] Another wireless electronic identification system utilizes a large, board level, active transponder device affixed to an object to be monitored which receives a signal from an interrogator. The device receives the signal, then generates and transmits a responsive signal. The interrogation signal and the responsive signal are typically radio-frequency (RF) signals produced by an RF transmitter circuit. Because active devices have their own power sources. The active devices do not need to be in close proximity to an interrogator or reader to receive power via magnetic coupling. Therefore, active transponder devices tend to be more suitable for applications requiring tracking of objects that may not be in close proximity to the interrogator, such as a railway car.

[0007] Spread spectrum modulation techniques are known in the art. Utilization of spread spectrum modulation provides distinct advantages in some communication applications. For example, some spread spectrum modulation techniques enable desired signals to be distinguished from other signals (e.g., radar, microwave ovens, etc.) operating at approximately the same frequencies.

[0008] Federal Communication Commission (FCC) regulations require that spread spectrum systems meet various requirements. For example, spread spectrum systems operating in the 2.4-2.485 GHz band should comply with FCC rule 15.247 which states, in relevant part, that the power spectral density cannot be more than +8 dBm in any given 3 kHz band. Further, the maximum power output is 1 Watt into a 6 dBi gain antenna. The minimum 6 dB bandwidth for a direct sequence spread spectrum is 500 kHz. In addition, the energy within restricted bands of 0-2.390 GHz and 2.4835-2.5 GHz should be lower than 500 uV/m at three meters. Communication systems operating within this specified band should be designed with regard to these regulations.

[0009] Amplitude modulation (AM) communication techniques enable communications with the use of relatively straightforward detectors. Typically, such AM detectors can be efficiently implemented with the utilization of relatively few components. However, drawbacks exist with the utilization of amplitude modulation techniques. For example, approximately half the total power of AM communications resides within the carrier. This limits the power which can be used for communicating data if AM modulation and spread spectrum techniques are utilized within the above specified frequency band.

[0010] Therefore, there exists a need to provide communication systems which comply with radio frequency regulations while also providing robust communications.

SUMMARY OF THE INVENTION

[0011] The present invention includes backscatter interrogators, communication systems and backscatter communication methods.

[0012] One aspect of the invention provides a backscatter interrogator. The backscatter interrogator includes a data path configured to communicate a data signal and a signal generator configured to generate a carrier signal. The carrier signal comprises a microwave signal in preferred embodiments. The interrogator also provides a modulator coupled with the data path and the signal generator. The modulator is configured to spread the data signal to define a spread data signal and amplitude modulate the carrier signal using the spread data signal. The modulator is further configured to phase modulate the carrier signal to reduce the power within the carrier signal.

[0013] A second aspect of the present invention provides a backscatter interrogator including a data path configured to communicate a data signal and a signal generator configured to output a microwave carrier signal. The backscatter interrogator further includes a modulator coupled with the data path and the signal generator. One configuration of the modu-

lator is operable to spread the data signal and selectively invert the spread data signal. The modulator is further configured to band limit the inverted spread data signal and modulate the carrier signal using the band limited data signal.

[0014] Another aspect of the present invention provides a backscatter communication system including an interrogator and an electronic communication device. The interrogator is configured to spread a data signal. The interrogator is further configured to amplitude modulate a carrier signal using the data signal and phase modulate the carrier signal using the data signal. The interrogator is arranged to output the amplitude modulated and phase modulated carrier signal. The electronic communication device is configured to output a reply signal responsive to reception of the amplitude modulated and phase modulated carrier signal.

[0015] Another aspect of the invention provides a backscatter communication method including the steps of providing a data signal and providing a carrier signal. This method also includes spreading the data signal, amplitude modulating the carrier signal using the spread data signal, and phase modulating the carrier signal. The amplitude modulated and phase modulated carrier signal is thereafter communicated.

[0016] Another aspect of the invention provides a method of communication in a backscatter system including an interrogator and a communication device. The method includes providing a data signal, providing a carrier signal and spreading the data signal. The method also includes modulating the carrier signal using the spread data signal, communicating the modulated carrier signal, and suppressing the carrier signal during the communicating.

[0017] Yet another aspect of the invention provides a backscatter communication method including the steps of providing a data signal and a carrier signal. The invention also includes spreading the data signal, selectively inverting the spread data signal, amplitude modulating the carrier signal using the data signal, and communicating the modulated carrier signal.

[0018] In another aspect, an RFID system enables backscatter communication between a reader and a tag. A baseband data signal is encoded, and it may be selectively inverted and used to modulate a carrier using amplitude modulation, phase modulation, or both amplitude and phase modulation. A reply received from the tag in response to a command from the reader may include an identification code associated with an object to which the tag is affixed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

[0020] FIG. **1** is a block diagram illustrating a communication system embodying the invention.

[0021] FIG. **2** is a front view of an employee badge according to one embodiment of the invention.

[0022] FIG. **3** is a front view of a radio frequency identification tag according to another embodiment of the invention.

[0023] FIG. **4** is a circuit schematic of a transponder included in the system of FIG. **1**.

[0024] FIG. **5** is a block diagram of an interrogator in accordance with one embodiment of the invention.

[0025] FIG. **6** is a circuit schematic of RF circuitry included in the interrogator of FIG. **5**.

[0026] FIG. **7** is a circuit schematic of one embodiment of circuitry included in the RF configuration of FIG. **6**.

[0027] FIG. **8** is an illustrative representation of a tri-level communication signal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

[0029] FIG. **1** illustrates a wireless communications system **10** embodying the invention. Communications system **10** includes a first transponder including an interrogator **26** and a host computer **48** in communication with interrogator **26**. Communications system **10** further includes an electronic communications device **12**, such as the device disclosed in U.S. patent application Ser. No. 08/705,043, filed Aug. 29, 1996. In one embodiment, wireless communications device **12** comprises a wireless identification device such as the Microstamp™ integrated circuit available from Micron Communications, Inc., 3176 S. Denver Way, Boise, Id. 83705. Interrogator **26** communicates with the communications device **12** via an electromagnetic link, such as via an RF link (e.g., at microwave frequencies, in one embodiment). While other embodiments are possible, in the illustrated embodiment the communications device **12** includes a transponder **16** having a receiver **30** and a transmitter **32** (FIG. **4**). Communications device **12** further includes a power source **18** connected to transponder **16** to supply power to transponder **16**. Communications device **12** further includes at least one antenna connected to transponder **16** for wireless transmission and reception. In the illustrated embodiment, communications device **12** includes at least one antenna **46** connected to transponder **16** for radio frequency transmission by transponder **16**, and at least one receive antenna **44** connected to transponder **16** for radio frequency reception by transponder **16**. In the illustrated embodiment, the transmit antenna **46** is a dipole antenna, and the receive antenna **44** is a loop antenna. In the illustrated embodiment, the transponder **16** is in the form of an integrated circuit. However, in alternative embodiments, all of the circuitry of transponder **16** is not necessarily all included in a single integrated circuit.

[0030] Power source **18** is a thin film battery in the illustrated embodiment; however, in alternative embodiments, other forms of power sources can be employed. If the power source **18** is a battery, the battery can take any suitable form. Preferably, the battery type will be selected depending on weight, size, and life requirements for a particular application. In one embodiment, the battery **18** is a thin profile button-type cell forming a small, thin energy cell more commonly utilized in watches and small electronic devices requiring a thin profile. A conventional button-type cell has a pair of electrodes, an anode formed by one face and a cathode formed by an opposite face. In an alternative embodiment, the battery comprises a series connected pair of button type cells.

[0031] The communications device **12** can be included in any appropriate housing or packaging.

[0032] FIG. **2** shows but one example of a housing in the form of a card **11** comprising plastic or other suitable material. The plastic card **11** houses communications device **12** to define an employee identification badge **13** including the communications device **12**. In one embodiment, the front face of badge **13** has visual identification features such as an employee photograph or a fingerprint in addition to identifying text.

[0033] FIG. **3** illustrates but one alternative housing supporting the device **12**. More particularly, FIG. **3** illustrates a miniature housing **20** encasing the device **12** to define a tag which can be supported by an object (e.g., hung from an object, affixed to an object, etc.).

[0034] Although two particular types of housings have been disclosed, the communications device **12** can be included in any appropriate housing. Communications device **12** is of a small size that lends itself to applications employing small housings, such as cards, miniature tags, etc. Larger housings can also be employed. The communications device **12**, housed in any appropriate housing, can be supported from or attached to an object in any desired manner.

[0035] Interrogator unit **26** includes a plurality of antennas X**1**, R**1**, as well as transmitting and receiving circuitry, similar to that implemented in the device **16**. The host computer **48** acts as a master in a master-slave relationship with interrogator **26**. The host computer **48** includes an applications program for controlling the interrogator **26** and interpreting responses, and a library of radio frequency identification device applications or functions. Most of the functions communicate with interrogator **26**. These functions effect radio frequency communication between interrogator **26** and communications device **12**.

[0036] Communications system **10** includes a transmit antenna X**1**, and a receive antenna R**1** connected to interrogator **26**. In operation, the interrogator **26** transmits an interrogation signal or command **27** ("forward link") via the antenna X**1**. The communications device **12** receives the incoming interrogation signal via its antenna **44**. Upon receiving the signal **27**, the communications device **12** responds by generating and transmitting a responsive signal or reply signal **29** ("return link"). The interrogator **26** is described in greater detail below.

[0037] In one embodiment, the responsive signal **29** is encoded with information that uniquely identifies, or labels the particular device **12** that is transmitting, so as to identify any object or person with which communications device **12** is associated.

[0038] In the embodiment illustrated in FIG. **1**, multiple communications devices **12** can be employed; however, there is no communication between multiple devices **12**. Instead, the multiple communications devices **12** communicate with interrogator **26**. FIG. **1** illustrates the communications device **12** as being in the housing **20** of FIG. **3**. The system would operate in a similar manner if the device **12** is provided in a housing such as the housing **10** of FIG. **2**, or any other appropriate housing. Multiple communications devices **12** can be used in the same field of an interrogator **26** (i.e., within communications range of an interrogator **26**). Similarly, multiple interrogators **26** can be in proximity to one or more of the devices **12**.

[0039] The above described system **10** is advantageous over prior art devices that utilize magnetic field effect systems because, with the system **10**, a greater range can be achieved, and more information can be obtained (instead of just an identification number).

[0040] As a result, such a system **10** can be used, for example, to monitor large warehouse inventories having many unique products needing individual discrimination to determine the presence of particular items within a large lot of tagged products.

[0041] FIG. **4** is a high level circuit schematic of the transponder **16** utilized in the devices of FIGS. **1-3**. In the embodiment shown in FIG. **4**, the transponder **16** is a monolithic integrated circuit. More particularly, in the illustrated embodiment, the integrated circuit **16** comprises a single die, having a size of 209×116 mils^2, including the receiver **30**, the transmitter **32**, a micro controller or microprocessor **34**, a wake up timer and logic circuit **36**, a clock recovery and data recovery circuit **38**, and a bias voltage and current generator **42**.

[0042] In one embodiment, the communications devices **12** switch between a "sleep" mode of operation, and higher power modes to conserve energy and extend battery life during periods of time where no interrogation signal **27** is received by devices **12**, using the wake up timer and logic circuitry **36**.

[0043] In one embodiment, a spread spectrum processing circuit **40** is included in transponder **16**. In this embodiment, signals transmitted and received by interrogator **26**, and transmitted and received by communications device **12** are modulated spread spectrum signals. Spread spectrum modulation is described below.

[0044] Many modulation techniques minimize required transmission bandwidth. However, the spread spectrum modulation technique employed in the illustrated embodiment requires a transmission bandwidth that is up to several orders of magnitude greater than the minimum required signal bandwidth. Although spread spectrum modulation techniques are bandwidth inefficient in single user applications, they are advantageous where there are multiple users, as is the case with the instant radio frequency identification system **24**. The spread spectrum modulation technique of the illustrated embodiment is advantageous because the interrogator signal can be distinguished from other signals (e.g., radar, microwave ovens, etc.) operating at the same frequency. The spread spectrum signals transmitted by communications device **12** and by interrogator **26** are pseudo random and have noise-like properties when compared with the digital command or reply. The spreading waveform is controlled by a pseudo-noise or pseudo random number (PN1) sequence or code. The PN code is a binary sequence that appears random but can be reproduced in a predetermined manner by the device **12**. More particularly, incoming spread spectrum signals are demodulated by communications device **12** or by interrogator **26** through cross correlation with a version of the pseudo random carrier that is generated by communications device **12** itself or interrogator **26** itself, respectively. Cross correlation with the correct PN sequence unspreads the spread spectrum signal and restores the modulated message in the same narrow band as the original data.

[0045] A pseudo-noise or pseudo random sequence (PN sequence) is a binary sequence with an autocorrelation that resembles, over a period, the autocorrelation of a random binary sequence. The autocorrelation of a pseudo-noise sequence also roughly resembles the autocorrelation of band-limited white noise. A pseudo-noise sequence has many characteristics that are similar to those of random binary sequences. For example, a pseudo-noise sequence has a nearly equal number of zeros and ones, very low correlation between shifted versions of the sequence, and very low cross correlation between any two sequences. A pseudo-noise sequence is usually generated using sequential logic circuits. For example, a pseudo-noise sequence can be generated using a feedback shift register.

[0046] A feedback shift register comprises consecutive stages of two state memory devices, and feedback logic. Binary sequences are shifted through the shift registers in response to clock pulses, and the output of the various stages are logically combined and fed back as the input to the first stage. The initial contents of the memory stages and the feedback logic circuit determine the successive contents of the memory.

[0047] The illustrated embodiment employs direct sequence spread spectrum modulation. A direct sequence spread spectrum (DSSS) system spreads the baseband data by directly multiplying the baseband data pulses with a pseudo-noise sequence that is produced by a pseudo-noise generator. A single pulse or symbol of the PN waveform is called a “chip.” Synchronized data symbols, which may be information bits or binary channel code symbols, are added in modulo-2 fashion to the chips before being modulated. The receiver performs demodulation. For example, in one embodiment the data is amplitude modulated. Assuming that code synchronization has been achieved at the receiver, the received signal passes through a wideband filter and is multiplied by a local replica of the PN code sequence. This multiplication yields the unspread signal.

[0048] A pseudo-noise sequence is usually an odd number of chips long. In the illustrated embodiment, one bit of data is represented by a thirty-one chip sequence. A zero bit of data is represented by inverting the pseudo-noise sequence.

[0049] Spread spectrum techniques are also disclosed in “Spread Spectrum Systems,” by R. C. Dixon, published by John Wiley and Sons, Inc., incorporated herein by reference.

[0050] In operation, the interrogator sends out a command that is spread around a certain center frequency (e.g., 2.44 GHz). After the interrogator transmits the command, and is expecting a response, the interrogator switches to a CW mode (continuous wave mode). In the continuous wave mode, the interrogator does not transmit any information. Instead, the interrogator just transmits 2.44 GHz radiation. In other words, the signal transmitted by the interrogator is not modulated. After the communications device **12** receives the command from the interrogator, the communications device **12** processes the command. If communications device **12** is in a backscatter mode it alternately reflects or does not reflect the signal from the interrogator to send its reply. For example, in the illustrated embodiment, two halves of a dipole antenna are either shorted together or isolated from each other to send a reply.

[0051] In one embodiment, the clock for the entire integrated circuit **16** is extracted from the incoming message itself by clock recovery and data recovery circuitry **38**. This clock is recovered from the incoming message, and used for timing for the micro controller **34** and all the other clock circuitry on the chip, and also for deriving the transmitter carrier or the subcarrier, depending on whether the transmitter is operating in active mode or backscatter mode.

[0052] In addition to recovering a clock, the clock recovery and data recovery circuit **38** also performs data recovery on valid incoming signals. The valid spread spectrum incoming signal is passed through the spread spectrum processing circuit **40**, and the spread spectrum processing circuit **40** extracts the actual ones and zeros of data from the incoming signal. More particularly, the spread spectrum processing circuit **40** takes the chips from the spread spectrum signal, and reduces each thirty-one chip section down to a bit of one or zero, which is passed to the micro controller **34**.

[0053] Micro controller **34** includes a serial processor, or I/O facility that receives the bits from the spread spectrum processing circuit **40**. The micro controller **34** performs further error correction. More particularly, a modified hamming code is employed, where each eight bits of data is accompanied by five check bits used by the micro controller **34** for error correction. Micro controller **34** further includes a memory, and after performing the data correction, micro controller **34** stores bytes of the data bits in memory. These bytes contain a command sent by the interrogator **26**. The micro controller **34** responds to the command.

[0054] For example, the interrogator **26** may send a command requesting that any communications device **12** in the field respond with the device’s identification number. Status information is also returned to interrogator **26** from communications device **12** when communications device **12** responds.

[0055] The transmitted replies have a format similar to the format of incoming messages. More particularly, a reply starts with a preamble (e.g., all zeros in active mode, or alternating double zeros and double ones in backscatter mode), followed by a Barker or start code, followed by actual data.

[0056] The incoming message and outgoing reply preferably also include a check sum or redundancy code so that integrated circuit **16** or interrogator **12** can confirm receipt of the entire message or reply.

[0057] Interrogator **26** provides a communication link between a host computer and transponder **16**. Interrogator **26** connects to the host computer **48** via an IEEE-1284 enhanced parallel port (EPP). The interrogator communicates with transponder **16** via the RF antennas X**1** and R**1**.

[0058] A Maximal Length Pseudo Noise (PN) Sequence is used in the Direct Sequence Spread Spectrum (DSSS) communications scheme in the forward link. In one embodiment, the sequence is generated by a linear feedback shift register. This produces a repeating multiple “chip” sequence.

[0059] A zero bit is transmitted as one inverted full cycle of the PN sequence. A one bit is transmitted as one full non-inverted cycle of the PN sequence.

[0060] After sending a command, the interrogator sends a continuous unmodulated RF signal with an approximate frequency of 2.44175 GHz. Return link data is Differential Phase Shift Key (DPSK) modulated onto a square wave subcarrier with a frequency of approximately 600 kHz (e.g., 596.1 kHz in one embodiment). A data **0** corresponds to one phase and data **1** corresponds to another, shifted 180 degrees from the first phase. The subcarrier is used to modulate antenna impedance of transponder **16**. For a simple dipole, a switch between the two halves of the dipole antenna is opened and closed. When the switch is closed, the antenna becomes the electrical equivalent of a single half-wavelength antenna that reflects a portion of the power being transmitted by the interrogator. When the switch is open, the antenna becomes the electrical equivalent of two quarter-wavelength antennas that reflect very little of the power transmitted by the interrogator. In one embodiment, the dipole antenna is a printed microstrip half wavelength dipole antenna.

[0061] Referring to FIG. **5**, one embodiment of interrogator **26** is illustrated. The depicted interrogator **26** includes enhanced parallel port (EPP) circuitry **50**, DPSK (differential phase shift keyed) circuitry **52**, and RF (radio frequency) circuitry **54**, as well as a power supply (not shown) and a housing or chassis (not shown). In the illustrated embodiment, the enhanced parallel port circuitry **50**, the DPSK circuitry **52**, and the RF circuitry **54** respectively define circuit card assemblies (CCAs).

[0062] The interrogator uses an IEEE-1284 compatible port in EPP mode to communicate with host computer **48**.

The EPP circuitry **50** provides digital logic required to coordinate sending and receiving a message with transponder **16**. The EPP circuitry **50** buffers data to transmit from host computer **48**, converts the data to serial data, and encodes it. The EPP circuitry **50** then waits for data from the transponder **16**, converts it to parallel, and transfers it to host computer **48**. In one embodiment, messages include up to 64 bytes of data.

[0063] The EPP mode interface provides an asynchronous, interlocked, byte wide, bi-directional channel controlled by a host device. The EPP mode allows the host computer to transfer, at high speed, a data byte to/from the interrogator within a single host computer CPU I/O cycle (typically 0.5 microseconds per byte).

[0064] RF circuitry **54** interfaces with the transmit and receive antennas X**1**, R**1**. Exemplary transmit operations of RF circuitry **54** are described with reference to FIGS. **6-8**. RF circuitry **54** modulates the data for transmission to transponder **16**, provides a continuous wave (CW) carrier for backscatter communications with transponder **16** (if backscatter communications are employed), and receives and down converts the signal received from transponder **16** (which comprises a backscatter signal in one embodiment).

[0065] Referring to FIG. **6**, RF circuitry **54** includes a data path **73**, signal generator **75**, amplifier **76** and modulator **77**. An exemplary signal generator comprises a frequency synthesizer configured to tune the RF continuous wave carrier. In the described embodiment, signal generator **75** is configured to generate a microwave carrier signal (e.g., approximately 2.44 GHz).

[0066] RF circuitry **54** defines a transmitter, and is configured to receive data from EPP circuitry **50**. Modulator **77** is coupled with data path **73** and signal generator **75**. Data path **73** comprises an interconnection such as a wire configured to communicate a data signal to modulator **77**. Modulator **77** receives the data from EPP circuitry **50** and amplitude modulates the data onto a carrier in the described embodiment. More particularly, modulator **77** turns the RF on and off (ON OFF KEY).

[0067] According to one embodiment, modulator **77** is configured to spread the data signal to provide spread spectrum communications including a spread data signal. Modulator **77** is further configured to amplitude modulate the carrier signal using the spread data signal. In a preferred embodiment, modulator **77** is configured to phase modulate the carrier signal. Phase modulation is utilized to provide suppression of power within the carrier signal in accordance with a preferred embodiment of the invention. Following such amplitude and phase modulation, interrogator **26** is preferably configured to communicate the carrier signal.

[0068] Modulator **77** can be configured to spread the data signal using the PN1 pseudo-noise sequence. The first pseudo-noise sequence code (PN1) is encoded with data received by communications path **73**. In a preferred embodiment, modulator **77** is thereafter configured to invert the spread data signal. Phase modulation of the carrier signal is responsive to selected inverting of the spread data signal. Encoding the pseudo-noise sequence with the data signal forms a plurality of chips. The chips individually correspond to one of two values, such as logical high (1) or logical low (0). Modulator **77** is configured in a preferred embodiment to selectively invert the chips of the spread signal to implement phase modulation.

[0069] In one embodiment, modulator **77** is configured to randomly invert the spread data signal. Modulator **77** is operable in the preferred embodiment to invert the spread data signal using a second pseudo-noise sequence (PN2). The second pseudo-noise sequence code (PN2) is utilized to modulate the phase of the RF carrier in the described embodiment. The second pseudo-noise sequence (PN2) utilized to provide random inversion of the spread data signal comprises a 1,023 bit sequence in one embodiment. Such can be implemented using logic circuitry and shift registers configured in a feedback arrangement in one embodiment.

[0070] Randomly changing the phase of the RF carrier signal implements phase modulation and provides the desired effect of spreading the carrier energy over a wider band width. Thus, the communication power can be increased while decreasing the amount of power present in the carrier.

[0071] The random code or pseudo-noise sequence (PN2) utilized to implement selected inversion of the spread data signal is preferably band limited to avoid excessive spectral spreading. The carrier signal can be modulated using the band limited data signal.

[0072] Modulator **77** can be arranged to implement the inversion operations responsive to the spread data signal being a predetermined value. For example, modulator **77** can be configured to invert one or more chips of the spread data signal responsive to the spread data signal being a logical low value (e.g., zero Volts). The inverting is preferably coordinated or synchronized with the spread data signal.

[0073] In particular, modulator **77** is preferably configured such that the second pseudo-noise sequence (PN2) changes state, and implements inversion of the spread data signal, at predetermined places corresponding to the spread data signal. It is preferred to restrict state changes of the PN2 pseudo-noise sequence to periods of time wherein the carrier signal is off during amplitude modulation. For example, during the presence of multiple adjacent zeros within the spread data signal, sufficient time typically exists for the second pseudo-noise sequence to complete a state change while the carrier signal is turned off. Such is preferred to reduce inducing of an amplitude variation within the output communicated signal which may cause error within the associated remote communication device inasmuch as the second pseudo-noise sequence pulses have a limited rise and fall time.

[0074] It is desired to reduce communicated energy present in restricted frequency bands in many applications. Modulator **77** is configured in one embodiment to band limit or filter signals within RF circuitry **54**. A preferred configuration is to filter baseband signals within modulator **77** before conversion to RF frequencies. Modulator **77** includes a filter configured to band limit the spread data signal in the described embodiment.

[0075] Referring to FIG. **7**, an exemplary modulator **77** is illustrated. The depicted modulator **77** includes logic circuitry **65**, summing amplifier **64**, low pass filter **66**, attenuator **68**, and mixer **69**. Modulator **77** is coupled with EPP circuitry **50**, code generator **60**, code generator **61**, signal generator **75**, and power amplifier **76**.

[0076] The depicted logic circuitry **65** comprises an exclusive NOR device **62** and an exclusive OR device **63**. Exclusive NOR device **62** is coupled with EPP circuitry **50** via data path **73** and code generator **60**. Device **62** is configured to encode the pseudo-noise sequence (PN1) from code generator **60** with data received via path **73**, and output a spread data signal. The spread data signal is applied to exclusive OR device **63** as well as code generator **61**.

[0077] Code generator **61** is configured to change state according to second pseudo-noise sequence (PN2) and responsive to the spread data signal being a predetermined value. The PN2 output of code generator **61** is applied to exclusive OR device **63** and summing amplifier **64**. In the described embodiment, code generator **61** is configured to change the state of the outputted signal according to pseudo-noise sequence (PN2) and responsive to the spread data being a logic low value as received from exclusive NOR device **62**. The pseudo-noise sequence (PN2) outputted from code generator **61** and applied to exclusive OR device **63** randomly inverts the spread data signal.

[0078] The output of exclusive OR device **63** is also applied to summing amplifier **64**. Summing amplifier **64** is configured to combine the pseudo-random noise sequences PN1, PN2. Summing amplifier **64** is further configured to output a tri-level or tri-state signal to implement the amplitude modulation and phase modulation of the carrier signal using mixer **69**. The carrier signal is modulated using the tri-level signal corresponding to the inverted data signal in the described embodiment. Combination of the spread data signal and the PN2 pseudo-noise sequence provided by code generator **61** is preferred to reduce the amount of hardware utilized within modulator **77**. Summing amplifier **64** preferably includes an offset adjustment **67** utilized to balance the amplitude outputted from mixer **69** to provide maximum carrier suppression in the preferred embodiment.

[0079] In the depicted embodiment, the tri-level or state output of summing amplifier **64** is applied to low pass filter **66**, attenuator **68** and mixer **69**. Low pass filter **66** is configured in the described embodiment to reduce spreading of energy into restricted bands adjacent the desired band for communication. In one embodiment, low pass filter **66** comprises a seven pole filter having a cutoff frequency of 20 MHz. In particular, filter **66** preferably limits the rise and fall time of the spread data signal represented within the tri-level signal as described below.

[0080] Attenuator **68** is configured to adjust the amplitude of the outputted signal of low pass filter **66**. Discrete components **78** are provided intermediate attenuator **68** and mixer **69**. The illustrated discrete components **78** include a series capacitor and a resistor coupled to ground. Discrete components **78** are operable to block DC components within the output of attenuator **68**.

[0081] The tri-level signal can comprise three states in the described embodiment. A logical high value can be represented be either a positive voltage or negative voltage within the tri-level signal. Communication device **12** is configured to interpret both positive and negative voltages as a logical high value in the described embodiment. A logical low value is preferably approximately zero Volts within the described tri-level signal.

[0082] Mixer **69** is configured to invert the phase of the carrier signal responsive to the reception of a negative value within the tri-level signal emitted from summing amplifier **64**. A positive voltage within the tri-level signal results in no change of the phase of the carrier signal. Mixer **69** turns the RF carrier signal off responsive to the tri-level signal being zero Volts.

[0083] The output of mixer **69** is applied to amplifier **76** in the described embodiment. The depicted amplifier **76** comprises a power amplifier coupled to modulator **77** and configured to amplify the signal. Amplifier **76** is operable responsive to control from EPP circuitry **50** in the illustrated embodiment.

[0084] Referring to FIG. **8**, operation of modulator **77** is illustrated. Plural signals **90**-**96** are shown in FIG. **8**. Signal **90** represents the data output of EPP circuitry **50**. Signal **91** corresponds to the first pseudo-noise sequence (PN1) signal outputted from code generator **60**. Signal **92** represents the output of exclusive NOR device **62**. Signal **93** corresponds to the second pseudo-noise sequence (PN2) signal outputted from code generator **61**. Signal **94** represents the output of exclusive OR device **63**. Signal **95** represents the output of summing amplifier **64** and signal **96** represents the output of low pass filter **66**.

[0085] Low pass filter **66** is preferably configured to reduce the presence of harmonic information within the tri-level signal. Filter **66** can be configured to pass fundamental frequency information and any other harmonic information necessary for proper operation of remote communication device **12**.

[0086] For example, low pass filter **66** can be configured to pass fundamental frequency and third harmonic information in one application (e.g., the remote communication device is sensitive to slow rising and falling edges). It is preferred to adjust filter **66** to provide optimal bandwidth efficiency while effectively communicating data to the associated remote electronic communication device **12**.

[0087] During continuous wave (CW) transmissions for the backscatter mode, modulator **77** is configured to apply the carrier signal to transmit antenna X1. Transponder **16** is operable to backscatter the signal with a DPSK modulated sub carrier. Following receipt of the command communication signal from interrogator **26**, communication device **12** can be configured to output a reply signal. In backscatter configurations, device **12** is operable to modulate the CW emission from interrogator **26**. The backscattered reply signal is received via receive antenna R1 of interrogator **26**.

[0088] Although not shown in FIGS. **6**-**8**, RF circuitry **54** can include a quadrature downconverter configured to coherently downconvert the received reply signal. RF circuitry **54** can also include automatic gain controls (AGCs) coupled to the quadrature downconverter and configured to set the amplitude of signals I and Q. The I and Q signals, which contain the DPSK modulated sub-carrier, are passed on to DPSK circuitry **52** for demodulation.

[0089] In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

[0090] This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote" the progress of science and useful arts" (Article 1, Section 8).

1-**47**. (canceled)

48: A method of communicating between a radio frequency identification (RFID) reader and at least one RFID tag, the method comprising:

providing an RFID tag, the RFID tag comprising an antenna and a single monolithic integrated circuit coupled to the antenna and configured to modulate an impedance of the antenna to enable backscatter communication with the RFID reader, the integrated circuit having stored therein an identification code;

encoding a baseband data signal to generate an encoded data signal wherein a data bit zero of the baseband data signal is represented by both logic high and logic low levels in the encoded data signal and a data bit one of the baseband data signal is represented by both logic high and logic low levels in the encoded data signal, the baseband data signal comprising a command;

transmitting the command from the RFID reader, including both amplitude and phase modulating a carrier wave using the encoded data signal;

transmitting, from the RFID reader, the carrier wave as a continuous wave after transmitting the command; and

receiving a reply, including the identification code, from the RFID tag in response to the command, the reply comprising backscatter modulation of the carrier wave.

49: The method of claim **48**, wherein transmitting the command from the RFID reader is done in accordance with an application program executing on a host computer to which the RFID reader is coupled, and the RFID reader communicates the received identification code to the host computer.

50: The method of claim **48**, further comprising providing power to the RFID tag from a battery.

51: The method of claim **48**, wherein the impedance of the antenna is configured to be modulated by shorting together and isolating from each other two halves of a dipole antenna.

52: The method of claim **48**, further comprising band limiting the encoded data signal before using the encoded data signal to modulate the carrier wave.

53: The method of claim **48**, wherein the data bit zero of the baseband data signal is represented by a plurality of logic high levels in the encoded data signal.

54: The method of claim **53**, wherein the data bit zero of the baseband data signal is represented by a plurality of logic low levels in the encoded data signal.

55: The method of claim **48**, wherein the RFID tag is affixed to an object, and the identification code is associated with the object.

56: The method of claim **55**, further comprising affixing the RFID tag to the object and associating the identification code with the object.

57: The method of claim **48**, wherein transmitting the command comprises the use of spread spectrum communication.

58: The method of claim **57**, further comprising band limiting the encoded data signal before using the encoded data signal to modulate the carrier wave.

59: The method of claim **48**, wherein the RFID reader communicates to the RFID tag a selected one of a plurality of data rates, and the reply is received at the selected one of the plurality of data rates.

60: A method of communicating between a radio frequency identification (RFID) reader and at least one RFID tag, the method comprising:

providing an RFID tag affixed to an object, the RFID tag comprising an antenna and a single monolithic integrated circuit coupled to the antenna and configured to modulate an impedance of the antenna to enable backscatter communication with the RFID reader, the integrated circuit having stored therein an identification code associated with the object;

providing the RFID reader coupled to a host computer, the RFID reader configured to transmit a continuous wave after transmitting a command, the continuous wave to enable backscatter communication with the RFID tag;

encoding a baseband data signal, including performing selective inversion responsive to a predetermined data value, to generate an encoded data signal wherein a data bit zero of the baseband data signal is represented by both logic high and logic low levels in the encoded data signal; and

modulating a carrier wave using the encoded data signal to communicate between the RFID reader and the RFID tag, the modulating using a modulation format selected from a group consisting of amplitude modulation, phase modulation, and amplitude and phase modulation.

61: The method of claim **60**, wherein the host computer associates the identification code with the object.

62: The method of claim **61**, further comprising affixing the RFID tag to the object and associating the identification code with the object.

63: The method of claim **60**, further comprising providing power to the RFID tag from a battery.

64: The method of claim **60**, wherein the impedance of the antenna is configured to be modulated by modulating a reflectivity of the antenna.

65: The method of claim **60**, wherein the data bit zero of the baseband data signal is represented by a plurality of logic high levels in the encoded data signal.

66: The method of claim **65**, wherein the data bit zero of the baseband data signal is represented by a plurality of logic high levels and a plurality of logic low levels in the encoded data signal.

67: The method of claim **66**, further comprising the use of spread spectrum to communicate between the RFID reader and the RFID tag.

68: The method of claim **60**, wherein the command indicates a selected data rate of a plurality of data rates, and the RFID tag communicates with the RFID reader at the selected data rate in response to the command.

69: The method of claim **60**, wherein the carrier wave is generated by the RFID reader.

70: A radio frequency identification (RFID) reader configured to communicate with a plurality of RFID tags, the RFID reader comprising:

a data path configured to provide a baseband data signal comprising a command;

a circuit to generate an encoded data signal wherein a data bit zero of the baseband data signal is represented by at least one logic high level and at least one logic low level in the encoded data signal and a data bit one of the baseband data signal is represented by at least one logic high level and at least one logic low level in the encoded data signal;

a signal generator configured to generate a carrier signal to be modulated during transmission of commands to the RFID tags and to be provided as a continuous wave during reception of replies from the RFID tags in accordance with backscatter communication;

a modulator configured to both amplitude modulate and phase modulate the carrier signal using the encoded data signal;

a transmitter to transmit the amplitude and phase modulated carrier signal; and

a receiver to receive a reply to the command from at least one RFID tag.

71: The RFID reader of claim **70**, further comprising a host computer to receive the reply, the reply including an identification code, the host computer configured to associate the identification code with an object to which the RFID tag is affixed.

72: The RFID reader of claim **71**, further comprising a filter to band limit the encoded data signal.

73: The RFID reader of claim **70**, wherein the circuit is further configured to generate the encoded data signal wherein the data bit one of the baseband data signal is represented by a plurality of logic high levels in the encoded data signal.

74: The RFID reader of claim **70**, further comprising a spread spectrum processing unit configured the implement spread spectrum transmission from the RFID reader.

75: The RFID reader of claim **74**, further comprising a filter to band limit the encoded data signal.

76: The RFID reader of claim **75**, further comprising a host computer configured to receive the reply, the reply including an identification code, the host computer further configured to associate the identification code with an object to which the RFID tag is affixed.

77: The RFID reader of claim **75**, wherein the command indicates a selected one of a plurality of data rates, and the receiver is configured to receive the reply at the selected one of the plurality of data rates.

78: A radio frequency identification (RFID) system, comprising:

an RFID reader comprising a transmitter configured to transmit a carrier signal that is modulated during a first period of time and that is unmodulated during a second period of time, and a receiver configured to receive the carrier signal modulated during the second period of time by one or more RFID tags in accordance with backscatter communication;

an object to be tracked;

an RFID tag affixed to the object, the RFID tag comprising a receiver to receive a command from the RFID reader during the first period of time, and a transmitter to modulate the carrier signal during the second period of time to communicate a reply to the RFID reader in accordance with backscatter communication;

a computer coupled to the RFID reader to associate the object with an identification code stored in the RFID tag; and

a circuit configured to receive a baseband data signal and to generate an encoded data signal therefrom, including performing selective inversion responsive to a predetermined data value, the circuitry further configured to modulate the carrier wave by the encoded data signal using a modulation format selected from a group consisting of amplitude modulation, phase modulation, and amplitude and phase modulation.

79: The RFID system of claim **78**, wherein the RFID tag further comprises a battery to provide power to the RFID tag.

80: The RFID system of claim **78**, wherein the RFID tag further comprises an antenna, and the transmitter is configured to modulate the carrier signal by modulating a reflectivity of the antenna.

81: The RFID system of claim **78**, wherein the circuit is configured to encode a data bit zero of the baseband data signal into at least one logic high level and at least one logic low level in the encoded data signal.

82: The RFID system of claim **81**, wherein the circuit is configured to encode a data bit zero of the baseband data signal into a plurality of logic high levels and a plurality of logic low levels in the encoded data signal.

83: The RFID system of claim **78**, wherein the RFID reader further comprises a spread spectrum processor to implement spread spectrum communication between the RFID reader and the RFID tag.

84: The RFID system of claim **78**, wherein the command indicates a selected data rate of a plurality of data rates, and the RFID tag is configured to communicate the reply at the selected data rate.

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