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(54) **METHOD OF ADDRESSING MESSAGES AND COMMUNICATIONS SYSTEM**

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Related U.S. Patent Documents

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(63) Continuation of application No. 10/652,573, filed on Aug. 28, 2003, which is a continuation of application No. 09/026,050, filed on Feb. 19, 1998, now Pat. No. 6,061,344.

(51) **Int. Cl.**
H04L 1/00 (2006.01)

(52) **U.S. Cl.** **370/346**

(58) **Field of Classification Search** ..... None
See application file for complete search history.

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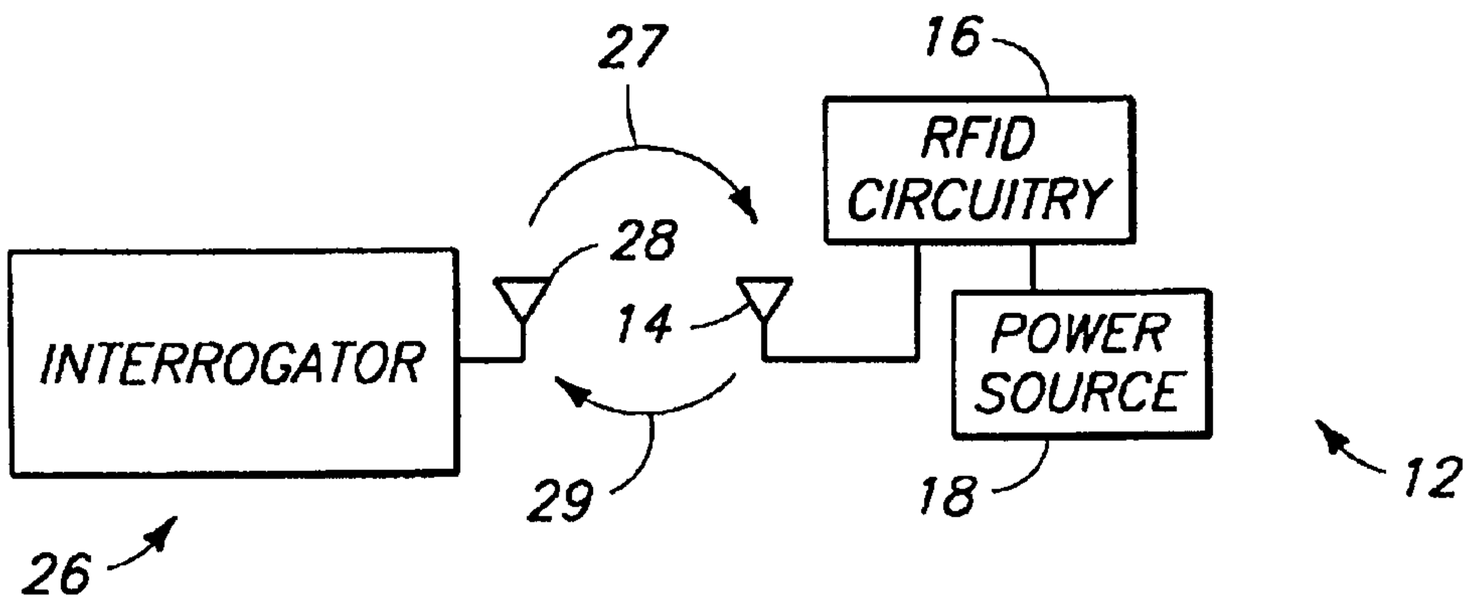
(57) **ABSTRACT**

A method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices, the method **[**comprising utilizing a tree search method to attempt to identify individual ones of the multiple wireless identification devices so as to be able to perform communications, without collision, between the interrogator and individual ones of the multiple wireless identification devices, a search tree being defined for the tree search method, the tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices, wherein the interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond, wherein the interrogator determines if a collision occurs in response to the command and, if not, repeats the command at the same node. An interrogator configured to transmit a command at a node, requesting that devices within the subgroup represented by the node respond, the interrogator further being configured to determine if a collision occurs in response to the command and, if not, to repeat the command at the same node**]** *includes: transmitting by an interrogator a first signal including a first set of bits, the interrogator to identify a first subgroup of a group of possible random numbers; communicating by each of one or more RFID devices a first response if the one or more RFID devices has generated a random number that is included in the first subgroup; receiving by the interrogator one or more received responses from respective ones of the one or more RFID devices; and responsive to receiving one of the one or more received responses without a collision, retransmitting by the interrogator at least the first signal.*

133 Claims, 3 Drawing Sheets



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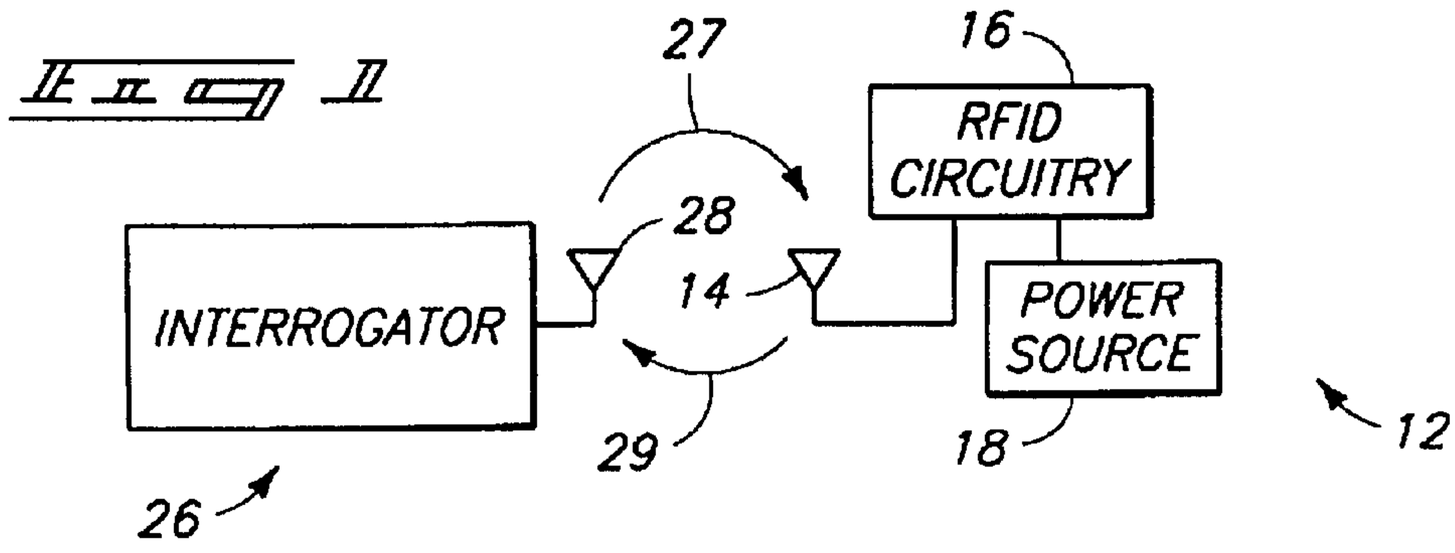


Fig. 1

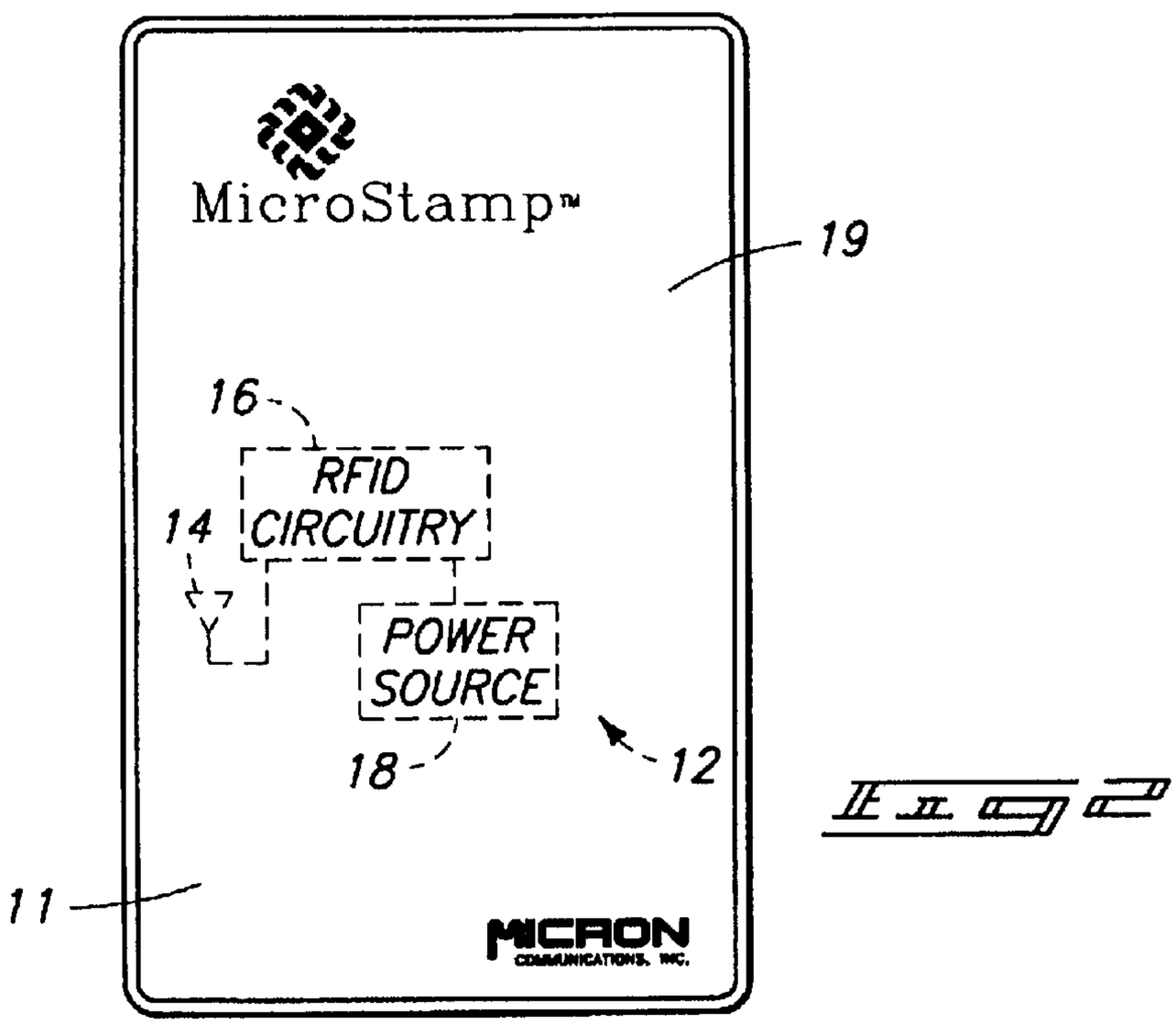


Fig. 2

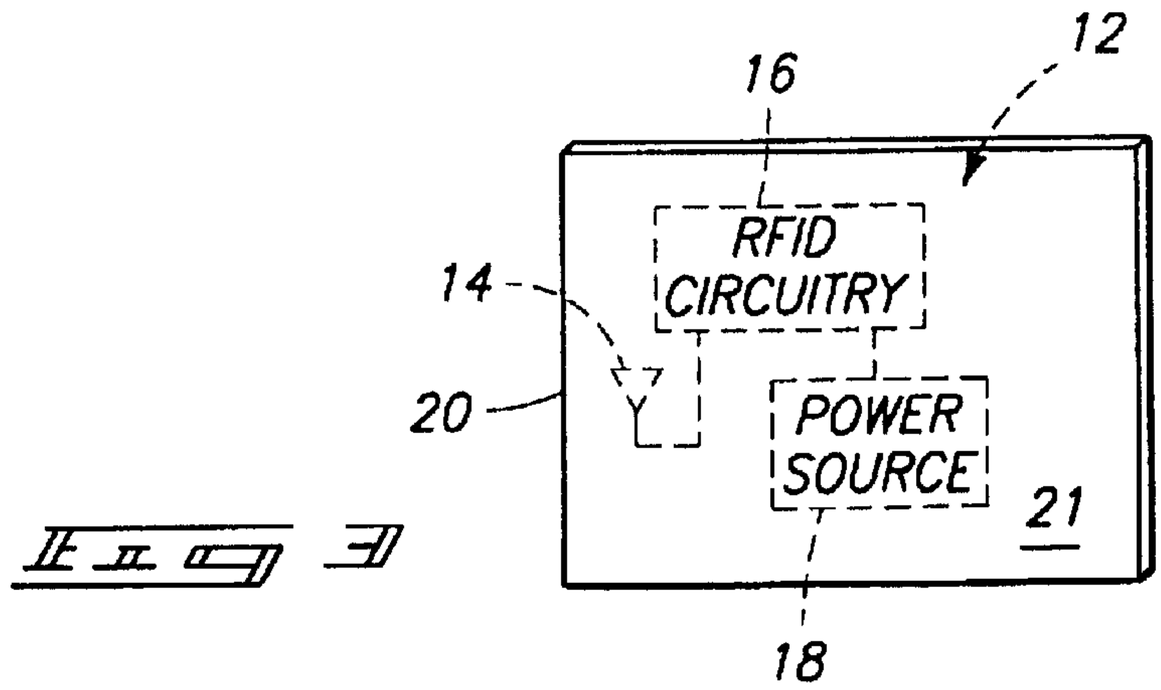
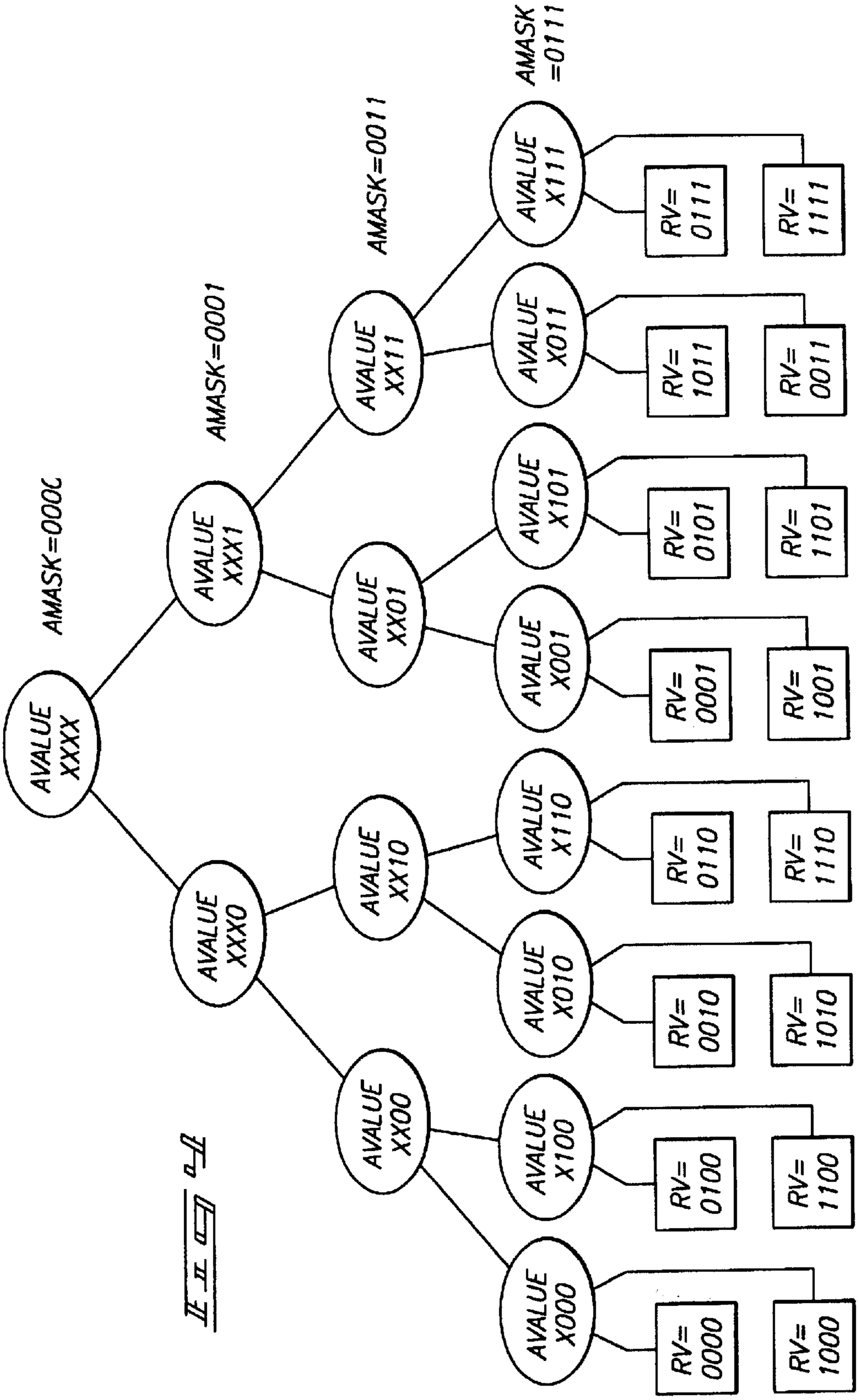
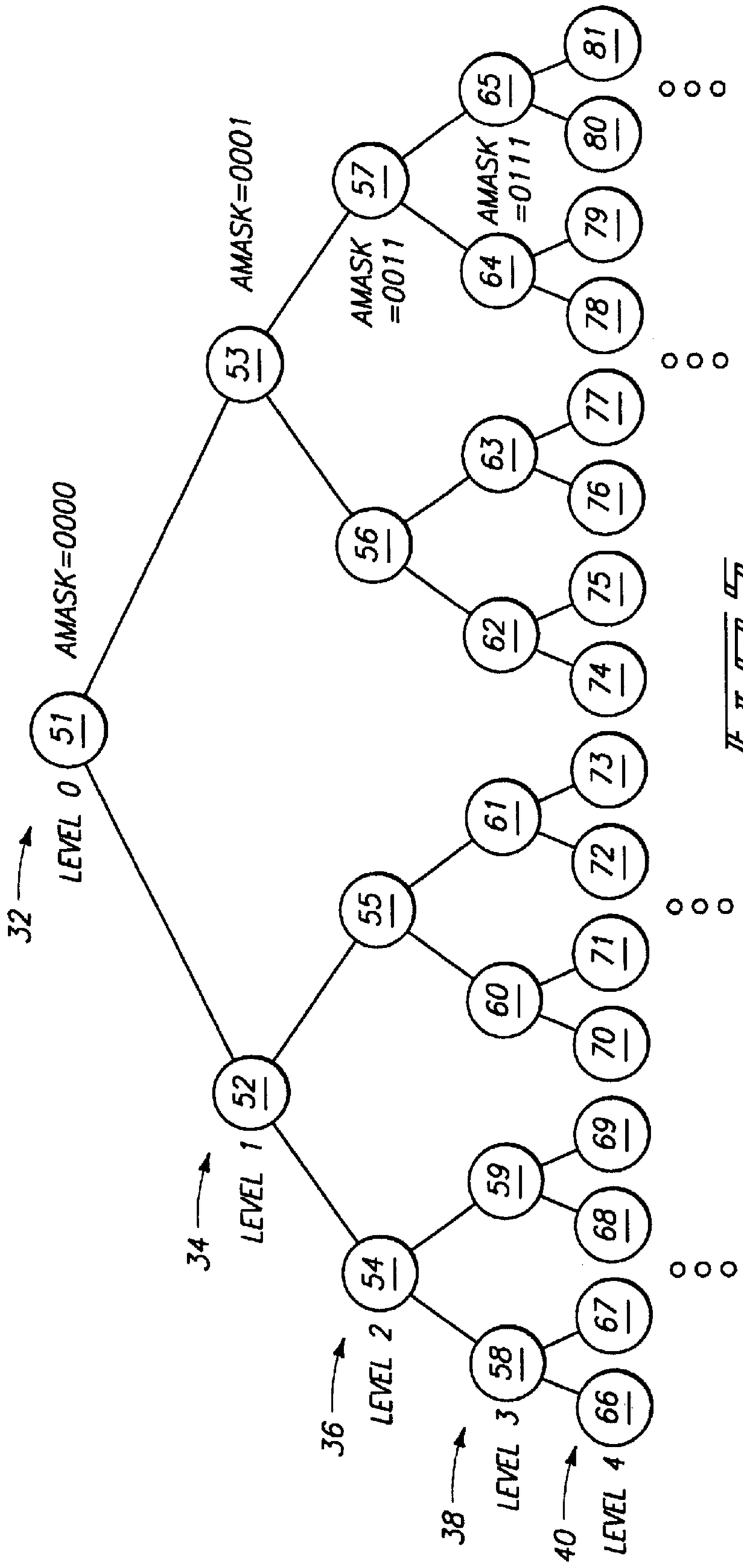


Fig. 3


AMASK=0000
AVALUE XXXX
AMASK=0001
AVALUE XXX1
AMASK=0011
AVALUE XXX0
AMASK=0111
AVALUE XX11
AVALUE XX01
AVALUE XX10
AVALUE XX00
AMASK=1111
AVALUE X111
AVALUE X011
AVALUE X101
AVALUE X001
AVALUE X110
AVALUE X010
AVALUE X100
AVALUE X000
RV= 1111
RV= 0111
RV= 1011
RV= 0011
RV= 1101
RV= 0101
RV= 1001
RV= 0001
RV= 1110
RV= 0110
RV= 1010
RV= 0010
RV= 1100
RV= 0100
RV= 1000
RV= 0000

Фиг 4


LEVEL 0
LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
32
34
36
38
40
AMASK=0000
AMASK=0001
AMASK =0011
AMASK =0111
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
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80
81

FIG 5

METHOD OF ADDRESSING MESSAGES AND COMMUNICATIONS SYSTEM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

RELATED REISSUE APPLICATIONS

More than one reissue application has been filed for the reissue of U.S. Pat. No. 6,282,186. The reissue applications are the initial reissue application Ser. No. 10/652,573 filed Aug. 28, 2003, a continuation reissue application Ser. No. 11/862,130, filed Sep. 26, 2007, a continuation reissue application Ser. No. 11/862,124, filed Sep. 26, 2007, and the present continuation reissue application.

CROSS REFERENCE TO RELATED APPLICATION

This is a [Continuation] *continuation application of a reissue application Ser. No. 10/652,573, filed Aug. 28, 2003, which is a reissue application of U.S. patent application Ser. No. 09/556,235, now U.S. Pat. No. 6,282,186, which is a continuation application* of U.S. patent application Ser. No. 09/026,050, filed Feb. 19, 1998, now U.S. Pat. No. 6,061,344 and titled "Method of Addressing Messages and Communications System".

TECHNICAL FIELD

This invention relates to communications protocols and to digital data communications. Still more particularly, the invention relates to data communications protocols in mediums such as radio communication or the like. The invention also relates to radio frequency identification devices for inventory control, object monitoring, determining the existence, location or movement of objects, or for remote automated payment.

BACKGROUND OF THE INVENTION

Communications protocols are used in various applications. For example, communications protocols can be used in electronic identification systems. As large numbers of objects are moved in inventory, product manufacturing, and merchandising operations, there is a continuous challenge to accurately monitor the location and flow of objects. Additionally, there is a continuing goal to interrogate the location of objects in an inexpensive and streamlined manner. One way of tracking objects is with an electronic identification system.

One presently available electronic identification system utilizes a magnetic coupling system. In some cases, an identification device may be 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 communication with the devices.

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, and 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 a tagged device that may not be in close proximity to an interrogator. For example, active transponder devices tend to be more suitable for inventory control or tracking.

Electronic identification systems can also be used for remote payment. For example, when a radio frequency identification device passes an interrogator at a toll booth, the toll booth can determine the identity of the radio frequency identification device, and thus of the owner of the device, and debit an account held by the owner for payment of toll or can receive a credit card number against which the toll can be charged. Similarly, remote payment is possible for a variety of other goods or services.

A communication system typically includes two transponders: a commander station or interrogator, and a responder station or transponder device which replies to the interrogator.

If the interrogator has prior knowledge of the identification number of a device which the interrogator is looking for, it can specify that a response is requested only from the device with that identification number. Sometimes, such information is not available. For example, there are occasions where the interrogator is attempting to determine which of multiple devices are within communication range.

When the interrogator sends a message to a transponder device requesting a reply, there is a possibility that multiple transponder devices will attempt to respond simultaneously, causing a collision, and thus causing an erroneous message to be received by the interrogator. For example, if the interrogator sends out a command requesting that all devices within a communications range identify themselves, and gets a large number of simultaneous replies, the interrogator may not be able to interpret any of these replies. Thus, arbitration schemes are employed to permit communications free of collisions.

In one arbitration scheme or system, described in commonly assigned U.S. Pat. Nos. 5,627,544; 5,583,850; 5,500,650; and 5,365,551, all to Snodgrass et al. and all incorporated herein by reference, the interrogator sends a command causing each device of a potentially large number of responding devices to select a random number from a known range and use it as that device's arbitration number. By transmitting requests for identification to various subsets of the full range of arbitration numbers, and checking for an error-free response, the interrogator determines the arbitration number of every responder station capable of communicating at the same time. Therefore, the interrogator is able to conduct subsequent uninterrupted communication with devices, one at a time, by addressing only one device.

Another arbitration scheme is referred to as the Aloha or slotted Aloha scheme. This scheme is discussed in various references relating to communications, such as Digital Communications: Fundamentals and Application, Bernard Sklar, published January 1988 by Prentice Hall. In this type of scheme, a device will respond to an interrogator using one of many time domain slots selected randomly by the device. A problem with the Aloha scheme is that if there are many devices, or potentially many devices in the field (i.e. in communications range, capable of responding) then there must be many available slots or many collisions will occur. Having many available slots slows down replies. If the magni-

tude of the number of devices in a field is unknown, then many slots are needed. This results in the system slowing down significantly because the reply time equals the number of slots multiplied by the time period required for one reply.

An electronic identification system which can be used as a radio frequency identification device, arbitration schemes, and various applications for such devices are described in detail in commonly assigned U.S. [patent application Ser. No. 08/705,043, filed Aug. 29, 1996, and] *Pat. No. 6,130, 602, which is* incorporated herein by reference.

SUMMARY OF THE INVENTION

The invention provides a wireless identification device configured to provide a signal to identify the device in response to an interrogation signal.

In one aspect, a method includes: transmitting by an interrogator a first signal including a first set of bits, the interrogator to identify a first subgroup of a group of possible random numbers; communicating by each of one or more RFID devices a first response if the one or more RFID devices has generated a random number that is included in the first subgroup; receiving by the interrogator one or more received responses from respective ones of the one or more RFID devices; and responsive to receiving one of the one or more received responses without a collision, retransmitting by the interrogator at least the first signal.

One aspect of the invention provides a method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices. The method comprises utilizing a tree search method to attempt to identify individual ones of the multiple wireless identification devices so as to be able to perform communications, without collision, between the interrogator and individual ones of the multiple wireless identification devices. A search tree is defined for the tree search method. The tree has multiple nodes respectively representing subgroups of the multiple wireless identification devices. The interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond. The interrogator determines if a collision occurs in response to the command and, if not, repeats the command at the same node.

Another aspect of the invention provides a communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion. The interrogator is configured to employ tree searching to attempt to identify individual ones of the multiple wireless identification devices, so as to be able to perform communications without collision, between the interrogator and individual ones of the multiple wireless identification devices. The interrogator is configured to follow a search tree, the tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices. The interrogator is configured to transmit a command at a node, requesting that devices within the subgroup represented by the node respond. The interrogator is further configured to determine if a collision occurs in response to the command and, if not, to repeat the command at the same node.

One aspect of the invention provides a radio frequency identification device comprising an integrated circuit including a receiver, a transmitter, and a microprocessor. In one embodiment, the integrated circuit is a monolithic single die single metal layer integrated circuit including the receiver, the transmitter, and the microprocessor. The device of this embodiment includes an active transponder, instead of a transponder which relies on magnetic coupling for power and therefore has a much greater range.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. **1** is a high level circuit schematic showing an interrogator and a radio frequency identification device embodying the invention.

FIG. **2** is a front view of a housing, in the form of a badge or card, supporting the circuit of FIG. **1** according to one embodiment the invention.

FIG. **3** is a front view of a housing supporting the circuit of FIG. **1** according to another embodiment of the invention.

FIG. **4** is a diagram illustrating a tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

FIG. **5** is a diagram illustrating a modified tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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).

FIG. **1** illustrates a wireless identification device **12** in accordance with one embodiment of the invention. In the illustrated embodiment, the wireless identification device is a radio frequency data communication device **12**, and includes RFID circuitry **16**. The device **12** further includes at least one antenna **14** connected to the circuitry **16** for wireless or radio frequency transmission and reception by the circuitry **16**. In the illustrated embodiment, the RFID circuitry is defined by an integrated circuit as described in the above-incorporated [patent application Ser. No. 08/705,043, filed Aug. 29, 1996] *U.S. Pat. No. 6,130,602*. Other embodiments are possible. A power source or supply **18** is connected to the integrated circuit **16** to supply power to the integrated circuit **16**. In one embodiment, the power source **18** comprises a battery.

The device **12** transmits and receives radio frequency communications to and from an interrogator **26**. An exemplary interrogator is described in commonly assigned U.S. [patent application Ser. No. 08/907,689, filed Aug. 8, 1997] *Pat. No. 6,289,209* and incorporated herein by reference. Preferably, the interrogator **26** includes an antenna **28**, as well as dedicated transmitting and receiving circuitry, similar to that implemented on the integrated circuit **16**.

Generally, the interrogator **26** transmits an interrogation signal or command **27** via the antenna **28**. The device **12** receives the incoming interrogation signal via its antenna **14**. Upon receiving the signal **27**, the device **12** responds by generating and transmitting a responsive signal or reply **29**. The responsive signal **29** typically includes information that uniquely identifies, or labels the particular device **12** that is transmitting, so as to identify any object or person with which the device **12** is associated. Although only one device **12** is shown in FIG. **1**, typically there will be multiple devices **12** that correspond with the interrogator **16**, and the particular devices **12** that are in communication with the interrogator **26** will typically change over time. In the illus-

trated embodiment in FIG. **1**, there is no communication between multiple devices **12**. Instead, the devices **12** respectively communicate with the interrogator **26**. Multiple devices **12** can be used in the same field of an interrogator **26** (i.e., within communications range of an interrogator **26**).

The radio frequency data communication device **12** can be included in any appropriate housing or packaging. Various methods of manufacturing housings are described in commonly assigned U.S. [patent application Ser. No. 08/800,037, filed Feb. 13, 1997, and] *Pat. No. 5,988,510 which is* incorporated herein by reference.

FIG. **2** shows but one embodiment in the form of a card or badge **19** including a housing **11** of plastic or other suitable material supporting the device **12** and the power supply **18**. In one embodiment, the front face of the badge has visual identification features such as interrogators, text, information found on identification or credit cards, etc.

FIG. **3** illustrates but one alternative housing supporting the device **12**. More particularly, FIG. **3** shows a miniature housing **20** encasing the device **12** and power supply **18** to define a tag which can be supported by an object (e.g., hung from an object, affixed to an object, etc.). Although two particular types of housings have been disclosed, other forms of housings are employed in alternative embodiments.

If the power supply **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 power source **18** comprises a series connected pair of button type cells. In other alternative embodiments, other types of suitable power source are employed.

The circuitry **16** further includes a backscatter transmitter and is configured to provide a responsive signal to the interrogator **26** by radio frequency. More particularly, the circuitry **16** includes a transmitter, a receiver, and memory such as is described in U.S. [patent application Ser. No. 08/705,043] *Pat. No. 6,130,602*.

Radio frequency identification has emerged as a viable and affordable alternative to tagging or labeling small to large quantities of items. The interrogator **26** communicates with the devices **12** via an electromagnetic link, such as via an RF link (e.g., at microwave frequencies, in one embodiment), so all transmissions by the interrogator **26** are heard simultaneously by all devices **12** within range.

If the interrogator **26** sends out a command requesting that all devices **12** within range identify themselves, and gets a large number of simultaneous replies, the interrogator **26** may not be able to interpret any of these replies. Therefore, arbitration schemes are provided.

If the interrogator **26** has prior knowledge of the identification number of a device **12** which the interrogator **26** is looking for, it can specify that a response is requested only from the device **12** with that identification number. To target a command at a specific device **12**, (i.e., to initiate point-on-point communication), the interrogator **26** must send a number identifying a specific device **12** along with the command. At start-up, or in a new or changing environment, these identification numbers are not known by the interrogator **26**. Therefore, the interrogator **26** must identify all devices **12** in the field (within communication range) such as by determining the identification numbers of the devices **12** in the field. After this is accomplished, point-to-point communication can proceed as desired by the interrogator **26**.

Generally speaking, RFID systems are a type of multiaccess communication system. The distance between the interrogator **26** and devices **12** within the field is typically fairly short (e.g., several meters), so packet transmission time is determined primarily by packet size and baud rate. Propagation delays are negligible. In such systems, there is a potential for a large number of transmitting devices **12** and there is a need for the interrogator **26** to work in a changing environment, where different devices **12** are swapped in and out frequently (e.g., as inventory is added or removed). In such systems, the inventors have determined that the use of random access methods work effectively for contention resolution (i.e., for dealing with collisions between devices **12** attempting to respond to the interrogator **26** at the same time).

RFID systems have some characteristics that are different from other communications systems. For example, one characteristic of the illustrated RFID systems is that the devices **12** never communicate without being prompted by the interrogator **26**. This is in contrast to typical multiaccess systems where the transmitting units operate more independently. In addition, contention for the communication medium is short lived as compared to the ongoing nature of the problem in other multiaccess systems. For example, in a RFID system, after the devices **12** have been identified, the interrogator can communicate with them in a point-to-point fashion. Thus, arbitration in a RFID system is a transient rather than steady-state phenomenon. Further, the capability of a device **12** is limited by practical restrictions on size, power, and cost. The lifetime of a device **12** can often be measured in terms of number of transmission before battery power is lost. Therefore, one of the most important measures of system performance in RFID arbitration is total time required to arbitrate a set of devices **12**. Another measure is power consumed by the devices **12** during the process. This is in contrast to the measures of throughput and packet delay in other types of multiaccess systems.

FIG. **4** illustrates one arbitration scheme that can be employed for communication between the interrogator and devices **12**. Generally, the interrogator **26** sends a command causing each device **12** of a potentially large number of responding devices **12** to select a random number from a known range and use it as that device's arbitration number. By transmitting requests for identification to various subsets of the full range of arbitration numbers, and checking for an error-free response, the interrogator **26** determines the arbitration number of every responder station capable of communicating at the same time. Therefore, the interrogator **26** is able to conduct subsequent unterrupted communication with devices **12**, one at a time, by addressing only one device **12**.

Three variables are used: an arbitration value (AVALUE), an arbitration mask (AMASK), and a random value ID (RV). The interrogator sends an Identify command (IdentifyCmnd) causing each device of a potentially large number of responding devices to select a random number from a known range and use it as that device's arbitration number. The interrogator sends an arbitration value (AVALUE) and an arbitration mask (AMASK) to a set of devices **12**. The receiving devices **12** evaluate the following equation: (AMASK & AVALUE)==(AMASK & RV) wherein "&" is a bitwise AND function, and wherein "==" is an equality function. If the equation evaluates to "1" (TRUE), then the device **12** will reply. If the equation evalu-

ates to "0" (FALSE), then the device **12** will not reply. By performing this in a structured manner, with the number of bits in the arbitration mask being increased by one each time, eventually a device **12** will respond with no collisions. Thus, a binary search tree methodology is employed.

An example using actual numbers will now be provided using only four bits, for simplicity, reference being made to FIG. **4**. In one embodiment, sixteen bits are used for AVALUE and AMASK. Other numbers of bits can also be employed depending, for example, on the number of devices **12** expected to be encountered in a particular application, on desired cost points, etc.

Assume, for this example, that there are two devices **12** in the field, one with a random value RV) of 1100 (binary), and another with a random value (RV) of 1010 (binary). The interrogator is tying to establish communications without collisions being caused by the two devices **12** attempting to communicate at the same time.

The interrogator sets AVALUE to 0000 (or "don't care" for all bits, as indicated by the character "X" in FIG. **4**) and AMASK to 0000. The interrogator transmits a command to all devices **12** requesting that they identify themselves. Each of the devices **12** evaluate (AMASK & AVALUE)==(AMASK & RV) using the random value RV that the respective devices **12** selected. If the equation evaluates to "1" (TRUE), then the device **12** will reply. If the equation evaluates to "0" (FALSE), then the device **12** will not reply. In the first level of the illustrated tree, AMASK is 0000 and anything bitwise ANDed with all zeros results in all zeros, so both the devices **12** in the field respond, and there is a collision.

Next, the interrogator sets AMASK to 0001 and AVALUE to 0000 and transmits an Identify command. Both devices **12** in the field have a zero for their least significant bit, and (AMASK & AVALUE)==(AMASK & RV) will be true for both devices **12**. For the device **12** with a random value of 1100, the left side of the equation is evaluated as follows (0001 & 0000)=0000.

The right side is evaluated as (0001 & 1100)=0000. The left side equals the right side, so the equation is true for the device **12** with the random value of 1100. For the device **12** with a random value of 1010, the left side of the equation is evaluated as (0001 & 0000)=0000. The right side is evaluated as (0001 & 1010)=0000. The left side equals the right side, so the equation is true for the device **12** with the random value of 1010. Because the equation is true for both devices **12** in the field, both devices **12** in the field respond, and there is another collision.

Recursively, the interrogator next sets AMASK to 0011 with AVALUE still at 0000 and transmits an Identify command. (AMASK & AVALUE)==(AMASK & RV) is evaluated for both devices **12**. For the device **12** with a random value of 1100, the left side of the equation is evaluated as follows (0011 & 0000)=0000. The right side is evaluated as (0011 & 1100)=0000. The left side equals the right side, so the equation is true for the device **12** with the random value of 1100, so this device **12** responds. For the device **12** with a random value of 1010, the left side of the equation is evaluated as (0011 & 0000)=0000. The right side is evaluated as (0011 & 1010)=0010. The left side does not equal the right side, so the equation is false for the device **12** with the random value of 1010, and this device **12** does not respond; Therefore, there is no collision, and the interrogator can determine the identity (e.g., an identification number) for the device **12** that does respond.

De-recursion takes place, and the devices **12** to the right for the same AMASK level are accessed when AVALUE is set at 0010, and AMASK is set to 0011.

The device **12** with the random value of 1010 receives a command and evaluates the equation (AMASK & AVALUE)==(AMASK & RV). The left side of the equation is evaluated as (0011 & 0010)=0010. The right side of the equation is evaluated as (0011 & 1010)=0010. The right side equals the left side, so the equation is true for the device **12** with the random value of 1010. Because there are no other devices **12** in the subtree, a good reply is returned by the device **12** with the random value of 1010. There is no collision, and the interrogator **26** can determine the identity (e.g., an identification number) for the device **12** that does respond.

By recursion, what is meant is that a function makes a call to itself. In other words, the function calls itself within the body of the function. After the called function returns, de-recursion takes place and execution continues at the place just after the function call; i.e. at the beginning of the statement after the function call.

For instance, consider a function that has four statements (numbered 1,2,3,4) in it, and the second statement is a recursive call. Assume that the fourth statement is a return statement. The first time through the loop (iteration 1) the function executes the statement 2 and (because it is a recursive call) calls itself causing iteration 2 to occur. When iteration 2 gets to statement 2, it calls itself making iteration 3. During execution in iteration 3 of statement 1, assume that the function does a return. The information that was saved on the stack from iteration 2 is loaded and the function resumes execution at statement 3 (in iteration 2), followed by the execution of statement 4 which is also a return statement. Since there are no more statements in the function, the function de-recurses to iteration 1. Iteration 1, had previously recursively called itself in statement 2. Therefore, it now executes statement 3 (in iteration 1). Following that it executes a return at statement 4. Recursion is known in the art.

Consider the following code which can be used to implement operation of the method shown in FIG. **4** and described above.

```
Arbitrate(AMASK, AVALUE)
    {
        collision=IdentifyCmnd(AMASK, AVALUE) if
        (collision) then
        {
            /* recursive call for left side */ Arbitrate
                ((AMASK<<1)+1, AVALUE)
            /* recursive call for right side */ Arbitrate
                ((AMASK<<1)+1, AVALUE+(AMASK+1))
        } /* endif */
}/* return */
```

The symbol "<<" represents a bitwise left shift. "<<" means shift left by one place. Thus, 0001<<1 would be 0010. Note, however, that AMASK is originally called with a value of zero, and 0000<<1 is still 0000. Therefore, for the first recursive call, AMASK=(AMASK<<1)+1. So for the first recursive call, the value of AMASK is 0000+0001=0001. For the second call, AMASK=(0001<<)+1=0010+1=0011. For the third recursive call, AMASK=(0011<<1)+1=0110+1=0111.

The routine generates values for AMASK and AVALUE to be used by the interrogator in an Identify command "IdentifyCmnd." Note that the routine calls itself if there is a collision. De-recursion occurs when there is no collision. AVALUE and AMASK would have values such as the fol-

lowing assuming collisions take place all the way down to the bottom of the tree.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	0111
0000	1111*
1000	1111*
0100	0111
0100	1111*
1100	1111*

This sequence of AMASK, AVALUE binary numbers assumes that there are collisions all the way down to the bottom of the tree, at which point the Identify command sent by the interrogator is finally successful so that no collision occurs. Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "*". Note that if the Identify command was successful at, for example, the third line in the table then the interrogator would stop going down that branch of the tree and start down another, so the sequence would be as shown in the following table.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011*
0010	0011
...	...

This method is referred to as a splitting method. It works by splitting groups of colliding devices **12** into subsets that are resolved in turn. The splitting method can also be viewed as a type of tree search. Each split moves the method one level deeper in the tree. Either depth-first or breadth-first traversals of the tree can be employed. Depth first traversals are performed by using recursion, as is employed in the code listed above. Breadth-first traversals are accomplished by using a queue instead of recursion.

Either depth-first or breadth-first traversals of the tree can be employed. Depth first traversals are performed by using recursion, as is employed in the code listed above. Breadth-first traversals are accomplished by using a queue instead of recursion. The following is an example of code for performing a breadth-first traversal.

```
Arbitrate(AMASK, AVALUE)
    {
        (AMASK,AVALTE)=dequeue( )
        collision=IdentifyCmnd(AMASK, AVALUE)
        if (collision) then
        {
            TEMP = AMASK+1
            NEW__AMASK = (AMASK<<1)+1
            enqueue(NEW__AMASK, AVALUE)
            enqueue(NEW__AMASK, AVALUE+TEMP)
            } /* endif */
endwhile
}/* return */
```

The symbol "!=" means not equal to. AVALUE and AMASK would have values such as those indicated in the following table for such code.

AVALUE	AMASK
0000	0000
0000	0001
0001	0001
0000	0011
0010	0011
0001	0011
0011	0011
0000	0111
0100	0111
...	...

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "*".

FIG. **5** illustrates an embodiment wherein the interrogator **26** retries on the same node that yielded a good reply. The search tree has a plurality of nodes **51**, **52**, **53**, **54** etc. at respective levels **32**, **34**, **36**, **38**, or **40**. The size of subgroups of random values decrease in size by half with each node descended.

The interrogator performs a tree search, either depth-first or breadth-first in a manner such as that described in connection with FIG. **4**, except that if the interrogator determines that no collision occurred in response to an Identify command, the interrogator repeats the command at the same node. This takes advantage of an inherent capability of the devices, particularly if the devices use backscatter communication, called self-arbitration. Arbitration times can be reduced, and battery life for the devices can be increased.

When a single reply is read by the interrogator, for example, in node **52**, the method described in connection with FIG. **4** would involve proceeding to node **53** and then sending another Identify command. Because a device **12** in a field of devices **12** can override weaker devices, this embodiment is modified such that the interrogator retries on the same node **52** after silencing the device **12** that gave the good reply. This, after receiving a good reply from node **52**, the interrogator remains on node **52** and reissues the Identify command after silencing the device that first responded on node **52**. Repeating the Identify command on the same node often yields other good replies, thus taking advantage of the devices natural ability to self-arbitrate.

AVALUE and AMASK would have values such as the following for a depth-first traversal in a situation similar to the one described above in connection with FIG. **4**.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	1111*
0000	1111*
1000	1111*
1000	1111*
0100	0111
0100	1111*
0100	1111*
1100	1111*
1100	1111*

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "*".

In operation, the interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond. The interrogator determines if a collision occurs in response to the command and, if not, repeats the command at the same node.

In one alternative embodiment, the upper bound of the number of devices in the field (the maximum possible number of devices that could communicate with the interrogator) is determined, and the tree search method is started at a level **32**, **34**, **36**, **38** or **40** in the tree depending on the determined upper bound. The level of the search tree on which to start the tree search is selected based on the determined maximum possible number of wireless identification devices that could communicate with the interrogator. The tree search is started at a level determined by taking the base two logarithm of the determined maximum possible number. More particularly, the tree search is started at a level determined by taking the base two logarithm of the power of two nearest the determined maximum possible number of devices **12**. The level of the tree containing all subgroups of random values is considered level zero, and lower levels are numbered 1, 2, 3, 4, etc. consecutively.

Methods involving determining the upper bound on a set of devices and starting at a level in the tree depending on the determined upper bound are described in a commonly assigned **[**patent application (attorney docket MI40-118)**]** *U.S. Pat. No. 6,118,789,* naming Clifton W. Wood, Jr. as an inventor, titled "Method of Addressing Messages and Communications System," **[**filed concurrently herewith, and**]** *which is* incorporated herein by reference.

In one alternative embodiment, a method involving starting at a level in the tree depending on a determined upper bound (such as the method described in the commonly assigned patent application mentioned above) is combined with a method comprising re-trying on the same node that gave a good reply, such as the method shown and described in connection with FIG. **5**.

Another arbitration method that can be employed is referred to as the "Aloha" method. In the Aloha method, every time a device **12** is involved in a collision, it waits a random period of time before retransmitting. This method can be improved by dividing time into equally sized slots and forcing transmissions to be aligned with one of these slots. This is referred to as "slotted Aloha." In operation, the interrogator asks all devices **12** in the field to transmit their identification numbers in the next time slot. If the response is garbled, the interrogator informs the devices **12** that a collision has occurred, and the slotted Aloha scheme is put into action. This means that each device **12** in the field responds within an arbitrary slot determined by a randomly selected value. In other words, in each successive time slot, the devices **12** decide to transmit their identification number with a certain probability.

The Aloha method is based on a system operated by the University of Hawaii. In 1971, the University of Hawaii began operation of a system named Aloha. A communication satellite was used to interconnect several university computers by use of a random access protocol. The system operates as follows. Users or devices transmit at any time they desire. After transmitting, a user listens for an acknowledgment from the receiver or interrogator. Transmissions from different users will sometimes overlap in time (collide), causing reception errors in the data in each of the contending messages. The errors are detected by the receiver, and the receiver sends a negative acknowledgment to the users. When a negative acknowledgment is received, the messages are retransmitted by the colliding users after a random delay. If the colliding users attempted to retransmit without the random delay, they would collide again. If the user does not receive either an acknowledgment or a negative acknowledgment within a certain amount of time, the user "times out" and retransmits the message.

There is a scheme known as slotted Aloha which improves the Aloha scheme by requiring a small amount of coordination among stations. In the slotted Aloha scheme, a sequence of coordination pulses is broadcast to all stations (devices). As is the case with the pure Aloha scheme, packet lengths are constant. Messages are required to be sent in a slot time between synchronization pulses, and can be started only at the beginning of a time slot. This reduces the rate of collisions because only messages transmitted in the same slot can interfere with one another. The retransmission mode of the pure **11** Aloha scheme is modified for slotted Aloha such that if a negative acknowledgment occurs, the device retransmits after a random delay of an integer number of slot times.

Aloha methods are described in a commonly assigned **[**patent application (attorney docket MI40-089)**]** *U.S. Pat. No. 6,275,476,* naming Clifton W. Wood, Jr. as an inventor, titled "Method of Addressing Messages and Communications System," **[**filed concurrently herewith, and**]** *which is* incorporated herein by reference.

In one alternative embodiment, an Aloha method (such as the method described in the commonly assigned patent application mentioned above) is combined with a method involving re-trying on the same node that gave a good reply, such as the method shown and described in connection with FIG. **5**.

In another embodiment, levels of the search tree are skipped. Skipping levels in the tree, after a collision caused by multiple devices **12** responding, reduces the number of subsequent collisions without adding significantly to the number of no replies. In real-time systems, it is desirable to have quick arbitration sessions on a set of devices **12** whose unique identification numbers are unknown. Level skipping reduces the number of collisions, both reducing arbitration time and conserving battery life on a set of devices **12**. In one embodiment, every other level is skipped. In alternative embodiments, more than one level is skipped each time.

The trade off that must be considered in determining how many (if any) levels to skip with each decent down the tree is as follows. Skipping levels reduces the number of collisions, thus saving battery power in the devices **12**. Skipping deeper (skipping more than one level) further reduces the number of collisions. The more levels that are skipped, the greater the reduction in collisions. However, skipping levels results in longer search times because the number of queries (Identify commands) increases. The more levels that are skipped, the longer the search times. Skipping just one level has an almost negligible effect on search time, but drastically reduces the number of collisions. If more than one level is skipped, search time increases substantially. Skipping every other level drastically reduces the number of collisions and saves battery power without significantly increasing the number of queries.

Level skipping methods are described in a commonly assigned **[**patent application (attorney docket MI40-117)**]** *U.S. Pat. No. 6,072,801,* naming Clifton W. Wood, Jr. and Don Hush as inventors, titled "Method of Addressing Messages, Method of Establishing Wireless Communications, and Communications System," **[**filed concurrently herewith, and**]** *which is* incorporated herein by reference.

In one alternative embodiment, a level skipping method is combined with a method involving re-trying on the same node that gave a good reply, such as the method shown and described in connection with FIG. **5**.

In yet another alternative embodiment, any two or more of the methods described in the commonly assigned, concurrently filed, applications mentioned above are combined.

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.

What is claimed is:

[1. A method of establishing wireless communications between an interrogator and wireless identification devices, the method comprising utilizing a tree search technique to establish communications, without collision, between the interrogator and individual ones of the multiple wireless identification devices, the method including using a search tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices, the method further comprising, for a node, transmitting a command, using the interrogator, requesting that devices within the subgroup represented by the node respond, determining with the interrogator if a collision occurred in response to the command and, if not, repeating the command at the same node.**]**

[2. A method in accordance with claim **1** and further comprising, if a collision occurred in response to the first mentioned command, sending a command at a different node, using the interrogator.**]**

[3. A method in accordance with claim **1** wherein when a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, the device that is not within communications range of the interrogator does not respond to the command.**]**

[4. A method in accordance with claim **1** wherein when a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, the device that is within communications range of the interrogator responds to the command.**]**

[5. A method in accordance with claim **1** wherein a device in a subgroup changes between being within communications range of the interrogator and not being within interrogators range, over time.**]**

[6. A method in accordance with claim **1** wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.**]**

[7. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices, the method comprising:

establishing for respective devices unique identification numbers;

causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

transmitting a communication, from the interrogator, requesting devices having random values within a first specified group of random values to respond;

receiving the communication at multiple devices, devices receiving the communication respectively determining if the random value chosen by the device falls within the first specified group and, if so, sending a reply to the interrogator; and

determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a second specified group smaller than the first specified group; and, if not, again transmitting a communication requesting devices having random values within the first specified group of random values to respond.**]**

[8. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance with claim **7** wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.**]**

[9. A method in accordance with claim **7** wherein one of the first and second specified groups contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is not within communications range of the interrogator does not respond to the interrogator.**]**

[10. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance with claim **7** wherein, after receiving a reply without collision from a device, the interrogator sends a communication individually addressed to that device.**]**

[11. A method of addressing messages from a transponder to a selected one or more of a number of communications devices, the method comprising:

establishing unique identification numbers for respective devices;

causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

transmitting a communication from the transponder requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels, the specified group being defined as being at one of the nodes;

receiving the communication at multiple devices, devices receiving the communication respectively determining if the random value chosen by the device falls within the specified group and, if so, sending a reply to the transponder; and, if not, not sending a reply; and

determining using the transponder if a collision occurred between devices that sent a reply and, if so, creating a new, smaller, specified group by descending in the tree; and, if not, transmitting a communication at the same node.**]**

[12. A method of addressing messages from a transponder to a selected one or more of a number of communications devices in accordance with claim **11** wherein establishing unique identification numbers for respective devices comprises establishing a predetermined number of bits to be used for the unique identification numbers.**]**

[13. A method of addressing messages from a transponder to a selected one or more of a number of communications devices in accordance with claim **12** and further including establishing a predetermined number of bits to be used for the random values.**]**

[14. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices, the method comprising:

establishing for respective devices unique identification numbers;

causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

transmitting a command using the interrogator requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the specified group being equal to or less than the entire set of random values, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels;

receiving the command at multiple RFID devices, RFID devices receiving the command respectively determining if their chosen random values fall within the specified group and, only if so, sending a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply;

determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a new, smaller, specified group using a different level of the tree, the interrogator transmitting a command requesting devices having random values within the new specified group of random values to respond; and, if not, the interrogator re-transmitting a command requesting devices having random values within the first mentioned specified group of random values to respond; and

if a reply without collision is received from a device, the interrogator subsequently sending a command individually addressed to that device.]

[15. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **14** wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is not within communications range of the interrogator does not respond to the transmitting of the command or the re-transmitting of the command.]

[16. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **14** wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is within communications range of the interrogator responds to the transmitting of the command and the re-transmitting of the command.]

[17. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **14** wherein a device in the first mentioned specified group is capable of changing between being within communications range of the interrogator and not being within communications range of the interrogator over time.]

[18. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **14** wherein the devices respectively comprise an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.]

[19. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **14** and further comprising, after the interrogator transmits a command requesting devices having random values within the new specified group of random values to respond;

devices receiving the command respectively determining if their chosen random values fall within the new smaller specified group and, if so, sending a reply to the interrogator.]

[20. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim **19** and further comprising, after the interrogator transmits a command requesting devices having random values within the new specified group of random values to respond;

determining if a collision occurred between devices that sent a reply and, if so, creating a new specified group and repeating the transmitting of the command requesting devices having random values within a specified group of random values to respond using different specified groups until all of the devices capable of communicating with the interrogator are identified.]

[21. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator using RF, the interrogator being configured to employ tree searching to attempt to identify individual ones of the multiple wireless identification devices, so as to be able to perform communications without collision between the interrogator and individual ones of the multiple wireless identification devices, the interrogator being configured to follow a search tree, the tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices, the interrogator being configured to transmit a command at a node, requesting that devices within the subgroup represented by the node respond, the interrogator further being configured to determine if a collision occurs in response to the command and, if not, to repeat the command at the same node.]

[22. A communications system in accordance with claim **21** wherein the interrogator is configured to send a command at a different node if a collision occurs in response to the first mentioned command.]

[23. A communications system in accordance with claim **21** wherein a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator.]

[24. A communications system in accordance with claim **21** wherein a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is within communications range of the interrogator responds to the command.]

[25. A communications system in accordance with claim **21** wherein a device in a subgroup is movable relative to the interrogator so as to be capable of changing between being within communications range of the interrogator and not being within communications range.]

[26. A communications system in accordance with claim **21** wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.]

[27. A system comprising:

an interrogator;

a number of communications devices capable of wireless communications with the interrogator;

means for establishing for respective devices unique identification numbers respectively having the first predetermined number of bits;

means for causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

means for causing the interrogator to transmit a command requesting devices having random values within a specified group of random values to respond;

means for causing devices receiving the command to determine if their chosen random values fall within the specified group and, if so, to send a reply to the interrogator; and

means for causing the interrogator to determine if a collision occurred between devices that sent a reply and, if so, to create a new, smaller, specified group; and, if not, transmit a command requesting devices having random values within the same specified group of random values to respond.]

[**28**. A system in accordance with claim **27** wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.]

[**29**. A system in accordance with claim **27** wherein a specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator.]

[**30**. A system in accordance with claim **27** wherein the interrogator further includes means for, after receiving a reply without collision from a device, sending a command individually addressed to that device.]

[**31**. A system comprising:

an interrogator configured to communicate to a selected one or more of a number of communications devices; and

a plurality of communications devices; the devices being configured to select random values, wherein respective devices choose random values independently of random values selected by the other devices; the interrogator being configured to transmit a command requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the specified group being less than the entire set of random values, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels, the specified group being defined as being at one of the nodes; devices receiving the command being configured to respectively determine if their chosen random values fall within the specified group and, only if so, send a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply; the interrogator being configured to determine if a collision occurred between devices that sent a reply and, if so, create a new, smaller, specified group using a different level of the tree, the interrogator being configured to transmit a command requesting devices having random values within the new specified group of random values to respond; and, if not, the interrogator being configured to re-transmit a command requesting devices having random values within the first mentioned specified group of random values to respond.]

[**32**. A system in accordance with claim **31** wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator.]

[**33**. A system in accordance with claim **31** wherein a device in the first mentioned specified group is capable of changing between being within communications range of the interrogator and not being within communications range of the interrogator over time.]

[**34**. A system in accordance with claim **31** wherein the respective devices comprise an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.]

[**35**. A system comprising:

an interrogator configured to communicate to a selected one or more of a number of RFID devices;

a plurality of RFID devices, respective devices being configured to store a unique identification number, respective devices being further configured to store a random value;

the interrogator being configured to transmit a command requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels, the specified group being defined as being at one of the nodes;

devices receiving the command respectively being configured to determine if their chosen random values fall within the specified group and, if so, send a reply to the interrogator; and, if not, not send a reply; and

the interrogator being configured to determine if a collision occurred between devices that sent a reply and, if so, to create a new, smaller, specified group by descending in the tree; and, if not, to transmit a command at the same node.]

[**36**. A system in accordance with claim **35** wherein the unique identification numbers for respective devices are stored in digital form and respectively comprise a predetermined number of bits.]

[**37**. A system in accordance with claim **35** wherein the random values for respective devices are stored in digital form and respectively comprise a predetermined number of bits.]

[**38**. A system in accordance with claim **35** wherein the interrogator is configured to determine if a collision occurred between devices that sent a reply in response to respective Identify commands and, if so, to create further new specified groups and repeat the transmitting of the command requesting devices having random values within a specified group of random values to respond using different specified groups until all responding devices capable of responding are identified.]

39. A method for performing radio frequency communications, the method comprising:

transmitting by an interrogator a first signal, the first signal including a first set of bits to identify a first subgroup of a group of possible random numbers;

receiving by one or more RFID devices the first signal;

communicating by each of the one or more RFID devices a first response if the one or more RFID devices has generated a random number that is included in the first subgroup;

receiving by the interrogator one or more received responses, the one or more received responses being received from respective ones of the one or more RFID devices; and

responsive to receiving one of the one or more received responses without a collision, retransmitting by the interrogator at least the first signal.

40. The method of claim 39, wherein the first signal includes a selection indicator, the selection indicator identifying one or more RFID devices, the communicating by each of the one or more RFID devices only being performed if the selection indicator corresponds to one or more selection bits stored on each respective RFID device.

41. The method of claim 39, further comprising setting, by the one or more RFID devices communicating the first response, an inventoried flag to a first state to indicate that each respective RFID device has responded to the interrogator.

42. The method of claim 39, further comprising transmitting by the interrogator a wake-up signal, the wake-up signal causing an RFID device to transition out of a sleep state.

43. The method of claim 39, wherein the one of the one or more received responses without a collision is received from a first RFID device, and further comprising the interrogator transmitting a command to silence the first RFID device.

44. The method of claim 39, wherein the one of the one or more received responses without a collision is received from a first RFID device and includes at least one random number generated by the first RFID device, and further comprising transmitting by the interrogator at least one additional command to the first RFID device, the first RFID device being identified in the at least one additional command by an identifier including the at least one random number.

45. The method of claim 39, further comprising transmitting by the interrogator a wake up signal.

46. The method of claim 39, further comprising responsive to a collision occurring in the receiving by the interrogator one or more received responses, transmitting by the interrogator a second signal, the second signal including a second set of bits to identify a second subgroup of the group of possible random numbers, wherein the second subgroup is a subgroup of the first subgroup, the second set of bits includes the first set of bits plus one or more additional bits, and the second signal includes the first signal.

47. The method of claim 46, wherein the second subgroup is determined at least in part by skipping one or more levels of a search tree.

48. The method of claim 46, wherein the second set of bits includes the first set of bits plus two or more of the additional bits.

49. The method of claim 39, wherein the first subgroup is based at least in part on a maximum number of possible random numbers.

50. A system for performing radio frequency communications, the system comprising:

a first radio frequency identification (RFID) device configured to generate a random number and to communicate a response, including at least a portion of the random number, upon receiving a request that includes an indication of a subset of possible random numbers if the first RFID device determines that the subset includes the random number generated by the first RFID device;

an antenna positioned in a first region; and

an interrogator coupled to the antenna, the interrogator configured to transmit a signal comprising a portion of an identifier and to receive a reply to the signal from a target RFID device that has generated a random number having a portion equal to the portion of the identifier, the interrogator further configured to re-transmit the signal, including at least the portion of the identifier, if the reply is received without a collision.

51. The system of claim 50, wherein the request includes a selection indicator, the selection indicator identifying one or more RFID devices, the first RFID device being configured to communicate the response only if the selection indicator corresponds to one or more selection bits stored on the first RFID tag.

52. The system of claim 50, wherein the first RFID device is further configured to set an inventoried flag to a first state to indicate that the first RFID device has responded to the at least one interrogator.

53. The system of claim 50, wherein the first RFID device is further configured to communicate the response after receiving a wake-up signal.

54. The system of claim 50, wherein the first RFID device is further configured to communicate a response at a time slot corresponding to a random number generated by the first RFID device.

55. The system of claim 50, wherein the interrogator is further configured to transmit a sleep command upon receiving the reply without a collision.

56. The system of claim 50, wherein the interrogator is further configured to transmit a larger portion of the identifier if the reply is received with a collision.

57. The system of claim 56, wherein a difference between the portion of the identifier and the larger portion of the identifier is two or more bits.

58. An interrogator comprising:

one or more antennas;

a receiver communicatively coupled to at least one of the one or more antennas to receive one or more messages from one or more radio frequency identification (RFID) devices;

a transmitter communicatively coupled to at least one of the one or more antennas to transmit one or more messages; and

a control unit communicatively coupled to the transmitter and the receiver, the control unit configured to implement an algorithm to detect at least a single RFID device in a field of the interrogator, including re-transmitting a first signal responsive to receipt of a first response from the one or more RFID devices without a collision, the first signal including a first set of bits of at least a first portion of possible random numbers that may be generated by the one or more RFID devices, and the first response including at least a second portion of a random number generated by the one or more RFID devices.

59. The interrogator of claim 58, wherein the first signal includes a selection indicator, the selection indicator corresponding to one or more selection bits stored on the one or more RFID devices.

60. The interrogator of claim 58, wherein the control unit is further configured to transmit a command to silence the one or more RFID devices from which the first response was received without a collision, and the control unit is further configured to indicate a number of time slots from which at least a first RFID device is to randomly select a time slot in which to communicate a random value generated by the first RFID device.

61. The interrogator of claim 58, wherein the control unit is further configured to define a second set of bits of at least a second portion, greater than the first portion, of possible random numbers responsive to a collision detected in the receipt of the first response from the one or more RFID devices.

62. The interrogator of claim 61, wherein the control unit is further configured to define the second set of bits to be at least two bits greater than the first portion.

63. The interrogator of claim 58, wherein the possible random numbers define a binary search tree, the first set of bits define a level in the search tree, and the control unit is further configured to skip one or more intermediate levels in the binary search tree to implement the algorithm.

64. The interrogator of claim 58, wherein the control unit is further configured to transmit a wake-up signal, indicate a number of time slots, and receive a random value from a first RFID device in a time slot randomly determined by the first RFID device from among the number of time slots.

65. A method comprising:

providing an interrogator to generate an RF field and to initiate the implementation of an algorithm to detect at least a single target RFID device out of potentially multiple target RFID devices in the RF field, the algorithm including:

defining a first subgroup of possible random numbers that may be generated by the target device, the first subgroup being defined by a first set of bits common to the first subgroup;

transmitting a signal comprising at least the first set of bits to identify the first subgroup of possible random numbers and requesting the target device to respond if the target device has generated a random number included in the subgroup;

receiving a response from the target device if the target device has generated the random number included in the subgroup;

if no collision is detected in the receiving of the response from the target device, determining, from the response, the random number generated by the target device and retransmitting the signal; and

if a collision is detected in the receiving of the response from the target device, defining a second subgroup of possible random numbers that may be generated by the target device, the second subgroup being a subset of the first subgroup and being defined by a second set of bits common to the second subgroup, and retransmitting the signal.

66. The method of claim 65, wherein the signal includes a selection indicator that identifies a class of one or more of a plurality of RFID devices from which a response is being requested.

67. The method of claim 65, wherein the algorithm further includes transmitting a command to silence the target device after the determining of the random number generated by the target device.

68. The method of claim 65, wherein the algorithm further includes transmitting a number of time slots from which at least a first RFID device is to randomly select a time slot in which to communicate a random value generated by the first RFID device.

69. The method of claim 65, wherein the algorithm further comprises transmitting a number of time slots, and receiving a random value from a first RFID device in a time slot randomly determined by the first RFID device from among the number of time slots.

70. The method of claim 65, wherein the second set of bits includes the first set of bits and the algorithm further comprises transmitting the second set of bits if the collision is detected in the receiving of the response from the target device.

71. The method of claim 70, wherein the algorithm accommodates the second set of bits being two or more bits longer than the first set of bits.

72. A method, comprising:

receiving a first signal from an interrogator in accordance with an algorithm to identify a radio frequency identification (RFID) device in a field of the interrogator, the first signal comprising a first set of bits and requesting a response from one or more RFID devices in the field selected in accordance with at least the first set of bits;

responsive to receiving the first signal, determining if the first set of bits is equal to a first portion of a random number generated by the RFID device, and, if so, modulating an RF field, provided by the interrogator, to communicate a reply to the interrogator in accordance with the algorithm; and

receiving, in accordance with the algorithm, a retransmission of the first signal from the interrogator in response to the interrogator receiving the reply without detecting a collision.

73. The method of claim 72, further comprising communicating with the interrogator in one of a first communication mode and a second communication mode determined by the interrogator, wherein in accordance with the first communication mode the RFID device modulates an RF field generated by the RFID device and in accordance with the second communication mode the RFID device modulates an RF field generated by the interrogator.

74. The method of claim 73, further comprising communicating with the interrogator at one of a plurality of bit rates determined by the interrogator.

75. The method of claim 72, further comprising receiving a wake up command from the interrogator and, in response, transitioning from a sleep state.

76. The method of claim 75, further comprising receiving a sleep command from the interrogator.

77. The method of claim 76, wherein the sleep command is received in response to the interrogator receiving the reply without detecting a collision, in accordance with the algorithm, before the receiving of the retransmission of the first signal.

78. The method of claim 72, wherein the reply comprises a random value generated by the RFID device.

79. The method of claim 78, wherein the random number comprises the random value.

80. The method of claim 79, wherein the random value is the random number.

81. The method of claim 72, further comprising

receiving, in accordance with the algorithm, a second signal from the interrogator in response to the interrogator detecting a collision in the reply, the second signal comprising a second set of bits and requesting a response from one or more RFID devices in the field selected in accordance with at least the second set of bits; and

responsive to receiving the second signal, determining if the second set of bits is equal to a second portion of the random number generated by the RFID device, and, if so, modulating the RF field to communicate a second reply to the interrogator in accordance with the algorithm, wherein the second signal comprises the first signal, the second set of bits comprises the first set of bits plus at least two additional bits, and the second portion of the random number comprises the first portion of the random number.

82. The method of claim 81, wherein the second reply comprises at least a portion of the random number.

83. The method of claim 82, further comprising communicating a random value to the interrogator during a time slot randomly selected from a number of time slots.

84. The method of claim 72, further comprising communicating a random value to the interrogator during a time slot randomly selected from a number of time slots.

85. A system, comprising:

a radio frequency identification (RFID) device comprising a receiver to receive a first command including a portion of an identification number, a random number generator to generate a random number to identify the device, and a transmitter to communicate a reply to the first command if the portion of the identification number is equal to a first portion of the random number; and

an interrogator configured to implement an algorithm to identify one or more RFID devices in a field of the interrogator, the algorithm comprising transmitting a first signal with a first set of bits to request a response from a selected one or more devices, receiving a first response thereto from the selected one or more devices, detecting if a collision occurred in the first response, and retransmitting the first signal with at least the first set of bits to request a second response from at least one of the selected one or more devices in response to detecting no collision in the first response.

86. The system of claim 85, further comprising memory storing a unique identification code to be transmitted by the system.

87. The system of claim 85, wherein the transmitter is configured to communicate by modulating an RF field provided by a remote device.

88. The system of claim 87, wherein the algorithm further comprises transmitting an indication of the number of bits of the first set of bits.

89. The system of claim 85, wherein retransmitting the first signal with at least the first set of bits comprises retransmitting the first signal with no more than the first set of bits.

90. The system of claim 85, wherein the system is configured to communicate at one of a plurality of bit rates determined by a remote device.

91. The system of claim 90, wherein the system is configured to operate in a first communication mode during a first period of time and in a second communication mode during a second period of time, wherein in accordance with the first communication mode the system is configured to modulate an RF field generated by the remote device and in accordance with the second communication mode the system is configured to generate and modulate an RF field.

92. The system of claim 85, wherein the RFID device is configured to receive a signal to silence the RFID device.

93. The system of claim 92, wherein the RFID device is configured to receive a wake up command and, in response, to transition from a sleep state.

94. The system of claim 85, wherein the algorithm further comprises transmitting a signal to silence at least one of the one or more RFID devices in response to the detecting no collision and before the retransmitting of the first signal.

95. The system of claim 85, wherein the replay comprises at least a second portion of the random number that is not part of the first portion of the random number.

96. The system of claim 95, wherein the interrogator is further configured to use the first response to determine a random value generated by the selected one or more devices in accordance with the algorithm.

97. The system of claim 85, wherein the algorithm further comprises transmitting a second signal from the interrogator in response to detecting a collision in the first response, the second signal comprising a second set of bits and requesting a response from at least one of the one or more RFID devices in the field selected in accordance with at least the second set of bits, wherein the second set of bits includes the first set of bits plus at least one additional bit.

98. The system of claim 97, wherein the interrogator is configured to generate, as part of the algorithm, the second set of bits including the first set of bits plus at least two additional bits.

99. The system of claim 85, wherein the RFID device is configured to communicate a random value during a first time slot randomly selected from a first number of time slots.

100. The system of claim 99, wherein the transmitter is configured to communicate by modulating an RF field provided by a remote device.

101. The system of claim 100, wherein the random value identifies the device to the remote device.

102. The system of claim 101, wherein the RFID device is further configured to communicate the random value to the remote device during a second time slot randomly selected from a second number of time slots, wherein the first number of time slots is different from the second number of time slots and is indicated by the remote device.

103. The system of claim 102, wherein the algorithm further comprises transmitting a second signal from the interrogator in response to detecting a collision in the first response, the second signal comprising a second set of bits and requesting a response from at least one of the one or more RFID devices in the field selected in accordance with at least the second set of bits, wherein, in accordance with the algorithm, the second set of bits include at least two bits in addition to the first set of bits.

104. An apparatus for wirelessly reading radio frequency identification (RFID) devices, comprising:

a transmitter to transmit a command along with a first portion of a set of random numbers to request a response from at least one RFID device that has generated a random number in the set;

an antenna to provide an RF field to be modulated by the device;

a receiver to receive the response; and

processing circuitry to perform collision detection, to determine the random number using the response, and to cause the transmitter to retransmit the command along with at least the first portion of the set of random numbers responsive to detecting no collision in the response.

105. The apparatus of claim 104, wherein the transmitter is configured to transmit the command along with an indication of the number of bits on the first portion.

106. The apparatus of claim 105, wherein the transmitter is configured to communicate with the RFID device at one of a plurality of bit rates determined by the apparatus.

107. The apparatus of claim 104, wherein the processing circuitry is configured to cause the transmitter to retransmit the command along with no more than the first portion of the set of random numbers responsive to the detecting.

108. The apparatus of claim 104, wherein the processing circuitry is configured to cause the transmitter to transmit a signal addressed to the RFID device responsive to receiving the response without collision.

109. The apparatus of claim 108, wherein the signal is configured to silence the RFID device.

110. The apparatus of claim 109, wherein the processing circuitry is configured to cause the transmitter to transmit the signal to silence the RFID device before causing the transmitter to retransmit the command.

111. The apparatus of claim 104, wherein the transmitter is configured to transmit a wake up command to transition the RFID device from a sleep state.

112. The apparatus of claim 104, wherein the response comprises at least a second portion of the random number that is not part of the first portion.

113. The apparatus of claim 112, wherein the processing circuitry is configured to determine a unique identification code stored in the RFID device in addition to the random number.

114. The apparatus of claim 104, wherein the processing circuitry is configured to specify a second portion of the set of random numbers in response to detecting a collision in the response, the second portion being a subset of the first portion.

115. The apparatus of claim 114, wherein the processing circuitry is further configured to enable the second portion to be less than half of the first portion.

116. The apparatus of claim 115, wherein the receiver is to receive a reply from one or more RFID devices in one of a number of time slots indicated by the apparatus to the one or more RFID devices.

117. The apparatus of claim 116, wherein the reply comprises a random value generated by the one or more RFID devices.

118. The apparatus of claim 104, wherein the processing circuitry if further configured to cause the transmitter to transmit a signal to indicate a number of time slots in which one or more RFID devices responds to the apparatus with a reply.

119. The apparatus of claim 118, wherein the reply comprises a random value generated by the one or more RFID devices.

120. The apparatus of claim 119, wherein the one or more RFID devices comprises the RFID device and the random value is equal to the random number.

121. The apparatus of claim 104, wherein the random number identifies the device to the apparatus.

122. A radio frequency identification (RFID) reader, comprising:

a transmitter to transmit at least a first portion of an identifier along with an indication of a first number of bits in the first portion, and to request a first response from an RFID device that has generated a first portion of a random number equal to the first portion of the identifier;

a receiver to receive the first response from the device; and

a processing circuit coupled to the transmitter and receiver to implement an algorithm to detect at least one from among potentially multiple RFID devices, wherein in accordance with the algorithm the processing circuit is to perform collision detection on the first response and, in response to detecting no collision, to retransmit, via the transmitter, the at least first portion of the identifier and to request a second response thereto.

123. The reader of claim 122, wherein the processing circuit is configured to determine the random number using the first response.

124. The reader of claim 123, wherein the transmitter is configured to provide an RF field to be modulated by the RFID device to communicate the first response.

125. The reader of claim 122, wherein in accordance with the algorithm the processing circuit is to retransmit no more than the first portion of the identifier.

126. The reader of claim 122, wherein the transmitter is configured to communicate at a first bit rate during a first period of time, and at a second bit rate during a second period of time.

127. The reader of claim 122, wherein the reader is configured to operate in a first communication mode during a first period of time and in a second communication mode during a second period of time, wherein in accordance with the first communication mode the receiver is configured to receive a remotely generated and remotely modulated RF field and in accordance with the second communication mode the receiver is configured to receive an RF field locally generated by the transmitter and remotely modulated.

128. The reader of claim 122, wherein the transmitter is configured to transmit a signal to silence the RFID device and to transmit a wake up command to transition the RFID device from a sleep state.

129. The reader of claim 122, wherein in accordance with the algorithm the processing circuit is to transmit, via the transmitter, a signal to silence the RFID device in response to the detecting no collision and before retransmitting the first portion.

130. The reader of claim 122, wherein in accordance with the algorithm the processing circuit is to transmit a second portion of the identifier along with an indication of a second number of bits in the second portion in response to detecting a collision on the first response, wherein the second portion includes the first portion.

131. The reader of claim 130, wherein in accordance with the algorithm the second number of bits is greater than the first number of bits by at least two bits.

132. The reader of claim 131, wherein the receiver is to receive the first response comprising at least a second portion of the random number that is not part of the first portion of the random number.

133. The reader of claim 122, wherein the transmitter is configured to transmit an indication of a first number of time slots from which one or more RFID devices are to randomly select a first time slot in which to communicate a random value identifier to the reader.

134. The reader of claim 133, wherein the transmitter is further configured to transmit an indication of a second number of time slots, different from the first number of time slots, responsive to collision detection by the processing circuit.

135. The reader of claim 134, wherein the processing circuit is to transmit a second portion of the identifier along with an indication of a second number of bits in the second portion in response to detecting a collision on the first response, wherein the second portion includes the first portion and the processing circuit supports the second number of bits being greater than the first number of bits by at least two bits.

136. A system, comprising:

an RFID target device to receive a portion of an identifier, to compare the portion of the identifier to a portion of a random value generated by the target device, and to communicate a reply value if the portion of the identifier is equal to the portion of the random value; and

an RFID initiating device to initiate communication with one or more RFID target devices, the initiating device to transmit a first request including a first command and first information, to receive a first response to the first request from each of one or more RFID target devices that has generated a respective random number that is included in a first subgroup of one or more of a group of possible random numbers indicated by the first information, to perform collision detection on the first response, and to transmit a second request including a retransmission of at least the first command and the first information responsive to detecting no collision.

137. The system of claim 136, wherein the target and initiating devices are to implement a time slot method in accordance with a protocol with which the target and initiating devices are compliant.

138. The system of claim 137, wherein the target device is to modulate an RF field provided by a remote device to communicate the reply.

139. The system of claim 138, wherein the system is to operate in a selectable one of a first communication mode and a second communication mode in accordance with the

protocol, wherein in accordance with the first communication mode the target device is to communicate by modulating a remotely generated RF field and in accordance with the second communication mode the target device is to generate an RF field.

140. The system of claim 139, wherein the target and initiating devices are to communicate at a selectable one of a plurality of bit rates in accordance with the protocol.

141. The system of claim 140, wherein the target device is to transition from a sleep state upon receiving a wake up command.

142. The system of claim 136, further comprising memory storing a unique identification code, separate from the random value and random number, to be transmitted by the system.

143. The system of claim 136, wherein the target device is to modulate an RF field provided by a remote device to communicate the reply.

144. The system of claim 136, wherein the initiating device is to transmit a signal to silence the one or more target devices.

145. The system of claim 144, wherein the initiating device is to transmit the signal in response to the detecting no collision before transmitting the second request.

146. The system of claim 136, wherein the random value comprises the reply value.

147. The system of claim 146, wherein the random number comprises the first response.

148. The system of claim 136, wherein the target device is to implement a slotted aloha algorithm in which the target device is to communicate an identifier, randomly generated by the target device, in a randomly selected time slot of a number of time slots indicated to the target device.

149. The system of claim 148, further comprising memory storing a unique identification code, separate from the random value, to be transmitted by the target device.

150. The system of claim 149, wherein the target device is to modulate a remotely generated RF field to communicate the reply.

151. The system of claim 136, wherein the initiating device is to transmit a third request, including a retransmission of at least the first command and the first information responsive to detecting a collision in the first response, wherein the third request indicates a second subgroup that is a subset of the first subgroup.

152. The system of claim 151, wherein the second subgroup is less than half of the first subgroup in accordance with a protocol with which the target and initiating devices are compliant.

153. The system of claim 152, wherein the target device is to implement a slotted aloha algorithm in which the target device is to communicate an identifier, randomly generated by the target device, in a randomly selected time slot of a number of time slots.

154. The system of claim 153, wherein the initiating device is to transmit a signal to indicate a number of time slots in which the initiating device is to receive a response.

155. The system of claim 136, wherein the one or more target devices comprises the target device.

156. The system of claim 136, wherein the first request includes a mask to identify a common portion of random numbers included in the first subgroup.

157. A radio frequency identification (RFID) device, comprising:

a random number generator to generate a first random number identifier;

a receiver coupled to an antenna to receive a transmission of a first set of bits from a reader in accordance with an algorithm to enable the reader to determine the first identifier;

processing circuitry to compare the first set of bits to a first portion of the first identifier; and

a modulating circuit to modulate an RF field produced by the reader to communicate a second set of bits to the reader if the first set of bits is equal to the first portion of the first identifier, wherein the first identifier comprises the second set of bits, and wherein in accordance with the algorithm the receiver is to further receive a retransmission of at least the first set of bits from the reader if the reader receives the second set of bits without collision.

158. The device of claim 157, wherein the second set of bits comprises the first set of bits.

159. The device of claim 157, wherein the random number generator is to generate a second random number identifier and a random value, wherein the random value is to be used to select a slot in which to communicate the second identifier in accordance with a time slot method.

160. The device of claim 157, wherein the modulating circuit is to operate in an alternate communication mode in which the modulating circuit is to modulate an RF field produced by the device itself.

161. The device of claim 157, wherein the modulating circuit is to communicate at one of a plurality of selectable bit rates.

162. The device of claim 161, wherein the receiver is receive a wake up command from the reader to transition the device from a sleep state.

163. The device of claim 157, wherein the processing circuitry is to implement a slotted aloha algorithm.

164. The device of claim 163, further comprising memory storing a unique identification code, separate from the first identifier, to be wirelessly communicated.

165. The device of claim 157, further comprising memory storing a unique identification code, separate from the first identifier, to be wirelessly communicated to a reader.

166. The device of claim 157, wherein in accordance with the algorithm the receiver is to receive a signal from the reader addressed to the device responsive to the reader receiving the second set of bits without collision.

167. The device of claim 166, wherein the signal is to silence the device.

168. The device of claim 167, wherein in accordance with the algorithm the signal is to be received by the receiver before the retransmission of the at least first set of bits.

169. The device of claim 157, wherein the receiver is to receive a retransmission of the first set of bits along with additional bits from the reader for comparison to at least a second portion of the first identifier in accordance with the algorithm if the reader detects a collision upon receiving the second set of bits, wherein in accordance with the algorithm, the additional bits are at least two bits.

170. The device of claim 169, wherein the modulating circuit is to communicate a second random number identifier in a randomly selected time slot of a number of time slots.

171. The device of claim 157, wherein the receiver is to receive an indication of a first number of time slots from which the device is to randomly select a first time slot in which to communicate a second random number identifier and to receive an indication of a second number of time slots, different from the first number of time slots.

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