US00RE42344E

(19) **United States**

(12) **Reissued Patent**

Wood, Jr. et al.

(10) **Patent Number: US RE42,344 E**

(45) **Date of Reissued Patent: May 10, 2011**

(54) **METHOD AND APPARATUS TO MANAGE RFID TAGS**

(75) Inventors: **Clifton W. Wood, Jr.**, Tulsa, OK (US); **Don Hush**, Los Almos, NM (US)

(73) Assignee: **Round Rock Research, LLC**, Mount Kisco, NY (US)

(21) Appl. No.: **10/693,697**

(22) Filed: **Oct. 23, 2003**

(Under 37 CFR 1.47)

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **6,307,848**
Issued: **Oct. 23, 2001**
Appl. No.: **09/773,461**
Filed: **Jan. 31, 2001**

U.S. Applications:

(63) Continuation of application No. 09/551,304, filed on Apr. 18, 2000, now Pat. No. 6,226,300, which is a continuation of application No. 09/026,045, filed on Feb. 19, 1998, now Pat. No. 6,072,801.

(51) **Int. Cl.**
H04J 1/16 (2006.01)
H04L 12/56

(52) **U.S. Cl.** **370/329**; 370/437; 370/462; 340/10.1

(58) **Field of Classification Search** 370/329, 370/437, 462; 340/10.1
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,075,632 A 2/1978 Baldwin et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0 779 520 9/1997

(Continued)

OTHER PUBLICATIONS

Transaction History of related U.S. Appl. No. 11/700,525, filed Jan. 30, 2007, entitled "Systems and Methods for RFID Tag Arbitration."

(Continued)

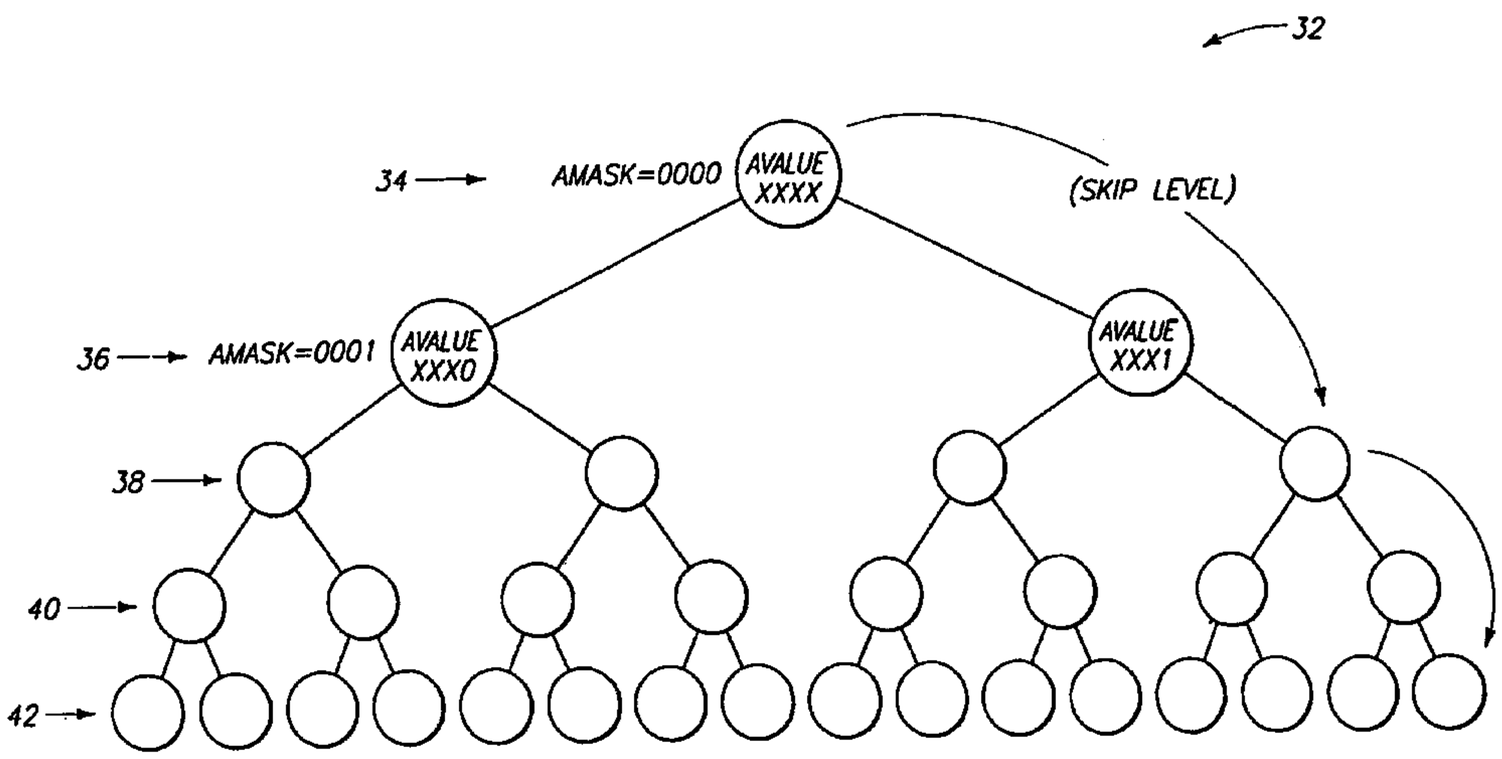
Primary Examiner—John Pezzlo

(74) *Attorney, Agent, or Firm*—Gazdzinski & Associates, PC

(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 establish 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 levels representing subgroups of the multiple wireless identification devices, the number of devices in a subgroup in one level being half of the number of devices in the next higher level, the tree search method employing level skipping wherein at least one level of the tree is skipped. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion, the respective wireless identification devices having a unique identification number, the interrogator being configured to employ a tree search technique to determine the unique identification numbers of the different wireless identification devices so as to be able to establish communications between the interrogator and individual ones of the multiple wireless identification devices without collision by multiple wireless identification devices attempting to respond to the interrogator at the same time, wherein levels of the tree are occasionally skipped.] *RFID tags are managed by an interrogator. In one embodiment, the interrogator sends a first command indicating a first value and a first memory range, and a second command indicating second value and a second memory range. The first memory range differs from the second memory range by at least two bits. RFID tags compare the first and second values to corresponding values stored in the tags to determine if the tags are selected. Selected tags may respond to the interrogator with independently generated random numbers.*

58 Claims, 3 Drawing Sheets



U.S. PATENT DOCUMENTS

4,761,778	A	8/1988	Hui	370/46
4,796,023	A	1/1989	King	
4,799,059	A	1/1989	Grindahl et al.	340/870.03
4,845,504	A	7/1989	Roberts et al.	342/457
4,862,453	A	8/1989	West et al.	
4,926,182	A	5/1990	Ohta et al.	
4,955,018	A	9/1990	Twitty et al.	370/85.1
4,969,146	A	11/1990	Twitty et al.	370/85.1
5,019,813	A	5/1991	Kip et al.	340/825.54
5,025,486	A	6/1991	Klughart	455/54
5,046,066	A	9/1991	Messenger	370/94.1
5,055,968	A	10/1991	Nishi et al.	361/737
5,121,407	A	6/1992	Partyka et al.	375/206
5,124,697	A	6/1992	Moore	340/825.53
5,142,694	A	8/1992	Jackson et al.	340/825.5
5,144,313	A	9/1992	Kirknes	342/42
5,144,668	A	9/1992	Malek et al.	380/48
5,150,114	A	9/1992	Johansson	340/825.08
5,150,310	A	9/1992	Greenspun et al.	364/516
5,164,985	A	11/1992	Nysen et al.	380/271
5,168,510	A	12/1992	Hill	375/40
5,194,860	A	3/1993	Jones et al.	340/370
5,231,646	A	7/1993	Heath et al.	375/1
5,266,925	A	11/1993	Vercellotti et al.	340/572
5,307,463	A	4/1994	Hyatt et al.	395/275
5,365,551	A	11/1994	Snodgrass et al.	
5,373,503	A	12/1994	Chen	370/95.2
5,449,296	A	9/1995	Jacobsen et al.	
5,461,627	A	10/1995	Rypinski	
5,479,416	A	12/1995	Snodgrass et al.	
5,500,650	A	3/1996	Snodgrass et al.	
5,530,702	A	6/1996	Palmer et al.	
5,550,547	A	8/1996	Chan et al.	
5,583,850	A	12/1996	Snodgrass et al.	
5,608,739	A	3/1997	Snodgrass et al.	
5,619,648	A	4/1997	Canale et al.	709/206
5,621,412	A	4/1997	Sharpe et al.	
5,625,628	A	4/1997	Heath	
5,627,544	A	5/1997	Snodgrass et al.	
5,640,151	A	6/1997	Reis et al.	340/10.2
5,649,296	A	7/1997	MacLellan et al.	
5,686,902	A	11/1997	Reis et al.	
5,790,946	A	8/1998	Rotzoll	455/343
5,805,586	A	9/1998	Perreault et al.	370/346
5,841,770	A	11/1998	Snodgrass et al.	370/449
5,914,671	A	6/1999	Tuttle	340/10.42
5,936,560	A	8/1999	Higuchi	
5,940,006	A	8/1999	MacLellan et al.	340/10.1
5,942,987	A	8/1999	Heinrich et al.	340/10.42
5,952,922	A	9/1999	Shober	340/572.4
5,966,471	A	10/1999	Fisher et al.	
5,974,078	A	10/1999	Tuttle et al.	375/200
5,988,510	A	11/1999	Tuttle et al.	235/492
6,038,455	A	3/2000	Gardner et al.	455/447
6,061,344	A	5/2000	Wood, Jr.	
6,072,801	A	6/2000	Wood, Jr. et al.	
6,075,973	A	6/2000	Greeff et al.	455/38.2
6,097,292	A	8/2000	Kelly et al.	
6,104,333	A	8/2000	Wood, Jr.	
6,118,789	A	9/2000	Wood, Jr.	
6,130,602	A	10/2000	O'Toole et al.	340/10.33
6,130,623	A	10/2000	MacLellan et al.	
6,150,921	A	11/2000	Werb et al.	
6,157,633	A	12/2000	Wright	370/349
6,169,474	B1	1/2001	Greeff et al.	340/10.1
6,177,858	B1	1/2001	Raimbault et al.	
6,185,307	B1	2/2001	Johnson, Jr.	
6,192,222	B1	2/2001	Greeff et al.	455/38.2
6,216,132	B1	4/2001	Chandra et al.	707/103 R
6,226,300	B1	5/2001	Hush et al.	
6,229,987	B1	5/2001	Greeff et al.	455/38.2
6,243,012	B1	6/2001	Shober et al.	
6,265,962	B1	7/2001	Black et al.	
6,265,963	B1	7/2001	Wood, Jr.	
6,275,476	B1	8/2001	Wood, Jr.	
6,282,186	B1	8/2001	Wood, Jr.	
6,288,629	B1	9/2001	Cofino et al.	
6,289,209	B1	9/2001	Wood, Jr.	455/277.1
6,307,847	B1	10/2001	Wood, Jr.	
6,307,848	B1	10/2001	Wood, Jr.	370/329
6,324,211	B1	11/2001	Ovard et al.	375/219
6,415,439	B1	7/2002	Randell et al.	
6,459,726	B1	10/2002	Ovard et al.	375/219
6,483,427	B1	11/2002	Werb	
6,566,997	B1	5/2003	Bradin	340/10.2
6,570,487	B1	5/2003	Steeves	
6,707,376	B1	3/2004	Patterson et al.	340/10.3
6,714,559	B1	3/2004	Meier	
6,771,634	B1	8/2004	Wright	370/349
6,778,096	B1	8/2004	Ward et al.	
6,784,787	B1	8/2004	Atkins	
6,850,510	B2	2/2005	Kubler et al.	
6,919,793	B2	7/2005	Heinrich et al.	
6,947,513	B2 *	9/2005	O'Toole et al.	375/374
7,026,935	B2	4/2006	Diorio et al.	340/572.2
7,315,522	B2	1/2008	Wood, Jr.	
7,385,477	B2	6/2008	O'Toole et al.	
7,672,260	B2	3/2010	Wood, Jr.	
2003/0235184	A1	12/2003	Dorenbosch	
2005/0060069	A1	3/2005	Breed et al.	
2005/0207364	A1	9/2005	Wood, Jr.	
2006/0022800	A1	2/2006	Krishna et al.	340/10.2
2006/0022801	A1	2/2006	Husak et al.	340/10.5
2006/0022815	A1	2/2006	Fischer et al.	340/505
2006/0056325	A1	3/2006	Wood, Jr.	
2006/0209781	A1	9/2006	Wood, Jr.	
2007/0139164	A1	6/2007	O'Toole et al.	
2007/0176751	A1	8/2007	Cesar et al.	
2008/0007412	A1	1/2008	Wood, Jr.	
2008/0042806	A1	2/2008	Wood, Jr.	
2008/0048832	A1	2/2008	O'Toole et al.	
2008/0048835	A1	2/2008	O'Toole et al.	
2008/0180221	A1	7/2008	Tuttle	
2009/0322491	A1	12/2009	Wood, Jr.	

FOREIGN PATENT DOCUMENTS

EP	1072128	5/2008
JP	9054213	2/1997
JP	2002228809	8/2002
WO	WO 97/48216	12/1997
WO	1999043127	8/1999
WO	2008094728	8/2008

OTHER PUBLICATIONS

Transaction History of related U.S. Appl. No. 11/755,073, filed May 30, 2007, entitled "Methods and Systems of Receiving Data Payload of RFID Tags."

USPTO Transaction History of related U.S. Appl. No. 12/493,542, filed Jun. 29, 2009, entitled "Method of Addressing Messages, Method and Communications System."

USPTO Transaction History of related U.S. Appl. No. 12/541,882, filed Aug. 14, 2009, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of related U.S. Appl. No. 12/556,530, filed Sep. 9, 2009, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of related U.S. Appl. No. 12/604,329, filed Oct. 22, 2009, entitled "Method of Addressing Messages, Method of Establishing Wireless Communications and Communications System."

Wood, Jr., Clifton W., U.S. Appl. No. 12/541,882, filed Aug. 14, 2009.

Wood, Jr., Clifton W., U.S. Appl. No. 11/865,580, filed Oct. 1, 2007.

Wood, Jr., Clifton W., U.S. Appl. No. 11/865,584, filed Oct. 1, 2007.

Wood, Jr., Clifton W., U.S. Appl. No. 10/652,573, filed Aug. 28, 2008.

Wood, Jr., Clifton W., U.S. Appl. No. 11/862,121, filed Sep. 26, 2007.

International Application No. PCT/US08/50630, Written Opinion, Jun. 27, 2008.

International Application No. PCT/US08/50630, International Search Report, Jun. 27, 2008.

Tuttle, John R., U.S. Appl. No. 11/755,073 entitled "Methods and Systems of Receiving Data Payload of RFID Tags," filed May 30, 2007.

International Application No. PCT/US99/02288, Written Opinion, Jan. 27, 2000.

Wood, Jr., Clifton W., U.S. Appl. No. 10/693,696, filed Oct. 23, 2003.

International Application No. PCT/US99/02288, International Search Report, Aug. 3, 1999.

Wood, Jr., Clifton W., U.S. Appl. No. 11/859,360, filed Sep. 21, 2007.

Wood, Jr., Clifton W., U.S. Appl. No. 11/859,364, filed Sep. 21, 2007.

Wood, Jr., Clifton W., U.S. Appl. No. 11/862,124, filed Sep. 26, 2007.

Wood, Jr., Clifton W., U.S. Appl. No. 11/862,130, filed Sep. 21, 2007.

USPTO Transaction History of U.S. Appl. No. 09/026,043, filed Feb. 19, 1998, entitled "Method of Addressing Messages and Communications System," now U.S. Patent No. 6,118,789.

USPTO Transaction History of U.S. Appl. No. 09/026,045, filed Feb. 19, 1998, entitled "Method of Addressing Messages, Methods of Establishing Wireless Communications, and Communications System," now U.S. Patent No. 6,072,801.

USPTO Transaction History of U.S. Appl. No. 09/026,050, filed Feb. 19, 1998, entitled "Method of Addressing Messages and Communications System," now U.S. Patent No. 6,061,344.

USPTO Transaction History of U.S. Appl. No. 09/026,248, filed Feb. 19, 1998, entitled "Method of Addressing Messages and Communications System," now U.S. Patent No. 6,275,476.

USPTO Transaction History of U.S. Appl. No. 09/551,304, filed Apr. 18, 2000, entitled "Method of Addressing Messages and Communications Systems," now U.S. Patent No. 6,282,186.

USPTO Transaction History of U.S. Appl. No. 09/556,235, filed Apr. 18, 2000, entitled "Method of Addresssing Messages, and Establishing Communications Using a Tree Search Technique That Skips Levels," now U.S. Patent No. 6,226,300.

USPTO Transaction History of U.S. Appl. No. 09/617,390, filed Jul. 17, 2000, entitled "Method of Addressing Messages and Communications System," now U.S. Patent No. 6,307,847.

USPTO Transaction History of U.S. Appl. No. 09/773,461, filed Jan. 31, 2001, entitled "Method of Addressing Messages, Methods of Establishing Wireless Communications, and Communications System," now U.S. Patent No. 6,307,848.

USPTO Transaction History of U.S. Appl. No. 09/820,467, filed Mar. 28, 2001, "Method of Addressing Messages and Communications System," now U.S. Patent No. 7,315,522.

USPTO Transaction History of U.S. Appl. No. 10/652,573, filed Aug. 28, 2003, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 10/693,696, filed Oct. 23, 2003, entitled "Method and Apparatus to Select Radio Frequency Identification Devices in Accordance with an Arbitration Scheme."

USPTO Transaction History of U.S. Appl. No. 11/143,395, filed Jun. 1, 2005, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/270,204, filed Nov. 8, 2005, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/416,846, filed May 2, 2006, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/855,855, filed Sep. 14, 2007, entitled "Method of Addressing Messages and communications System."

USPTO Transaction History of U.S. Appl. No. 11/855,860, filed Sep. 14, 2007, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/859,360, filed Sep. 21, 2007, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/859,364, filed Sep. 21, 2007, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/862,121, filed Sep. 26, 2007, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/862,124, filed Sep. 26, 2007, entitled "Method of Addressing Messages and Communications."

USPTO Transaction History of U.S. Appl. No. 11/862,130, filed Sep. 26, 2007, entitled "Method of Addressing Messages and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/865,580, filed Oct. 1, 2007, entitled "Method of Addressing Messages, Methods of Establishing Wireless Communications, and Communications System."

USPTO Transaction History of U.S. Appl. No. 11/865,584, filed Oct. 1, 2007, entitled "Method of Addressing Messages, Methods of Establishing Wireless Communications System."

EPC™Radio Frequency "identity Protocols Class–1 Generations–2 UHF RFID Protocol for Communications at 860 MHz—960 MHz", *EPC Global, Inc.*Version 1.09, Cover Sheet and pp. 37–38 (Jan. 2005).

Wright, Jim, "Trends and Innovations in RF Identification", *SUN Microsystems, Inc.,*(presentation); 30 pp. (Mar. 2005).

Whitepaper, "Understanding Gen 2: What It Is, How You Will Benefit and Criteria for Vendor Assessment", *Symbol Technologies, Inc.*, 8 pp. (Jan. 2006).
Capetanakis, John I., "Generalized TDMA: The Multi–Accessing Tree Protocol," *IEEE Transaction on Communications*vol. Com. 27, No. 10, pp. 1476–1484 (Oct. 1979).
Wolf, Jack Keil, "Principles of Group Testing and an Application to the Design and Analysis of Multi–Access Protocols," NATO ASI Series E, Applied Sciences, N. 91, pp. 237–257 (1985).
Humblet, Pierre A., et al., "Efficient Accessing of a Multiaccess Channel", *Proc IEEE Conference Decis Control Incl Symp Adapt Processes 1*, p. 624–627 (1980).
EP serial No. 05016513.3; Extended Search Report And Search Opinion; mailed Jan. 22, 2007; 5 pp.
EP serial No. 05016514.1; Extended Search Report And Search Opinion; mailed Jan. 26, 2007; 5 pp.
U.S. Appl. No. 11/607,263, filed Dec. 2006, John R. Tuttle.
http://www.rfid–handbook.com/, "Radio Frequency–Identification; The Autors Homepage of the RFID Handbook", ©1998–2006, 2 pp. (reprinted Feb. 22, 2007).
http://www.sal–c.org/, Smart Active Labels (SAL) Consortium), ©2007, 1 page (reprinted Apr. 26, 2007).
Capetankis, John I., "Tree Algorithms for Packet Broadcast Channels", *IEEE Transactions on Information Theory*, vol. IT–25, No. 5, pp. 505–515 (Sep. 1979).
http://ww/eretailnews.com/features/0105epc1.htm. The Electronic Product Code (EPC), 2 pp. (Printed Oct. 15, 2003).
http://www.eretailnews.com/Features/0105epcschema.htm, "The Electronic Product Code Schematic", 1 p. (Printed Oct. 15, 2003).
http://www.eretailnews.com/features/epc.htm, The Electronic Product Code (EPC), 2 pp. (Printed Oct. 15, 2003).
ECC Report 1, "Compatability between Inductive LF and HF RFID Transponder and Other Radio Communication Systems in the Frequency Ranges 135–148.5 kHz, 4.78–8.78 MHz and 11.56–15.56 MHz", *Electronic Comm. Committee*, 14 pp. (Feb. 2002).
http://216.121.131.129/article/articleview/330/1/1/: "EPC Doesn't Infinge RFID Patents," *RFID Journal*, 2 pp. (Mar. 4, 2003).
Mullin, Eileen, "Electronic Product Code", www.baselinemag.com, 4 pp. (printed Oct. 15, 2003).
http://www.rfid.zebra.com/epc.htm, Electronic Product Code (PEC), 1 page (Printed Oct. 15, 2003).
http://www./rfidjournal.com/article/articlereview/473/1/1. "Second Source of Class 1 EPC Chips", *RFID Journal*, 2 pp. (Jun. 26, 2003).
http://money.cnn.com/services/tickerheadlines/prn/cltu045.Pl.09162003122727.24911.htm, "Manhattan Associates Announces Next–Generation Microsoft–Based RFID Solutions", *CNN Money*, 3 pp. (Sep. 16, 2003).
Engels, Daniel, "Technical Report, The Use of the Electronic Product Code", *AUTO–ID Center, Massachusetts Institute of Technology*, 8 pp. (Feb. 1, 2003).
Auto–ID Center, Technical Report, "13.56 MHz ISM Band Class 1 Radio Frequency Identification Tag Interface Specification: Recommended Standard", Version 1.0.0, AUTO–ID Center, Massachusetts Institute of Technology, 31 pp. (Feb. 1, 2003).
http://www.hightechaid.com/standards/18000.htm. "ISO/IEC 180000—RFID Air Interface Standards", 6 pp. (Printed Oct. 15, 2003).
ISO, Automatic Identification—Radio Frequency Identification for Item Management—Communications and Interfaces—Part 3: Physical Layer, Anti collision System and Protocol Values at 13.56 MHz MODE 4, #ISO/WD 18000–3–v40–4, 24 pp. (Mar. 1, 2001).
ISO/IEC, "ISO/IEC 18000, p. 3, Information Technology AIDC Tecniques—RFID for Item Management—Air Interface, Part 3, Parameters for Air Interface Communications at 13.56 MHz", #IS) IEC SC31 WG4 FCD18000–3, 176 pp. May 27, 2002).
International Standard ISO/IEC, "Final Committee Draft, ISO/IEC 14443–1, Identification Cards—Contactless Integrated Circuit(s) Cards—Proximity Cards, Part 1: Physical Characteristics", 9 pp. (1997).
ISO/IEC, "Final Committee Draft, ISO/IEC 14443–2, Identification Cards—Contactless Integrated Circuit(s) cards—Proximity Cards—Part 2: Radio Frequency Power and Signal Interface", Editor D. Baddeley, #ISO/IEC JTC/SC17/WG8, 16 pp. (Mar. 26, 1999).
Association Francaise de Normalization (AFNOR), "Identification Cards—Contactless Integrated Cards—Proximity Cards—Part 3: Initialization and Anticollision", #ISO/IEC FDIS 14443–3:2000(E), 48 pp. (Jul. 13, 2000).
Association Francaise de Normalization (AFNOR), "Identification Cards—Contactless Integrated Circuit(s) Cards—Proximity Cards—Part 4: Transmission Protocol", ISO/IEC, #ISO/IEC FDIS 14443–4:2000(E). 37 pp. (Jul. 13, 2000).
Association Francaise de Normalization (AFNOR), "Identification Cards—Contactless Integrated Circuit(s) Cards—Vicinity Cards—Part 1: Physical Characteristics", FINAL DRAFT, ISO/IEC, #ISO/IEC FDIS 15693–1:2000(E), 8 pp. (May 19, 2000).
Association Francaise de Normalization (AFNOR), "Identification Cards—Contactless Circuit(s) Cards—Vicinity Cards—Part 2: Air Interface and Intialization", FINAL DRAFT ISO/IEC, #ISO/IEC, 15693–2:2000(E), 23 pp. (Feb. 3, 2000).
ISO/IEC, "Identification Cards—Contactless Integrated Circuit(s) Cards—Vicinity Cards—Part 3: Anticollision and Transmission Protocol", ISO/IEC, #ISO/IEC CD 15693:3:1999(e), 48 pp. (Nov. 17, 1999).
ISO/IEC, "Automatic Identification—Radio Frequency Identification for Item Management—Communications and Interfaces—Part 3: Physical Layer, Anti–Collision System and Protocol Values at 13.56 MHz MODE 1", ISO/IEC, #ISO/WD 18000–3–v40–1, 105 pp. (Mar. 1, 2001).

* cited by examiner

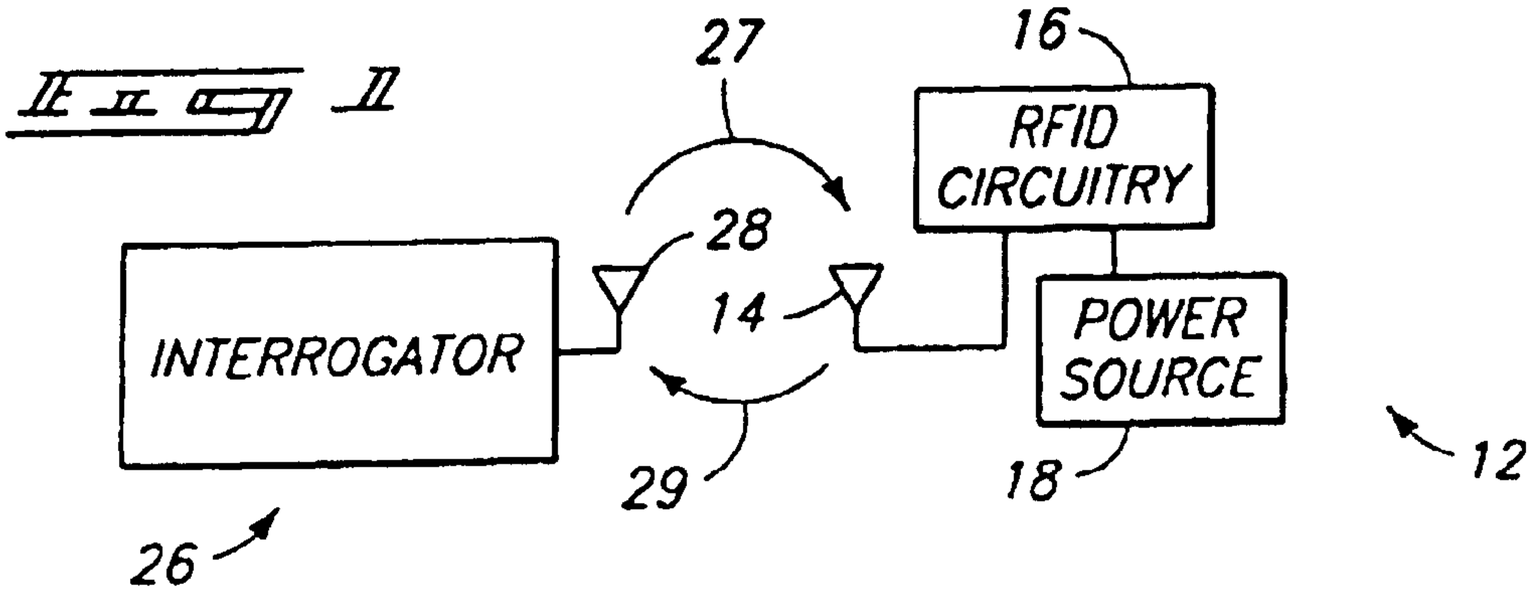


Fig. 1

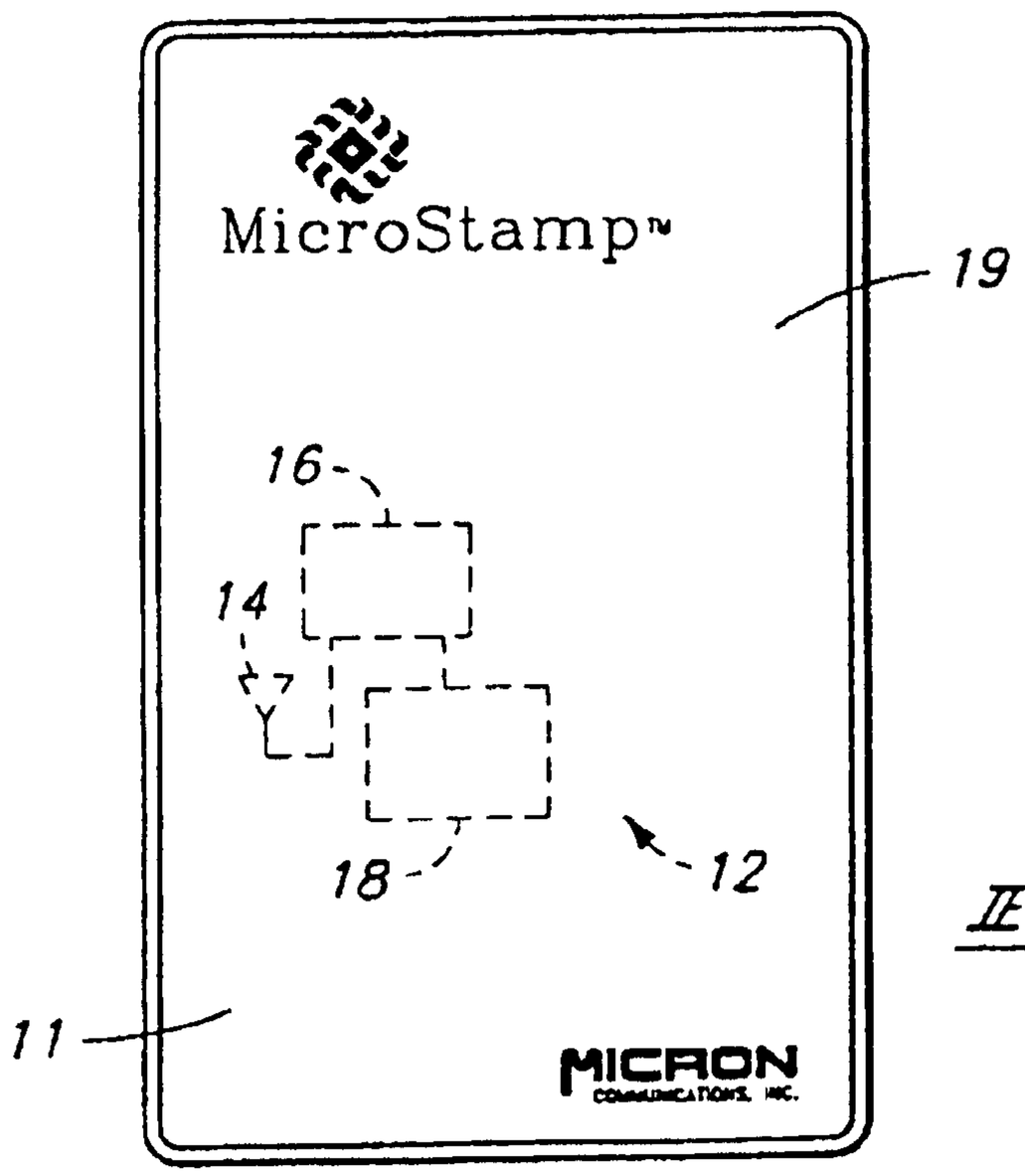


Fig. 2

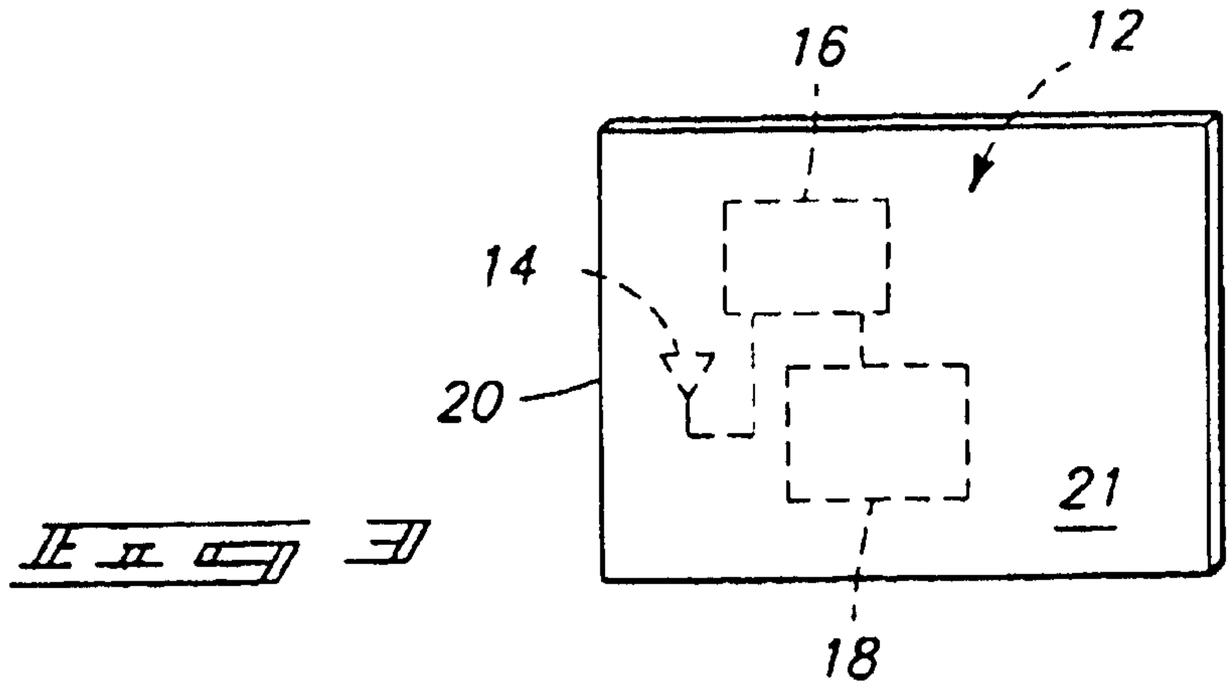
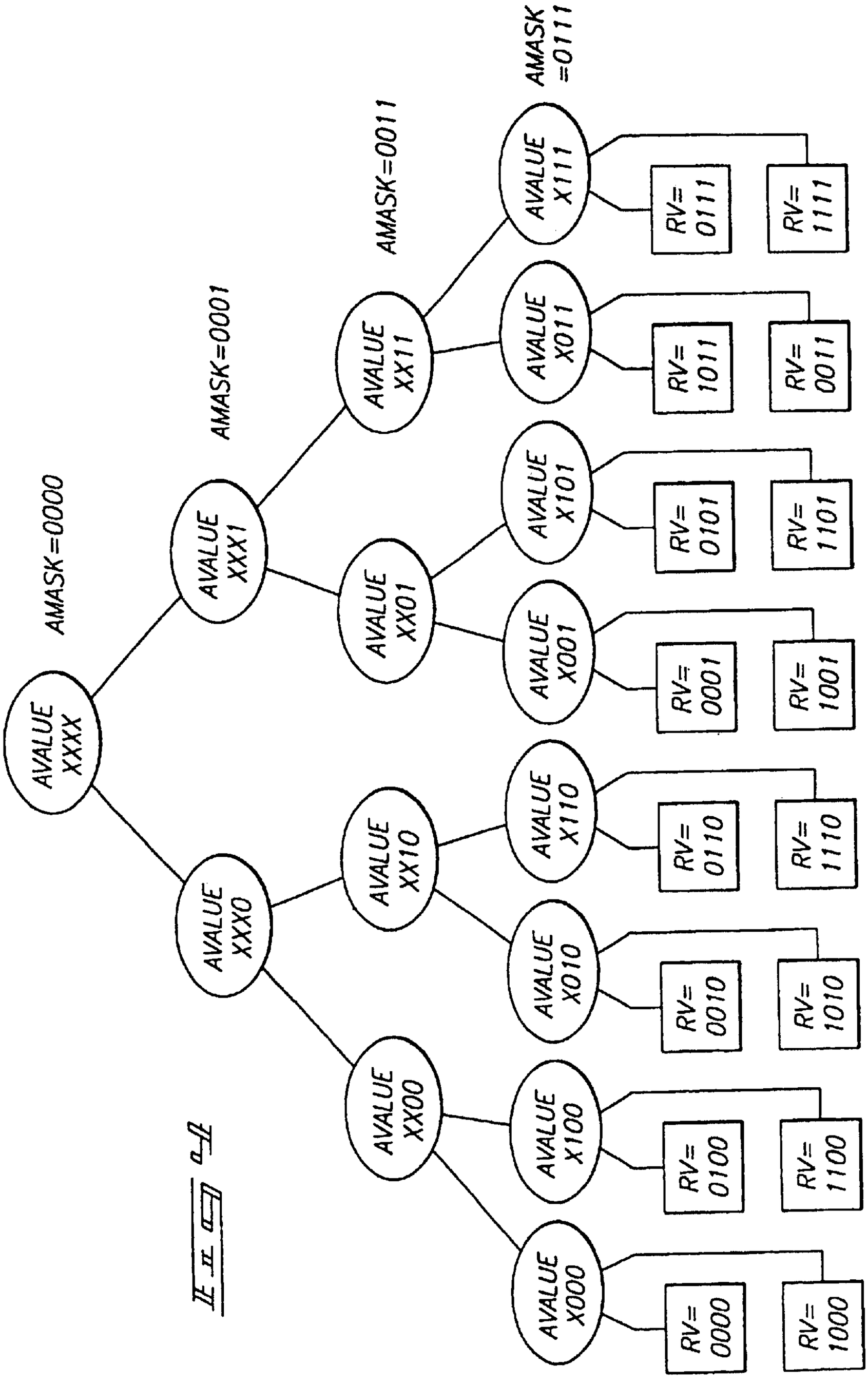


Fig. 3


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

Фиг 4

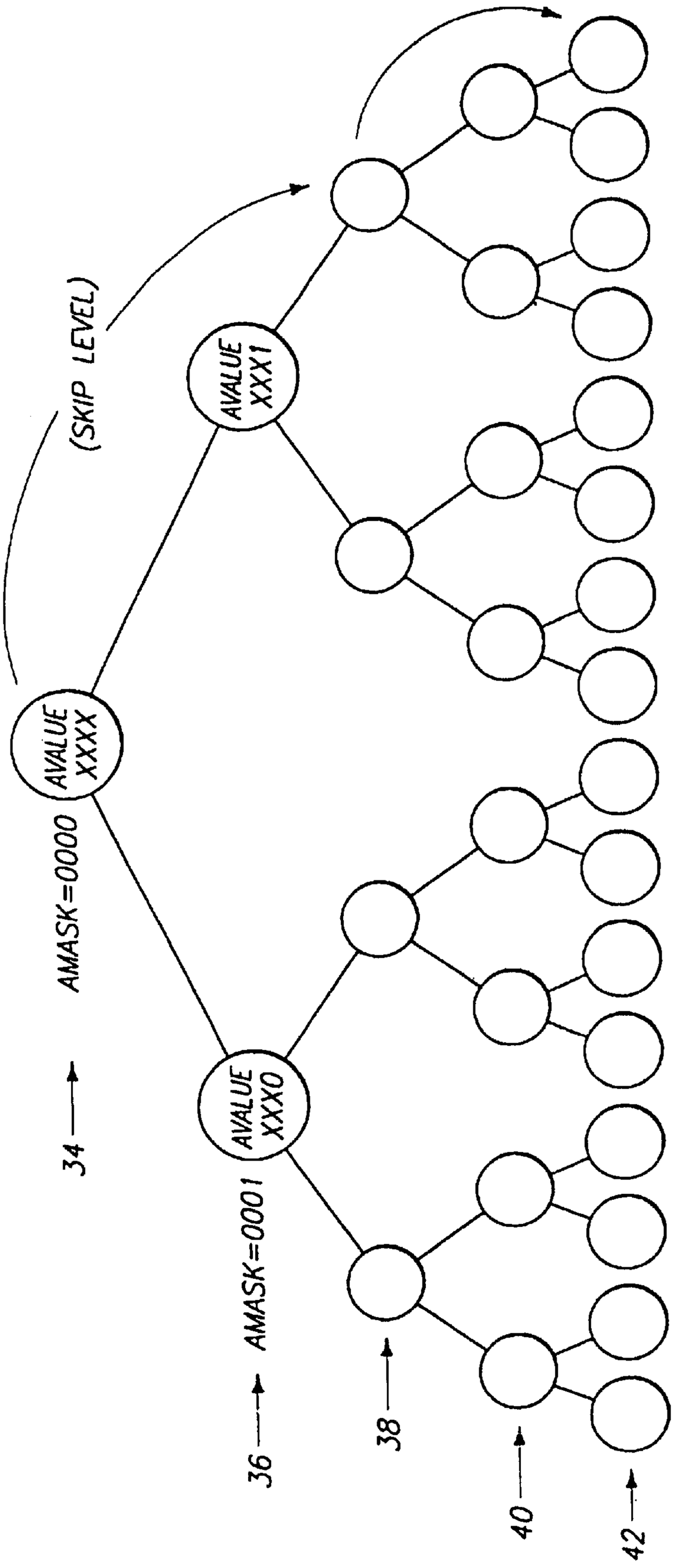

32
(SKIP LEVEL)
AMASK=0000
AVALUE XXXX
34
AVALUE XXX1
AVALUE XXX0
36
AMASK=0001
38
40
42

FIG 5

METHOD AND APPARATUS TO MANAGE RFID TAGS

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.

CROSS REFERENCE TO RELATED APPLICATION

[This] *More than one reissue application has been filed for the reissue of U.S. Pat. No. 6,307,848, which reissue applications are the initial, present reissue application Ser. No. 10/693,697 filed Oct. 23, 2003, a continuation reissue applciation Ser. No. 11/865,580 filed Oct. 1, 2007, a continuation reissue application Ser. No. 11/865,584 filed Oct. 1, 2007, and a further continuation reissue application Ser. No. 12/604,329 filed Oct. 22, 2009, where the present application* is a [Continuation] *reissue application of U.S. Pat. No. 6,307,848, issued from U.S. patent application Ser. No. 09/773,461, filed Jan. 31, 2001, which is a continuation application* of U.S. patent application Ser. No. 09/551,304, filed Apr. 18, 2000, [and] titled "Method of Addressing Messages, and Establishing Communications Using a Tree Search Technique That Skips Levels" *and now U.S. Pat. No. 6,226,300*, which in turn is a continuation of U.S. patent application Ser. No. 09/026,045, filed Feb. 19, 1998, which is now U.S. Pat. No. 6,072,801.

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 communicate with the devices.

Another wireless electronic identification system utilizes a large 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 Applications, 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 now U.S. Pat. No. 6,130,602,* and 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.

Another aspect of the invention provides a method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices. A tree search method is utilized to establish 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 levels representing subgroups of the multiple wireless identification devices. The number of devices in a subgroup in one level is half of the number of devices in the next higher level. The tree search method employs level skipping wherein at least one level of the tree is skipped.

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 respective wireless identification devices have a unique identification number. The interrogator is configured to employ a tree search technique to determine the unique identification numbers of the different wireless identification devices so as to be able to establish communications between the interrogator and individual ones of the multiple wireless identification devices without collision by multiple wireless identification devices attempting to respond to the interrogator at the same time. Levels of the tree are occasionally skipped.

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.

In one embodiment, an interrogator may send a first command indicating a first value and a first memory range, and a second command indicating second value and a second memory range. The first memory range may differ from the second memory range by at least two bits. RFID tags may compare the first and second values to corresponding values stored in the tags to determine if the tags are selected. Selected tags may respond to the interrogator with independently generated random numbers.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described below the 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**. 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 *and now U.S. Pat. No. 6,130,603*. Other embodiments are possible. A power source **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** further includes at least one antenna **14** connected to the circuitry **16** for wireless or radio frequency transmission and reception by the circuitry **16**.

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 and *now U.S. Pat. No. 6,289,209, which is* 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 **26**, and the particular devices **12** that are in communication with the interrogator **26** will typically change over time. In the illustrated 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**). Similarly, multiple interrogators **26** can be in proximity to one or more of the devices **12**.

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 *now U.S. 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 the radio frequency data communication device **12**, and a housing **11** including plastic or other suitable material. In one embodiment, the front face of the badge has visual identification features such as graphics, 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** 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, the device **12** can be included in any appropriate housing.

If the power source **18** is a battery, the battery can take any suitable form. Preferably, the battery type will be selected depending on weight, size, and life requirements for a particular application. In one embodiment, the battery **18** is a thin profile button-type cell forming a small, thin energy cell more commonly utilized in watches and small electronic devices requiring a thin profile. A conventional button-type cell has a pair of electrodes, an anode formed by one face and a cathode formed by an opposite face. In an alternative embodiment, the power source **18** comprises a series connected pair of button type cells. Instead of using a battery, any suitable power source can be 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, *filed Aug. 29, 1996 and now U.S. 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 RF link, 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 RFID systems, there is a potential for a large number of transmitting devices **12** and there is 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 transmissions 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 uninterrupted 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 (AM ASK), 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 receivins 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 evaluates 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 trying 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 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 fall, AMASK=(AMASKL<<1)+1. So for the first recursive call, the value of AMASK is 0000+0001=0001. For the second call, AMASK=(0001<<1)+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 following assuming collisions take place all the way down to the bottom of the tree.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011

-continued

AVALUE	AMASK
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. The following is an example of code for performing a breadth-first traversal.

```
Arbitrate(AMASK, AVALUE)
        {
          enqueue(0,0)
          while (queue != empty)
                (AMASK,AVALUE) = 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 levels in the tree are skipped. The inventors have determined that 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**.

Thus, FIG. **5** illustrates a binary search tree **32** being defined for a tree search method similar to the tree search method described in connection with FIG. **4**. The tree **32** has multiple levels **34**, **36**, **38**, **40**, and **42** representing subgroups of the multiple devices **12**. The number of devices in a subgroup in one level **34**, **36**, **38**, **40**, and **42** is half of the number of devices in the next higher level **34**, **36**, **38**, **40**, and **42**. Although only five levels are shown, if more bits are employed, (e.g., sixteen bits or an integer multiple of eight or sixteen bits for each of AMASK and AVALUE), there will of course be more levels. The tree search method illustrated in FIG. **5** employs level skipping wherein at least one level of the tree is skipped.

A first predetermined number of bits, e.g. sixteen or an integer multiple of eight or sixteen bits, are established to be used as unique identification numbers. Respective devices **12** are provided with unique identification numbers respectively having the first predetermined numbers of bits, in addition to their random values RV. For example, such unique identification numbers are stored in memory in the respective devices **12**.

A second predetermined number of bits are established to be used for the random values RV. The devices **12** are caused to select random values, RV. This is done, for example, by the interrogator **26** sending an appropriate command. Respective devices choose random values independently of random values selected by the other devices **12**. Random number generators are known in the art.

The interrogator transmits a command requesting devices **12** having random values RV within a specified group of random values to respond, using a methodology similar to that described in connection with FIG. **4**, except that levels are skipped. Four subsets of random values, instead of two, are probed when moving down the tree and skipping a level. This means that instead of eliminating half Of the remaining devices **12** and re-trying, after a collision, the interrogator eliminates three quarters of the remaining devices **12** and re-tries (by sending a command). In other words, a new specified group is created that is one quarter of the set of random values of the previous group.

Each devices **12** that receives the command determines if its chosen random value falls within the specified group by evaluating the equation (AMASK & AVALUE)=(AMASK & RV) and, if so, sends a reply, to the interrogator. The reply includes the random value of the replying device **12** and the unique identification number of the device **12**. The interrogator determines if a collision occurred between devices that sent a reply and, if so, creates a new, smaller, specified group, by moving down the tree, skipping a level.

In the illustrated 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 following. 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. The inventors have determined that 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.

The inventors have determined that skipping every other level drastically reduces the number of collisions and saves battery power with out significantly increasing the number of queries.

After receiving a reply without collision from a device **12**, the interrogator **26** can send a command individually addressed to that device by using its now known random value or its now known unique identification number.

The above described code for depth-first traversal is modified to provide for level skipping by increasing the number of recursive calls as shown below. For example, the above described code for depth-first traversal is replaced with code such as the following to provide for depth-first traversal employing level skipping.

```
Arbitrate(AMASK, AVALUE)
        {
          collision=IdentifyCmnd(AMASK, AVALUE)
          if (collision) then
                {
                  TEMP = AMASK+1
                  NEW_AMASK = (AMASK<<2)+3
                  Arbitrate(NEW_AMASK, AVALUE)
                  Arbitrate(NEW_AMASK, AVALUE+TEMP)
                  Arbitrate(NEW_AMASK, AVALUE+2*TEMP)
                  Arbitrate(NEW_AMASK, AVALUE+3*TEMP)
                }       /* endif */
          }/* return */
```

AVALUE and AMASK would have values such as those indicated in the following table for such code.

AVALUE	AMASK
0000	0000
0000	0011
0000	1111*
0100	1111*

-continued

AVALUE	AMASK
1000	1111*
1100	1111*
0001	0011
0001	1111*
0101	1111*
1001	1111*
1101	1111*
0010	0011
0010	1111*
0110	1111*
1010	1111*
1110	1111*
. . .	. . .

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

Similarly, the code provided above for breadth-first traversal can be readily modified to employ level skipping. Instead of inserting two items into the queue each time through the loop, four items are inserted into the queue each time through the loop. For either breadth-first traversal or depth-first traversal. AMASK will be shifted by two bits instead of one, and AVALUE will take on twice as many different values as in the case where level skipping is not employed.

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 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 number MI40-089)] *Ser. No. 09/026,248, filed Feb. 19, 1998, now U.S. Pat. No. 6,275,476B1* 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 is combined with level skipping, such as the level skipping shown and described in connection with FIG. **5**. For example, in one embodiment, devices **12** sending a reply to the interrogator **26** do so within a randomly selected time slot of a number of slots.

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 binary search tree having multiple levels representing subgroups of the multiple wireless identification devices, the number of devices in a subgroup in one level being less than the number of devices in the next level, the tree search technique employing level skipping wherein every second level of the tree is skipped.

2. 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.

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 communications range, over time.

6. 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 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 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 new, smaller, specified group, using a search tree, that is one quarter of the first mentioned specified group, wherein at least one level of a search tree is skipped.

7. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance with claim **6** wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.

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 **6** wherein sending a reply to the interrogator comprises transmitting the random value of the device sending the reply.

9. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance with claim **6** wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply.

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 **6** wherein, after receiving a reply without collision from a device, the interrogator sends a command 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:

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 specified group being less than or equal to the entire set of random values, the plurality of possible groups being organized in a binary tree having a plurality of levels, wherein groups of random values decrease in size with each level descended;

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 at least two levels in the tree.

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** and further comprising establishing unique identification numbers for respective devices.

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 a transponder to a selected one or more of a number of communications devices in accordance with claim 13 wherein the predetermined number of bits to be used for the random values comprises sixteen bits.

15. A method of addressing messages from a transponder to a selected one or more of a number of communications devices in accordance with claim 13 wherein devices sending a reply to the transponder do so within a randomly selected time slot of a number of slots.

16. 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 from the interrogator 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 or equal to the entire set of random values, the plurality of possible groups being organized in a binary tree having a plurality of levels, wherein groups of random values decrease in size with each level;

receiving the command at multiple of the devices, the devices receiving the command respectively determining if the random value chosen by the device falls within the specified group and, only if so, sending a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and 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 level of the tree different from the level used in the interrogator transmitting, wherein at least one level of the tree is skipped, the interrogator transmitting a command requesting devices having random values within the new 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.

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 16 wherein every second level is skipped.

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 16 wherein the unique identification numbers are respectively defined by a predetermined number of bits.

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 16 wherein the unique identification numbers are respectively defined by a predetermined number of bits and wherein the random values are respectively defined by a predetermined number of bits.

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 16 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.

21. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 20 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 within communications range are identified.

22. 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 that is one quarter of the first mentioned specified group, wherein at least one level of the tree is skipped.

23. A system in accordance with claim 22 wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.

24. A system in accordance with claim 22 wherein sending a reply to the interrogator comprises transmitting the random value of the device sending the reply.

25. A system in accordance with claim 22 wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply.

26. A system in accordance with claim 22 wherein the interrogator further includes means for, after receiving a reply without collision from a device, sending a command individually addressed to that device.

27. A method, comprising:

sending a first command from an interrogator to a plurality of RFID devices, the first command comprising a first set of fields, wherein the first set of fields includes a first bit string and describes a first memory range that starts at a first bit location;

receiving the first command by an RFID device of the plurality of RFID devices, and in response, the RFID

device comparing the first bit string to a first value stored in a first portion of a memory of the RFID device corresponding to the first memory range;

sending a second command from the interrogator to the plurality of RFID devices successively following the first command, the second command comprising a second set of fields, wherein the second set of fields includes a second bit string and describes a second memory range that starts at a second bit location offset from the first bit location by two or more bits;

receiving the second command by the RFID device, and in response, the RFID device comparing the second bit string to a second value stored in a second portion of the memory of the RFID device corresponding to the second memory range; and

receiving a reply from the RFID device based, at least in part, on a first result from the comparing of the first bit string to the first value, and on a second result from the comparing of the second bit string to the second value, wherein the reply includes a random number generated by the RFID device.

28. The method of claim 27, wherein the reply further includes an identification code that identifies an object to which the RFID device is attached.

29. The method of claim 27, further comprising sending a third command from the interrogator to the plurality of RFID devices after sending the second command and before receiving the reply from the RFID device.

30. The method of claim 27, wherein the reply is sent from the RFID device in accordance with an adaptive slotted arbitration scheme.

31. A method, comprising:

sending a first command followed by a second command, absent any intervening commands, to a plurality of RFID devices, wherein the first command comprises first and second radio frequency (RF) signals and the second command comprises third and fourth RF signals;

receiving a reply from at least one RFID device, the reply indicating that a first number stored in a memory of the RFID device bounded at a first location indicated by the first RF signal is equal to a first value indicated by the second RF signal, and a second number stored in the memory of the RFID device bounded at a second location indicated by the third RF signal is equal to a second value indicated by the fourth RF signal, the reply including a random number independently generated by the RFID device, wherein the second location is offset by two or more bits from the first location in the memory of the RFID device.

32. The method of claim 31, further comprising detecting a collision in the reply.

33. The method of claim 31, wherein the reply includes an identification number.

34. The method of claim 31, wherein the reply is received in accordance with a slotted arbitration scheme.

35. The method of claim 34, wherein the random number is 16 bits.

36. The method of claim 31, further comprising the RFID device picking a random value from a variable range of integers, the random value corresponding to a slot.

37. The method of claim 31, further comprising individually accessing the RFID device including sending the random number to the RFID device.

38. The method of claim 37, wherein the random number is 16 bits.

39. A method performed by an interrogator, comprising:

transmitting a first command to select a group of RFID devices based, at least in part, on a first memory range beginning at a first bit location;

transmitting a second command, successively following the first command, to select a subgroup of the group of RFID devices based, at least in part, on a second memory range beginning at a second bit location, wherein the second bit location is shifted by two or more bits from the first bit location; and

receiving a reply from at least one RFID device of the subgroup of RFID devices, the reply including a random number generated by the RFID device.

40. The method of claim 39, wherein the method further comprises transmitting a third command after transmitting the second command and before receiving the reply, the third command including a at least one field configured to select at least a portion of the subgroup of RFID devices to reply to the third command.

41. The method of claim 40, wherein the method further comprises transmitting a signal, the signal associated with a slotted arbitration scheme.

42. The method of claim 39, wherein the reply further includes an identification number that identifies an object to which the RFID device is attached.

43. The method of claim 39, wherein the method further comprises transmitting a command that causes the subgroup of RFID devices to independently generate random numbers.

44. The method of claim 39, wherein the method further comprises transmitting a signal after transmitting the second command and before receiving the reply, the signal indicating a number of slots in accordance with a slotted arbitration scheme.

45. The method of claim 44, wherein the reply further includes an identification number that identifies an object to which the RFID device is affixed.

46. The method of claim 39, wherein the method further comprises transmitting a 16 bit random number to the RFID device to access the RFID device.

47. The method of claim 46, wherein the reply further includes an identification number that identifies an object to which the RFID device is attached.

48. A method, comprising:

providing an RFID device affixed to an object to identify the object, the RFID device storing an identification number;

sending a first command from an interrogator, the first command configured to select a group of RFID devices based, at least in part, on a respective first value stored in each respective RFID device of the group of RFID devices, the respective first value bounded at a respective first bit location within a memory of the respective RFID device;

sending a second command from the interrogator after sending the first command and before sending any intervening command from the interrogator, the second command configured to select a subgroup of the group of RFID devices based, at least in part, on a respective second value stored in the respective RFID device of the group of RFID devices, the respective second value bounded at a respective second bit location within the memory of the respective RFID device, wherein the second bit location is at least two bits away from the first bit location; and

receiving a random number from the RFID device, the RFID device belonging to the subgroup, the random

number independently generated by the RFID device and being separate from the identification number.

49. The method of claim 48, wherein the respective first value of the RFID device comprises at least a portion of the random number.

50. The method of claim 48, further comprising receiving the identification number from the RFID device.

51. The method of claim 50, further comprising sending the random number to the device.

52. The method of claim 51, further comprising sending a third command to the RFID device, the third command associated with a slot value.

53. The method of claim 48, further comprising sending a third signal from the interrogator, the third signal being associated with a slotted random anticollision algorithm and indicating a number of slots for the RFID device.

54. The method of claim 53, further comprising receiving the identification number from the RFID device.

55. A system comprising:

an RFID reader configured to send a first command to indicate a first bit string and a first range of bits, followed, without any intervening query commands, by a second command to indicate a second bit string and a second range of bits, wherein the first range of bits differs from the second range of bits by at least two bits;

an object associated with an identification code; and

an RFID tag affixed to the object and storing the identification code, the RFID tag configured to compare the first bit string to a first value stored in memory corresponding to the first range of bits, to compare the second bit string to a second value stored in memory corresponding to the second range of bits, to backscatter a self-generated random number, and to backscatter the identification code.

56. The system of claim 55, wherein the reader is further configured to send the random number to the RFID tag.

57. The system of claim 56, wherein the RFID tag is further configured to pick a random slot value.

58. The system of claim 57, wherein the reader is further configured to send a third command to instruct the RFID tag to generate the random number.

* * * * *