Short Course on Electronically Scanned Reflectarrays - Wireless Communication & Passive Identification

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Overview

Wireless Communication

Passive Identification

- Retrodirective Arrays
- Identification Friend or Foe
- Radio Frequency Identification

Wireless Communication

Wireless Communication

- Business opportunities for electronically scanned reflectarrays include:
  - Airborne radars, such as FOPEN radar and SAR/ATR, which require low cross-polarization, low power consumption, and wideband ESAs, but do not require long-range search and track capability [1].
  - Passive identification (identification friend or foe (IFF), radio frequency identification (RFID)) requires low-power retrodirective arrays [2].
  - Wireless communication: Increasing the bandwidth or the signal-to-noise ratio (SNR), through spatial diversity, increases the Shannon channel capacity [3]. Depending on the propagation conditions, spatial diversity is best implemented using an electronically scanned array (line-of-sight (LOS)) or using a multiple in multiple out (MIMO) array (non line-of-sight (NLOS)).
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Shannon theorem [4] – The channel capacity, C, which is the theoretical upper bound on the bit rate, which can be transmitted with a given average signal power S through an analog communication channel subject to additive white Gaussian noise (AWGN) of power N, is:

$$C = BW \log_2 \left(1 + \frac{S}{N}\right) \qquad (1)$$

where:

- C is the channel capacity in bits per second.
- BW is the (passband) bandwidth of the channel in hertz.
- S is the total received signal (modulation) power over the bandwidth, measured in watt.
- N is the total noise or interference power over the bandwidth, measured in watt.
- S/N is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference expressed as a linear power ratio.

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Figure 1: Single-channel reflector antenna link in case of line-of-sight propagation. Picture of Paris, France.

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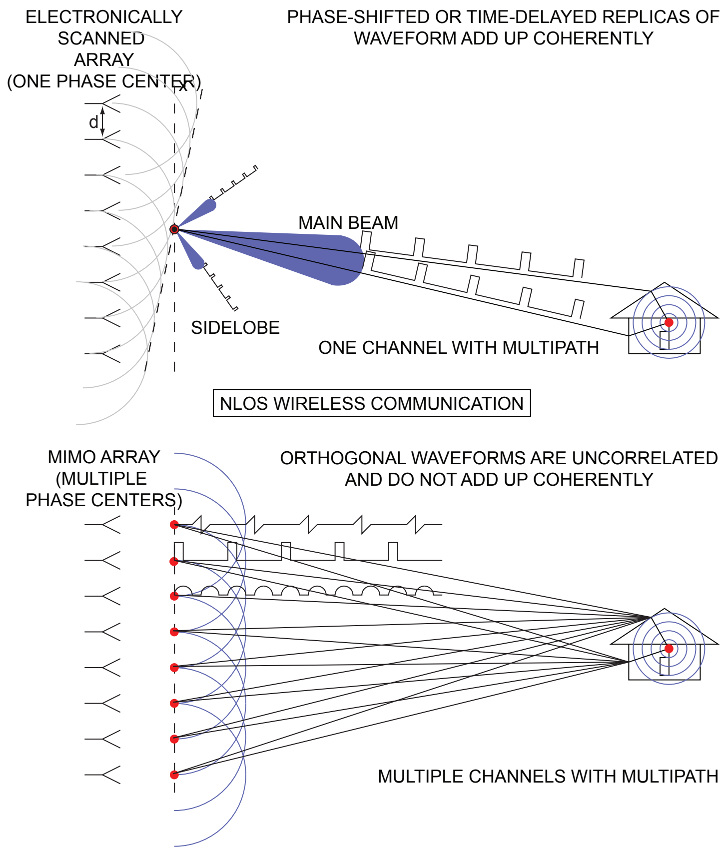

Figure 2: Single-channel electronically scanned array link versus a multi-channel MIMO array link in case of non-line-of-sight propagation. Electronically scanned arrays have one phase center and offer a single high-capacity channel. MIMO arrays have multiple phase centers and offer multiple low-capacity channels [5].

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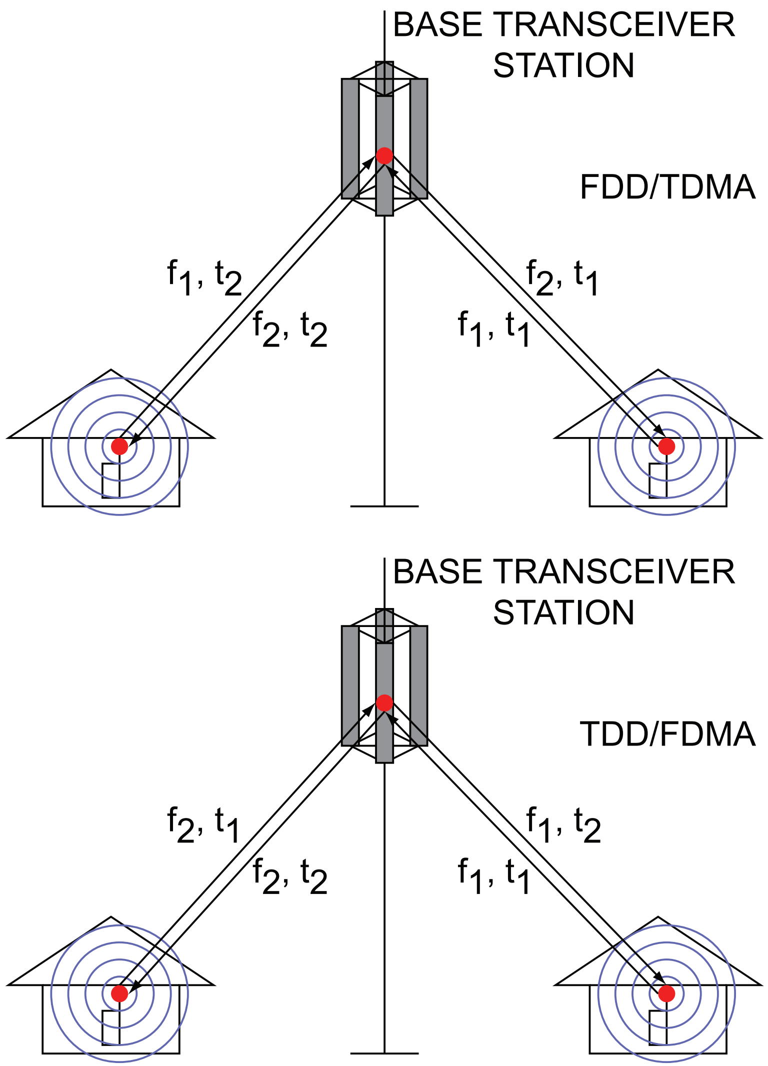


Figure 3: Frequency division duplex (FDD) communication versus time division duplex (TDD) communication.

Wireless Communication: References

[1] K. Van Caekenberghe, "RF MEMS on the radar," *IEEE Microwave Magazine*, vol. 10, no. 6, pp. 99–116, October 2009.

[2] R. Y. Miyamoto and T. Itoh, "Retrodirective arrays for wireless communications," *IEEE Microwave Magazine*, vol. 3, no. 1, pp. 71–79, Mar. 2002.

[3] S. Cherry, "Edholm's law of bandwidth," *IEEE Spectr.*, vol. 41, no. 7, pp. 58–60, July 2004.

[4] Wikipedia. [Online]. Available: http://en.wikipedia.org

[5] J. L. Volakis, *Antenna Engineering Handbook, Fourth Edition*. McGraw-Hill, 2007.

Passive Identification

Retrodirective Arrays

Van Atta array (1959, Van Atta [1])

- **Principle**: A passive retrodirective array transmits an unamplified signal back to the interrogator's position without any a-priori knowledge of the incoming angle or relying on sophisticated digital signal processing algorithms [2]. Self-focusing can be achieved using phase-conjugation (equal phase shifts) or time-reversal (equal time delays). An example of a retrodirective array is a Van Atta array, which consist of one set of antenna with equal length (time delays) connections between pairs of antennas that are equidistant from the phase center.

- **Advantages**:
  - Bandwidth: wideband (planar wavefront and time reversal, Van Atta array)
  - Gain: much higher gain than a single tag antenna
  - Frequency: feasible at microwave and millimeter-wave frequencies, which allow interrogation of fast-moving tags with high Doppler frequency shifts.

- **Disadvantages**:
  - Bandwidth: narrowband (phase conjugation)

- **Applications**:
  - Identification: identification friend or foe (IFF), radio frequency identification (RFID)
  - Microwave communication links: link budget improvement
  - RCS calibration target

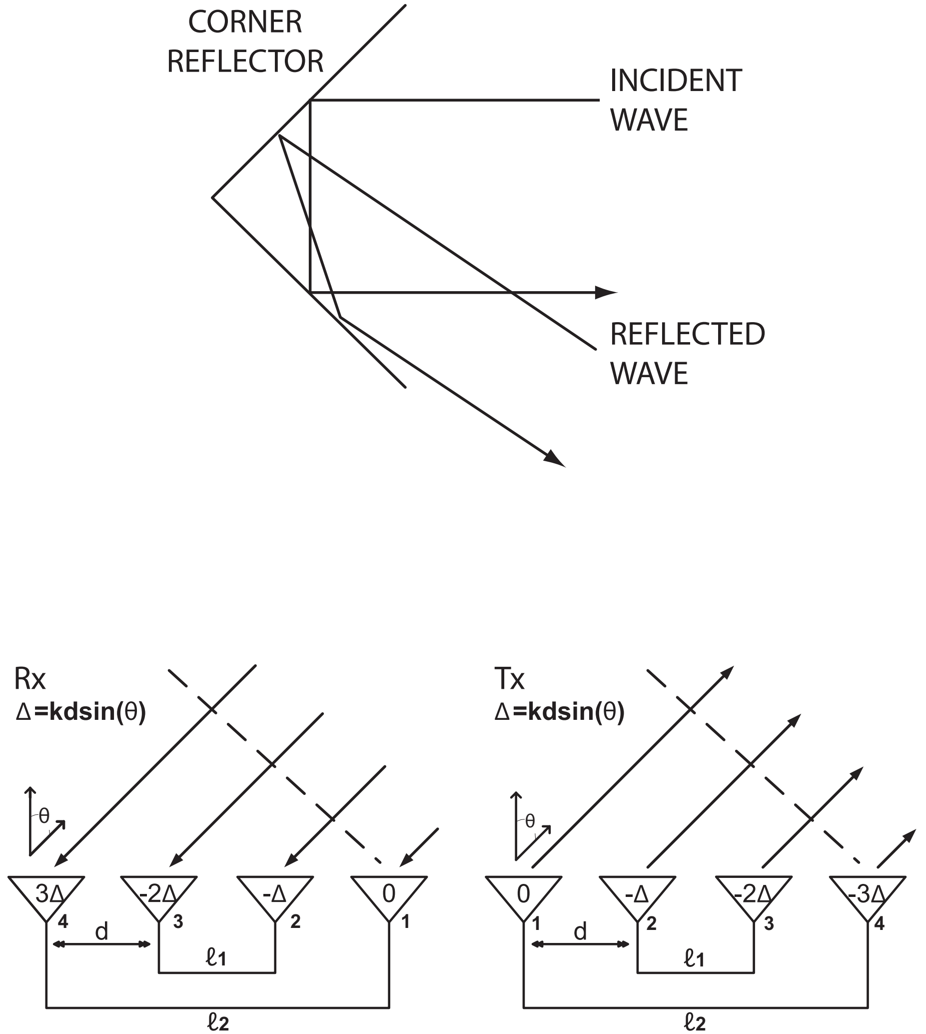


Figure 4: (a) Retroreflection on (dihedral) corner reflector. (b) Phase relationships of the radiating elements for the Van Atta configuration for transmit and receive. Antenna elements are labeled 1-4 while the phase of each element is identified as multiples of Δ.

Identification Friend or Foe (IFF)

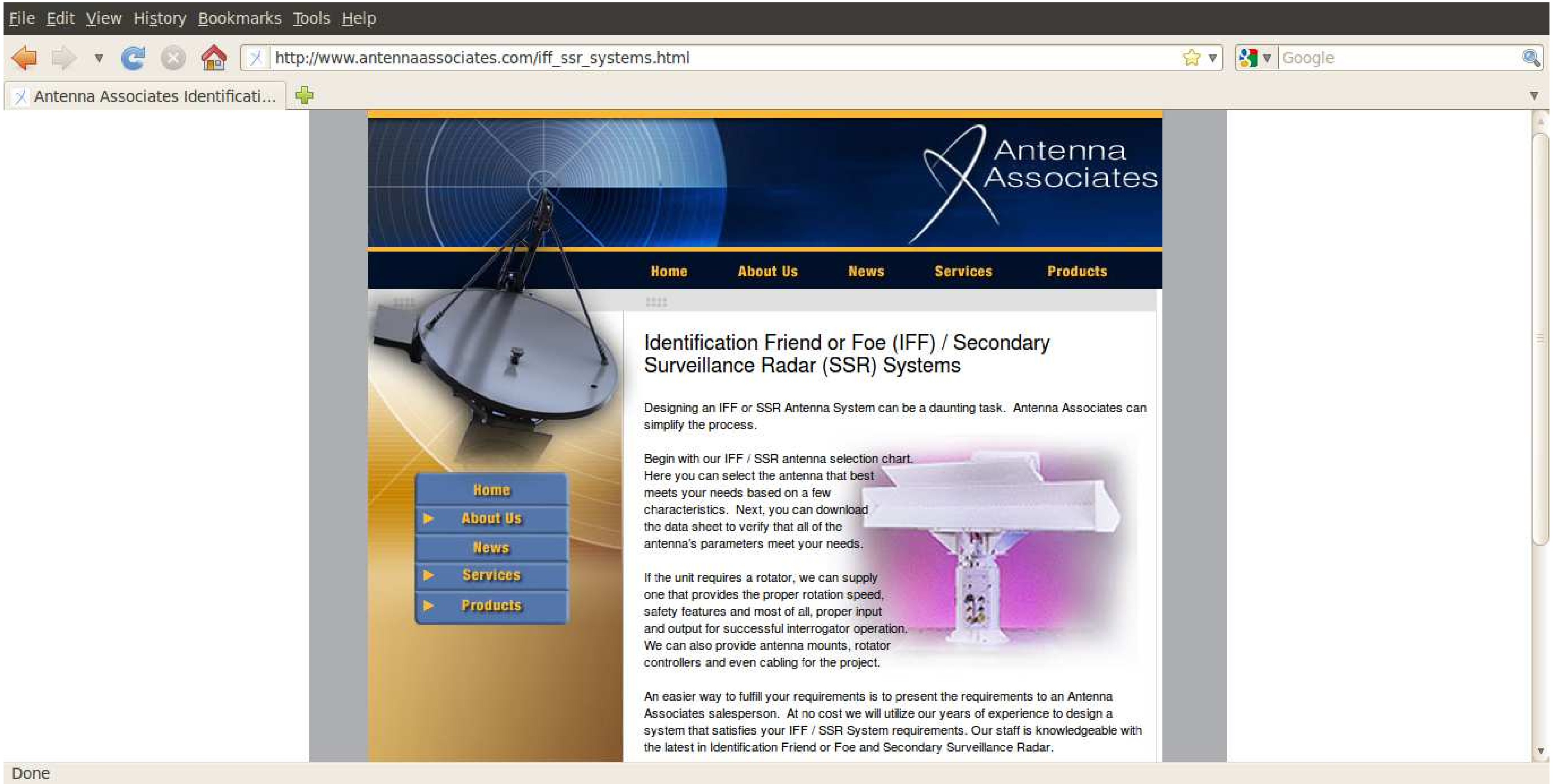


Figure 5: Antenna Associates' model AS-2189 antenna, also known as the AA75 antenna, is a slotted waveguide antenna, of which the Σ beam is highly directional, whereas the Δ_{AZ} beam generates superb side lobe suppression (SLS) and sum beam sharpening. Its function is to provide identification and position detection data for air traffic control (ATC) or military IFF Applications.

US005361071A

United States Patent [19]

van Zon

[11] **Patent Number: 5,361,071**

[45] **Date of Patent: Nov. 1, 1994**

[54] **MICROWAVE IDENTIFICATION SYSTEM**

[75] Inventor: **Bernardus C. van Zon,** Hengelo, Netherlands

[73] Assignee: **N.V. Nederlandsche Apparatenfabriek Nedap,** De Groenlo, Netherlands

[21] Appl. No.: **910,034**

[22] PCT Filed: **Dec. 6, 1991**

[86] PCT No.: **PCT/NL91/00254**

§ 371 Date: **Aug. 6, 1992**

§ 102(e) Date: **Aug. 6, 1992**

[87] PCT Pub. No.: **WO92/10765**

PCT Pub. Date: **Jun. 25, 1992**

[30] **Foreign Application Priority Data**

Dec. 6, 1990 [NL] Netherlands 9002683

[51] **Int. Cl.**[5] **G01S 13/80**
[52] **U.S. Cl.** **342/42;** 342/44; 342/51
[58] **Field of Search** 342/42, 44, 51

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,518,672	6/1970	Zimmer	342/370
3,898,663	8/1975	Albert	342/187
4,347,512	8/1982	Sweeney	342/6
4,364,043	12/1982	Cole et al.	340/825.54
4,370,653	1/1983	Crowley	342/44
4,647,931	3/1987	Mawhinney	342/44
4,899,158	2/1990	Saeki et al.	342/44
4,926,187	5/1990	Sugarawa et al.	342/361
4,963,887	10/1990	Kawashima et al.	342/44
4,983,976	1/1991	Ogata et al.	342/42
5,021,790	6/1991	Ohta et al.	342/44
5,053,774	10/1991	Schuermann et al.	342/44

FOREIGN PATENT DOCUMENTS

0079047	5/1983	European Pat. Off. .
0308964	3/1989	European Pat. Off. .

OTHER PUBLICATIONS

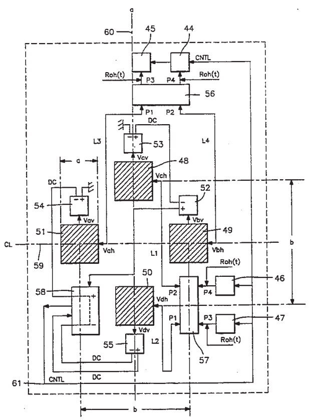
Microwave Journal, Flaherty: "Microcircuit Phased–Array Electronic Countermeasure System"; Sep. 1969.
Patent Abstracts of Japan; 12 Dec. 1977.

Primary Examiner—John B. Sotomayor
Attorney, Agent, or Firm—Jacobson, Price, Holman & Stern

[57] **ABSTRACT**

A microwave identification system comprising a transmitter/receiver provided with an antenna system, a plurality of responders provided with an antenna system, the communication between transmitter/receiver and responders taking place by means of electromagnetic waves in the microwave range, wherein the antenna system of the responders comprises an array with at least two antenna elements **(12, 13)** interconnected via a modulation device **(14, 15, 16)** and, for obtaining a retroreflective effect, the signal generated in an interrogation field by one of the two antenna elements is applied to the modulation device and, after being modulated with a code that is characteristic for the responder, is applied to the other antenna element to be radiated by the other antenna element.

14 Claims, 7 Drawing Sheets



US005426667A

United States Patent [19]

van Zon

[11] **Patent Number: 5,426,667**

[45] **Date of Patent: Jun. 20, 1995**

[54] **SYSTEM FOR THE CONTACTLESS EXCHANGE OF DATA, AND RESPONDER FOR USE IN SUCH A SYSTEM**

[75] Inventor: **Bernardus C. M. van Zon,** Hengelo, Netherlands

[73] Assignee: **N.V. Nederlandsche Apparatenfabriek NEDAP,** de Groenlo, Netherlands

[21] Appl. No.: **77,521**

[22] Filed: **Jun. 17, 1993**

[30] **Foreign Application Priority Data**

Jun. 18, 1992 [NL] Netherlands 9201072

[51] **Int. Cl.**[6] **H04B 1/00**
[52] **U.S. Cl.** **375/219;** 455/41
[58] **Field of Search** 455/41; 375/7

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,689,885	9/1972	Kaplan et al.	455/41
3,898,565	8/1975	Takeuchi et al.	455/41
5,054,112	10/1991	Ike	455/41
5,070,500	12/1991	Horinouchi et al.	455/41
5,128,972	7/1992	Horinuchi et al.	455/41
5,293,400	3/1994	Monod et al	455/41

FOREIGN PATENT DOCUMENTS

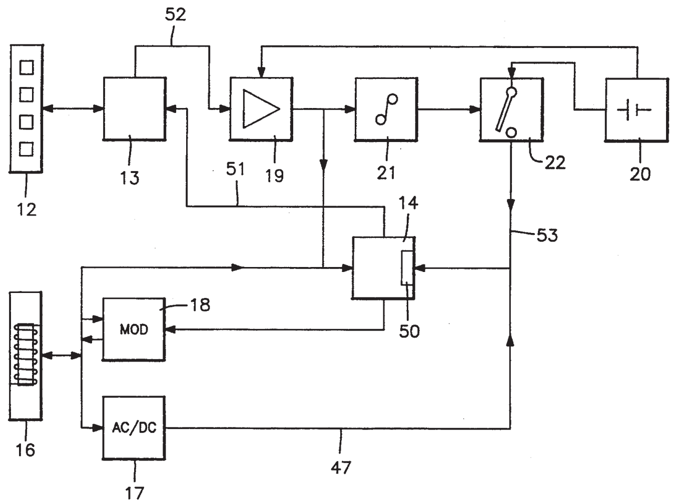
0242906	10/1987	European Pat. Off. .
0395188	10/1990	European Pat. Off. .
0446519	9/1991	European Pat. Off. .
0459477	12/1991	European Pat. Off. .

Primary Examiner—Edward L. Coles, Sr.
Assistant Examiner—Kimberly A. Williams
Attorney, Agent, or Firm—Jacobson, Price, Holman & Stern

[57] **ABSTRACT**

Disclosed is a system for the contactless exchange of data between one or more transmitter/receiver devices and a plurality of responders. According to the invention, at least one of the responders is designed to exchange data via a microwave connection with a transmitter/receiver device operating in the microwave range, and to exchange data via an inductive coupling with an inductively operating transmitter/receiver device.

22 Claims, 7 Drawing Sheets



Passive Identification: References

[1] L. C. Van Atta, "Electromagnetic reflector," U.S. Patent 2,908,002, October 6, 1959.

[2] R. Y. Miyamoto and T. Itoh, "Retrodirective arrays for wireless communications," *IEEE Microwave Magazine*, vol. 3, no. 1, pp. 71–79, Mar. 2002.