A Novel Card-Type Transponder Designed Using Retrodirective Antenna Array

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***Abstract* — A novel card-type 5.8 GHz passive transponder is designed for possible use in the Dedicated Short-Range Communication (DSRC) systems and/or the RF/ID systems. Four LHCP microstrip antennas are arranged in the transponder by using the Van Atta retrodirective design so that the transponder possesses the advantages of both a high responding signal level and a wide range of responding angles. Measurement results show that the present transponder produces a signal level 12 dB higher than a transponder with single-antenna design, while maintains the same range of the responding angles as the single-antenna one. Finally, by incorporating 8-bit test codes in the beacon (or interrogator) and in the transponder, the downlink and uplink performances of the transponder are demonstrated.**

I. INTRODUCTION

Intelligent Transportation Systems (ITS) have attracted much attention in recent years. Among the various communication systems, the Dedicated Short-Range Communication (DSRC) of the 5.8 GHz ISM frequency is one that can fulfill most of the requirements in ITS, and has been widely used for the Electronic Toll Collection (ETC) system. Depending on whether a microwave oscillator is incorporated in the vehicle communication unit (or simply On-Board-Unit, OBU), DSRC can be classified into two groups, that is, the active (transceiver) system and the passive (transponder) system. While the active system possesses the advantages of higher sensitivity and wider communication zone, the passive one has transponders with simple circuitry, low consumption power, and low cost.

Although many transponder designs were proposed in the literature [1]-[3], they used only one elementary antenna to re-radiate the uplink signal, thus limiting the responding signal level. To increase the signal level, an array antenna may be used in the transponder. However, the array suffers from the drawback of narrow beam, which thus constricts the responding angles of the transponder.

In this paper, we propose a novel card-type 5.8 GHz transponder as shown in Fig. 1. This transponder includes four microstrip antennas arranged as a Van Atta retro-irective array. Every two antennas in the array are connected with each other through a microstrip line. Each antenna performs as a receiving antenna and also a transmitting one. The wave received from one antenna, after encoded by an ASK modulator embedded in the connecting microstrip line, is re-radiated by the corresponding paired antenna. Since the waves re-radiated from all the antennas in a Van Atta retrodirective array are in-phase added in the beacon direction [4], the total responding signal level in the present transponder would thus be 12 dB higher than that of a traditional single-antenna transponder. Furthermore, the range of the responding angles of the proposed transponder would be the same as that of the traditional one, not being reduced due to the use of an antenna array.

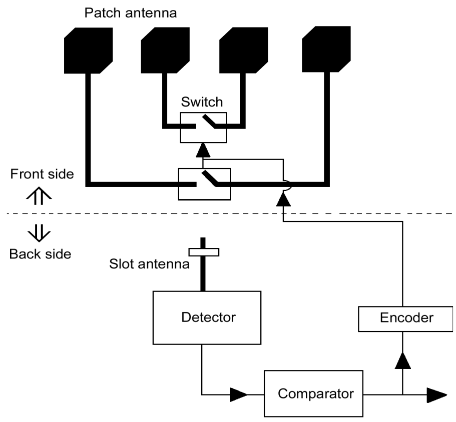


Fig. 1. Building blocks of a passive transponder using the Van Atta microstrip antenna array.

II. DESIGN OF THE TRANSPONDER CIRCUIT

The card-type transponder shown in Fig. 1 is a two-sided structure, which has an area of $12.5 \times 5.5\ cm^2$. The front side consists of four LHCP microstrip antennas with inter-element spacing of $0.6\lambda_0$ and two PIN diode switches, fabricated on a substrate of ε_r = 2.33 and h = 0.787mm. The two side antennas and the two middle ones are separately connected by two $50\,\Omega$ microstrip lines. The switches are then embedded in the midway of the connecting microstrip lines. To achieve the retrodirectivity purpose, the two connecting microstrip lines are designed with a length difference of one guided wavelength. The backside circuit is fabricated on a substrate of ε_r = 2.2 and h = 0.508*mm*, which contains a Schottky diode detector and a binary encoder circuit to control the switches on the front side. Finally, a receiving slot antenna is built on the ground plane between the two substrates. The slot output signal is connected to the diode detector through a microstrip line on the backside.

In the downlink mode, the ASK-modulated wave from the RSU is received by the slot antenna and fed to the diode detector. The detected binary signal is then sent to a voltage comparator to re-shape the signal and reject the noise. In the uplink mode, a continuous wave is received by the slot antenna so that the output from the detector is a small DC voltage. After passing the comparator, this DC voltage will trigger the following 74HC165 encoder circuit to produce a binary voltage code containing the uplink information. This voltage code is then used to control the PIN diode switches on the transponder's front side so that an ASK-modulated responding wave is produced. Note that the only power source in the transponder is a 1.5-V DC battery attached on the transponder backside. Only when the communication happens will the battery deliver power to the encoder and switch circuits. Otherwise, very little current is leaked (to the comparator), and thus very little power is consumed, from the battery.

Since the back-scattering field pattern of a Van Atta array is the same as that of the array element, it is important to design the elementary antenna with good performance. Here, to simplify the structure, an LHCP corner-trimmed square patch antenna is adopted to form the Van Atta array. The measured return loss of the antenna is –30 dB at the center frequency with a 10-dB bandwidth of 140 MHz (2.4%).

In designing the PIN diode switch for ASK modulation, it is understood that, in the uplink mode, the switch decides whether or not the continuous wave received from one antenna may be re-radiated from the corresponding paired antenna. When the switch is on, the received continuous wave should totally pass through the switch. And, when the switch is off, the wave should be stopped and little power is allowed to reflect back (otherwise the reflected wave will be re-radiated from the original antenna). To fulfill these requirements, a switch with two packaged PIN diode pairs was realized. A quarter-wavelength microstrip-line section is inserted between the two diode pairs to increase the isolation when the switch turns off. 50-Ω terminations are used to absorb the received wave when switch off. At the center frequency of 5.8 GHz, as the switch on, the measured insertion loss (S_{21}) was about 1.5 dB and the return loss (S_{11}) was –22 dB. When the switch off, the isolation between ports ($1/S_{21}$) was about 20 dB and the return loss was –14 dB.

The diode detector on the transponder backside was fabricated using a Schottky diode with an impedance matching stub. The detected signal is extracted out through a low-pass filter formed by a high-impedance choke and a lumped capacitor. A resistor is placed in parallel with the capacitor for the DC return of the diode current. The measured return loss of this diode detector is as low as –28 dB at the center frequency and has a 10-dB bandwidth of 450 MHz (7.8%). Finally, a half-wavelength slot was adopted for the design of the receiving slot antenna. The return loss was measured as –25 dB at 5.8 GHz with a 10-dB bandwidth of 465 MHz (8%). The radiation pattern has also been measured, which showed a radiation gain of 4.2 dBi at the normal directions.

III. MEASUREMENT OF THE TRANSPONDER

Fig. 2 illustrates the measurement setup for the fabricated transponder. The RSU (or interrogator) includes an LHCP helical antenna and the related circuit. An HP 83640L synthesizer is connected to the RSU input to supply a 5.8 GHz continuous wave. The RSU output is linked to an HP 8596E spectrum analyzer or an oscilloscope. The transponder under test is mounted on an azimuth positioner controlled by a personal computer. An oscilloscope is connected to the comparator output of the transponder for observing the received downlink signal. The binary code for uplink communication may be designed in the transponder (for a fixed code) or be supplied by an external square-wave generator. The measurement distance between the RSU and the transponder is fixed at 1.5 *m*.

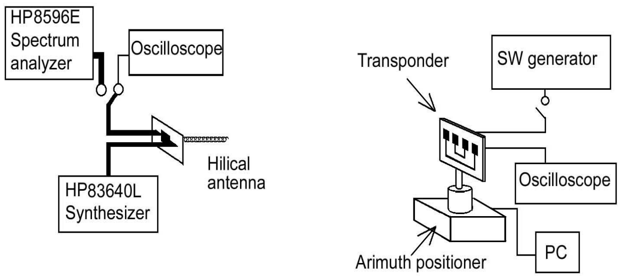


Fig. 2. Measurement setup for the transponder.

Fig. 3 shows the functional block diagram of the RSU circuit. Here, the LHCP helical antenna is used both for transmitting and receiving. This self-made 34-turns helical antenna possesses a return loss of –25 dB at 5.8 GHz with 10-dB bandwidth of 800 MHz (14%), and has an antenna gain of 16 dBi and axial ratio of 0.5 dB at the axial direction.

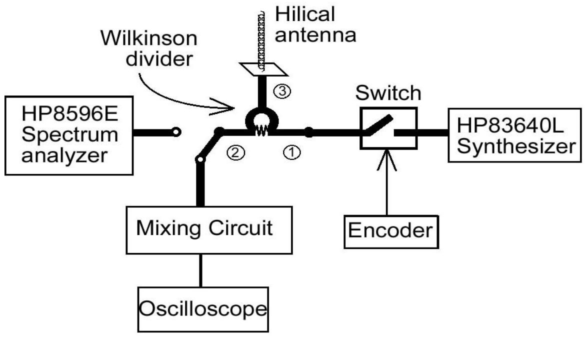
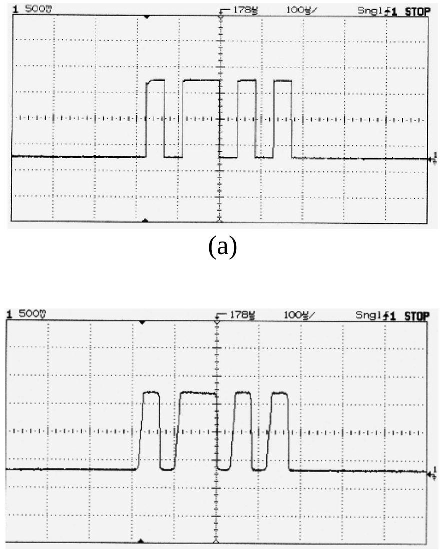


Fig. 3. Function block diagram of the RSU circuit.

The antenna is fed from Port 3 of a Wilkinson power divider as shown. Port 1 of the power divider is connected, through an ASK modulator together with an encoder circuit, to the 5.8-GHz continuous-wave source (HP 83640L). Port 2 of the divider is connected to a mixing circuit similar to the detector circuit in the transponder. The isolation between Ports 1 and 2 was measured as 28 dB. In the uplink mode, the continuous wave directly goes into the power divider without modulation. Half of the power is radiated through the helical antenna to the transponder. The modulated responding wave from the transponder is then received by the helical antenna and gets into the mixing circuit. In the mean time, the continuous wave leaked from Port 1 to Port 2 of the divider (-28-dB leakage) also enters this circuit and serves as a local oscillator signal. Thus, after the mixing of these two waves, the binary information carried by the responding wave can be extracted and observed in the oscilloscope.

In the measurement of the transponder performance, a fixed 8-bit binary code of "10110101" as shown in Fig. 4 (a) was first designed in the transponder's encoder circuit. In the uplink communication mode, this code was carried by the responding wave to the RSU and detected out in the mixing circuit. The detected signal is shown in Fig. 4 (b), which exhibits exactly the same code as the original one. For the downlink measurement, a binary code of "10101011" was embedded in the encoder circuit of the RSU and was added to the 5.8-GHz continuous wave. The modulated wave, after transmitted to the transponder, was then decoded in the detector circuit. Although not shown here, the binary signal extracted from the transponder exhibited the same code as that in the RSU.

Two additional transponders were made and compared to the present transponder. These additional transponders have the same building blocks in the transponder backside as those described in the last section, but with different antenna layouts in the front side. One uses a parallel-fed four-element microstrip antenna array and the other uses a



(a)

(b)

Fig. 4. (a) Signal embedded in the transponder. (b) Signal extracted from the RSU.

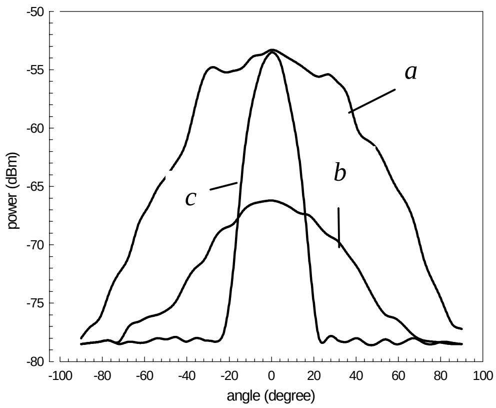


Fig. 5. Measured back-scattering field patterns for the retrodirective-array transponder (curve *a*), the single-antenna transponder (curve *b*), and the parallel-fed-array transponder (curve *c*).

single microstrip antenna, for both receiving and re-radiating. The feed line of the antenna array or the single antenna was connected to an ASK modulator with one port opened. The back-scattering patterns of the transponders were measured. The results are shown in Fig. 5. It is noticed that the retrodirective-array transponder has a back-scattering field level about 12 dB higher than the single-antenna one, and that both of these transponders possess a 3-dB back-scatting beamwidth of about 70°. On the other hand, due to the field cancellation, the back-scattering wave of the parallel-fed-array transponder was attenuated fast as the angle moved away from the normal direction. The 3-dB beamwidth is about 14°, which is much smaller than that of the retrodirective-array transponder.

IV. CONCLUSIONS

A novel card-type 5.8 GHz transponder has been proposed and demonstrated in this paper. The transponder used four LHCP microstrip antennas, arranged as a Van Atta retrodirective array, for receiving and re-radiating the in-coming wave. An ASK modulation circuit designed using PIN diode switches and an encoder circuit was embedded in the transponder to modulate the responding wave. Also, a slot antenna and a Schottky diode detector have been incorporated in the transponder for the purpose of downlink communication.

The experiment technique for measuring the transponder performances was described. A self-made LHCP helical antenna fed by the output of a Wilkinson power divider was used both for transmitting and receiving in the RSU. Also, in the RSU, the continuous wave leaked through the power divider served as a local-oscillator signal for mixing and thus decoding the received responding wave. 8-bit binary codes with different clock rates have been separately incorporated in the transponder and the RSU to demonstrate the uplink and downlink communication performances of the transponder. Finally, by comparing to the parallel-fed-array transponder and the single-antenna transponder, it has been verified that the proposed transponder is with both the benefits of high responding-wave levels and wide responding angles.

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