Design of a Planar Array Transponder with Broad Responding Beam

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Abstract— **A new planar array transponder, including four active receiving-transmitting microstrip antenna pairs, were demonstrated by using the Van Atta array design. The fields retransmitted by all the antenna pairs spatially combine in the wave-incidence direction while interfere with each other in other directions, so that the transponder responds the signal only to the on-line interrogator. The measured 10 dB (5 dB) responding beamwidth for the array transponder is 106°(80°), which is approximately the same as that of a transponder with a single antenna pair. Also, the measured radar cross section (RCS) patterns for the transponder at the on state (with bias) and off state (without bias) were compared. More than 20-dB difference between the patterns of these two states has been observed.**

Index Terms—**Broad responding beam, planar array transponder, transponder, Van Atta array design.**

I. INTRODUCTION

THE NEED FOR microwave/millimeter-wave transponders has grown rapidly in various commercial areas. By combining with the computerized systems for security and control tasks, the transponders can be used for remote identification of articles and personnel [1]. They are also useful in the rescue of maritime distress, where the transponders equipped on the ships in distress can provide the real-time range and bear information to the searching airborne (or ship borne) radars [2]. Other possible applications of the transponders can be found in road traffic management systems and automotive collision avoidance systems [3], [4], where they can be furnished in vehicles as on-board-units to communicate with roadside beacons, or be designed as traffic signs or obstacle warning signs to respond to the interrogations of vehicle radars.

The RF part of a microwave/millimeter-wave transponder includes a receiving antenna, a signal amplifier or mixer, and a transmitting antenna. A digital code of identification or communication can be used to control the amplifier (mixer) so that messages can be passed out to the interrogator from the transmitting antenna. For most applications, two aspects are needed for the transponders, that is, a wide range of responding angles and a high signal gain. To obtain a wide range of responding angles, broad-beam antennas can be used in the receiving and transmitting ends of the transponder. One feature of this design is that the transponder responds the signal not only to the on-line interrogator, but also to other ones which are not interrogating the transponder. On the other hand, to get a high signal responding gain, one may design a high-gain amplifier (mixer) in the transponder. The drawback is that the level of the retransmitted power is limited by the saturation of the active devices (especially for those used in the millimeter-wave range). Also, when more than one interrogating signals come into the transponder, the saturated amplifier (mixer) would mix the signals due to the nonlinear effect. Recently, a retrodirective array transponder, which may solve the first problem, has been designed by using heterodyne phased scattering elements [5]. In their design, a mixer was required for each antenna element and an additional local oscillator operating at twice the system frequency was needed to provide the reference signals to all the elements. Also, the transponder gain was limited by the power of the oscillator.

In this letter, we demonstrate a new transponder using an active planar antenna array. The array includes several receiving-transmitting antenna pairs, each with an amplifier, arranged by using the Van Atta array design [6], [7]. Due to this arrangement of the antennas, the array transponder possesses a range of responding angles as wide as that of a transponder with a single antenna pair. Also, since the fields retransmitted by all the antenna pairs spatially combine in the wave-incidence direction, no high-gain amplifiers are needed so that the nonlinear effect can be avoided. As long as the space is allowed, the signal gain can be increased without limit by just enlarging the size of the array.

II. DESIGN

Fig. 1 illustrates the structure of the planar array transponder, which contains four aperture-coupled microstrip antenna pairs. The transmitting antennas ($4'$, $3'$, $2'$, $1'$) were designed with different (linear) polarizations to the receiving antennas (1, 2, 3, 4). The dielectric constant and the thickness are, respectively, 2.3 and 0.787 mm for the antenna substrate [Fig. 1(a], and are 2.2 and 0.508 mm for the circuit substrate [Fig. 1(b)]. The aperture-coupled microstrip antenna [with feed line width of 1.6 mm (50 Ω)] has length of 8.73 mm, width of 12 mm, coupling aperture size of 4×1 mm^2, and tuning microstrip stub length of 5 mm. The measured return loss for this antenna is −19 dB at the frequency of 10.025 GHz [7]. The amplifier in each antenna pair was designed using LIBRA and was implemented with an NE32484 HEMT. A return loss of as low as −18 dB and a gain of 11 dB were measured at the design frequency ($I_D = 40\ mA$, $V_{DS} = 2V$, $V_{GS} = 0\ V$). The inter-element distance d between the receiving (transmitting) antennas was chosen to be 18 mm

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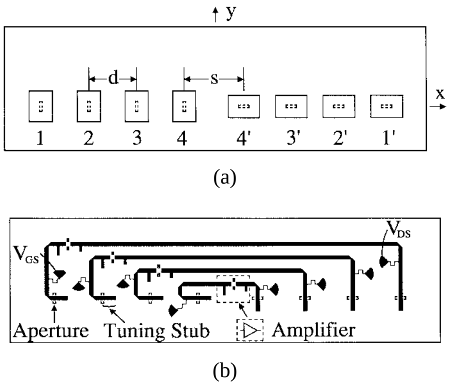

Fig. 1. (a) Top view and (b) bottom view of a planar array transponder. Patches 1, 2, 3, 4 are the receiving antennas and patches 4′, 3′, 2′, 1′ are the transmitting antennas.

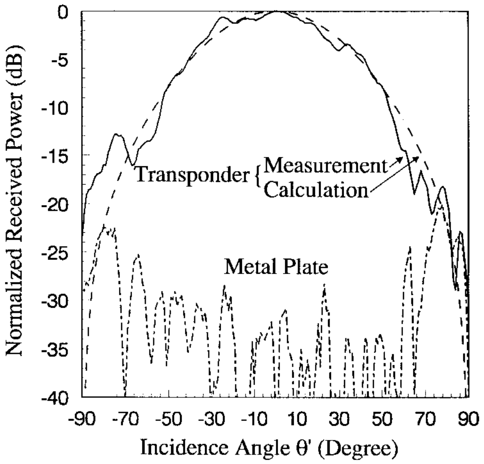

Fig. 2. Cross-polarized radar cross sections of the array transponder and a metal plate. $f = 10$ GHz.

$(= 0.6\lambda_0)$, and the distance s between antennas 4 and $4'$ was 21 mm $(= 0.7\lambda_0)$. The whole transponder measured a size of 160×48 mm^2.

The retransmitted field $E(\theta', \theta)$ can be easily derived as

$$E(\theta',\theta)=CE_r(\theta')E_t(\theta)\sum_{n=1}^{N}A_n e^{-j\phi_n}e^{-jk_0(n-1)d(\sin\theta'-\sin\theta)} \tag{1}$$

where θ' (θ) is the wave incidence (retransmission) angle (in the x-z plane). $E_r(\theta')$ and $E_t(\theta)$ are the radiation patterns of the receiving antennas and the transmitting antennas, which are, respectively, the E-plane and H-plane patterns of the microstrip antenna in the present design. A_n and ϕ_n are the gain and the phase delay caused when a wave travels along the microstrip line (and the amplifier) connecting the nth antenna pair. $N(= 4)$ is the number of the antenna pairs and C is a constant.

From the Van Atta array design [6], the differences between the signal path lengths (from the receiving antennas, passing the amplifiers, and to the corresponding transmitting antennas) were designed to equal multiples of the guided wavelength in the microstrip line so that the phase delays ϕ_n's are the same for all the antenna pairs. As can be seen from (1), the fields radiated from the transmitting antennas under this arrangement add coherently at the wave-incidence direction $(\theta = \theta')$, resulting in a maximum retransmitted field at this direction.

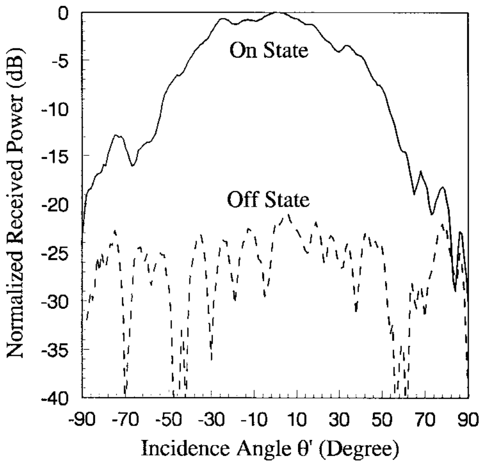

Fig. 3. Cross-polarized radar cross sections of the array transponder at on state (with bias) and off state (without bias). $f = 10$ GHz.

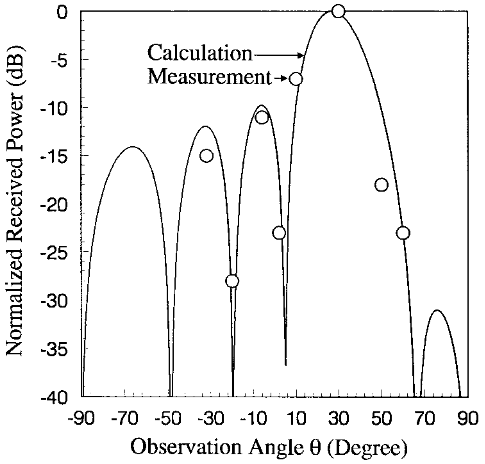

Fig. 4. Normalized received power, as a function of the observation angle θ', for a wave incident from the angle of $\theta = 30°$. f = 10 GHz.

III. RESULTS

The cross-polarized radar cross section (RCS) of the designed array transponder was measured at a distance of 146 cm (which is larger than the far field distance (35 cm) for the receiving or transmitting antenna array). Fig. 2 compares the results of the measurement and the calculation (from (1) with $\theta = \theta'$). For references, the measured result of a metal plate with the same size as the transponder is also shown in the figure. As can be seen, the measured results agree quite well with the calculated ones. The 10-dB (5 dB) beamwidth is about 106° (80°). In this range of the incidence angles, the RCS's of the metal plate are, in the average, 25-dB lower than those of the transponder. As mentioned above, a digital code can be used to control the bias conditions of the amplifiers so that identification or communication messages are produced. Fig. 3 illustrates the measured RCS patterns for the transponder at the on state (with bias) and off state (without bias). More than 20-dB difference between the patterns of the two states can be observed.

It can be derived from (1) that, for a constant incidence angle θ', the retransmitted field $E(\theta', \theta)$ of the array transponder has only one maximum (at $\theta = \theta$) if the incidence angle $|\theta|$ is smaller than $\theta_{\max}(= \sin^{-1}((\lambda_0/d) - 1) = 42^\circ)$. Fig. 4 depicts the measured and calculated received powers, as a function of the observation angle θ, for a wave incident from the angle of $\theta' = 30^\circ$. It can be seen that the measurements coincide very well with the calculations. The received power at the main lobe ($\theta = 30^\circ$) is at least 10-dB higher than those at the side lobes.

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