Design of a High Gain and Dual Polarized Transmitarray Using FSS of Smaller Unit Cells

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***Abstract* – This paper proposes a transmitarray antenna consisting of a four-layer FSS (Frequency Selective Surface) array and a horn antenna. From reciprocal theorem, the designed transmitarray system can be used to receive satellite signals using the horn antenna. The transmitarray system is operated in Ku-band satellite downlink band, which ranges from 10.7 GHz to 12.75 GHz. The four-layer FSS are printed on a low cost FR-4 substrate with a moderate loss tangent (=0.02). The unit cells of the FSS reported in this paper are smaller than those found in previous research [1-3], for example, it was about 0.39 λ_0 at 11.7 GHz. Also the four-layer FSS have a full transmission phase range of 360° and the transmission loss was equal to or less than 3.5 dB when subjected to two orthogonally polarized TE and TM waves. The transmitarray has a measured gain of 26.2 dB which resulted in the aperture efficiency of 62% for aperture diameter of about 8.2λ_0 at 11.7 GHz.**

***Index Terms* — transmitarray, dual polarization, multilayer FSS.**

1. Introduction

High gain antennas have been used in modern communication systems, for example, an army or an explorer radar and satellite communication [4]. High gain antennas, which employ two independent polarizations, can improve the efficiency of spectrum utilization in satellite communications [5]. Printed circuit technology has been applied since 1969. Many researchers utilize this technology to manufacture the feeding networks for antenna array [6-7]. Although the antenna array built on PCB offered many advantages such as low profile and easy integration with microwave circuits, it has some disadvantages. Among them, the loss from the feeding networks may be excessive, due to the moderate loss tangent of the substrate. As a consequence, the gain of antenna array can be limited. Although, the network loss problem can be solved by using low loss substrates, it is, nevertheless, not an economical solution, because low loss substrates are expensive. The proposed transmitarray is a more cost effective solution.

The transmitarray antenna is also known as plate array lens antenna, and is based on optical and microstrip array antenna theory. It consists of a feeding antenna, which illuminates multiple layers of transmitting surface as phase tuner. The goal is to achieve 360° fully transmission phase range by controlling the transmission phase of each unit cell. In [8] various lengths of FSS unit cells were used to obtain 360° transmission phase. Although transmitarray has many attractive features, it has at least one disadvantage, that is, low aperture efficiency, according to previous research. Low efficiency means the reflection or transmission aperture has not been designed properly [1-3].

In this work, transmitarray antenna using FSS array of smaller unit cells is proposed for dual polarization applications. Because of miniaturized unit cells, there will be more transmission apertures to function as phase tuners; thus to reduce the phase errors across the entire aperture.

2. Illuminate Horn Antenna

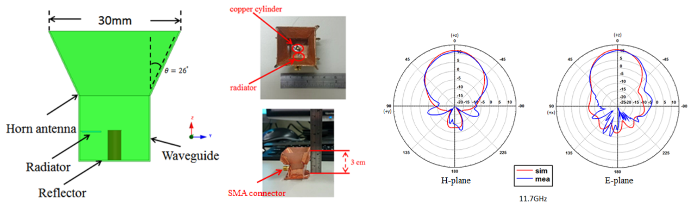

Fig. 1. (a) Horn antenna configuration, (b) 2-D radiation patterns.

Fig. 1 (a) shows the configuration and photo of the proposed horn antenna. The overall dimensions of horn antenna are 30 mm (W) × 30 mm (W) × 30 mm (high). The horn antenna shows the measured directivity gain of about 11.4 dB at 11.7 GHz and the E- and H-plane radiation pattern are shown in Fig.1 (b). Although a side beam was found in the E-plane of the 2-D pattern, it does not disturb the transmitarray because the transmitarray is far away from horn antenna and it just received the 30° radiation angle. The side beam may have been caused by the SMA connector.

3. FSS Design

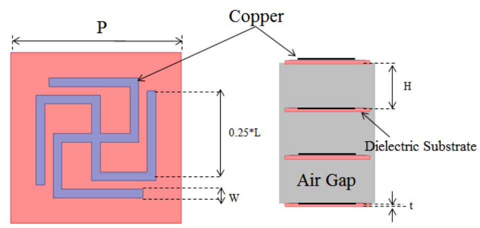

Fig. 2. Top (right) and side (left) views of FSS unit cell.

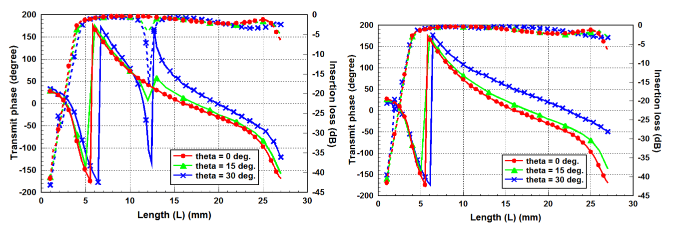

Fig. 3. Transmission phase with different incident wave angles for TE (left) TM (right) waves.

Fig. 2 shows an FSS unit cell, whose side, P, is equal to 10 mm ($\approx 0.39\lambda_0$, at 11.7 GHz), whereas w, the trace width, is 0.2 mm, H, the PCB layer height, is 5.2 mm, and t, the thickness of the FR-4 substrate, is 0.4 mm. Here we obtained the transmission coefficients and phase by changing the length (L) of the FSS unit cells [8]. Fig. 3 shows the results as a function of L at different oblique incident angles for both polarizations. The angle of the oblique incident wave, θ_i, is defined in Figure 4. From Fig. 3, the FSS unit cells have 360° fully transmission phase between L= 4.8 and 25 mm for both TE and TM polarizations for oblique wave incident angles up to 30°. Under the same conditions, the transmission losses are less than 3.4 dB. The FSS unit cells are indeed equipped with dual polarization property.

4. Transmitarray Antenna Design

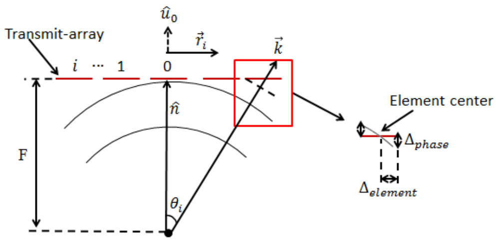

Fig. 4. Global and local phases in the transmitarray.

Fig. 4 shows the direction of the oblique incident wave, θ_i, and position vector $\vec{r_i}$. The local phase correction Δ_{phase} is given by (1),

$$\Delta_{phase} = {}^{2\pi}/_{\lambda} \times \Delta_{element} \times \sin\theta_i \quad (1)$$

where $\Delta_{element}$ is the size of the element, and θ_i is the direction of the oblique incident wave. The reduced element size $\Delta_{element}$ means the phase error in transmit plane is reduced too. Thus, we can control the transmit plane more precisely. The transmission phase from transmit plane position to the feed horn (F) has to be considered. And the required transmission phase φ_i for the i_{th} element is expressed in (2),

$$\varphi_i = k\left(\sqrt{F^2 + |\vec{r_i}|^2} - \vec{r_i} \cdot \hat{u}_0\right) + \varphi_c \quad (2)$$

where k is propagation constant, F is focal length, $\vec{r_i}$ is the position vector of the ith element, $\hat{u}_0$ is the unit vector of main beam. Finally, a transmitarray is fabricated in this work with 333 FSS elements, as show in Fig. 5. And the aperture diameter is equal to 210mm ($\approx 8.2\lambda_0$) and was 170 mm (F) above the horn antenna. Here we choose the center phase (φ_c) equal to 22° which ensure the following elements transmission loss be less than 1 dB.

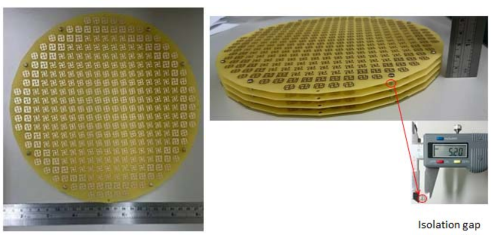

Fig. 5. Top and side views of proposed transmitarray.

Fig. 6 shows measured 2-D radiation pattern, gain, and the aperture efficiency with frequency between Ku-band satellite downlink. The measured result shows the tramsmitarray antenna has a high gain and aperture efficiency of 26.2 dB and 63%, respectively. Table 1 shows comparison of this work with previously reported results.

5. Conclusion

A high gain and high aperture efficiency transmitarray antenna with small FSS unit cells was manufactured and measured. By means of minimized FSS unit cells, more FSS unit cells can be present, and phase error in the transmit plane can be reduced at the same time. The proposed transmitarray antenna has the measured gain of 26.2 dB and 62% aperture efficiency with 1 dB gain bandwidth of 14%. There is 30% improvement in aperture efficiency as compared to [3].

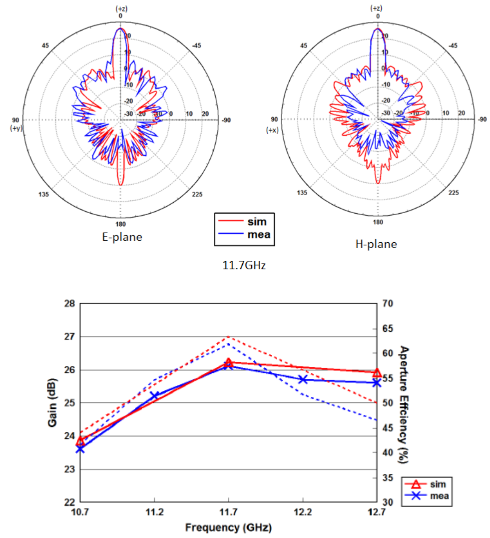

Fig. 6. 2-D radiation patterns and peak gain of the proposed transmitarray antenna.

Table 1. Comparison of results.

Ref.	Freq. (GHz)	FSS unit cell	Aperture Diameter	Gain (dB)	Aperture efficiency (%)
[1]	11.3	$0.62\lambda_0$	$13.02\lambda_0$	23.76	14.2
[2]	9.8	$0.5\lambda_0$	$10\lambda_0$	22.7	15.4
[3]	11.3	$0.6\lambda_0$	$16.2\lambda_0$	28.9	30
This work	11.7	$0.39\lambda_0$	$8.2\lambda_0$	26.2	62

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