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PERFORMANCE STUDIES OF RADIAL LINE SLOT ARRAY (RLSA) ANTENNA AT 5.8 GHz ON DIFFERENT MATERIALS

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9.1 INTRODUCTION

The type of dielectric material used as radial cavity in the Radial Line Slot Array (RLSA) antenna structure would influence the characteristics of the antenna, particularly its Radiation Pattern. The dielectric material create a slow wave structure, with the guided wavelength λ_g being smaller than the free space wavelength λ_0 to avoid grating lobes in the radiation pattern.

In this chapter, three RLSA antenna prototypes were developed using three different dielectric materials. The antenna prototypes are designed to have linear polarisation and operate at 5.8 GHz. For comparison purpose, the Return Loss, Radiation Pattern and Relative Gain measurement of each antenna prototype were carried out.

9.2 EM WAVE BEHAVIOUR WITHIN RADIAL CAVITY

Consider the basic structure of an RLSA antenna as shown in Figure 9.1. The power flow within the radial cavity for single layered RLSA antenna is shown, with reference to the transmission mode. Since an antenna is a reciprocal device, this would be sufficient to describe its operation, even for the receiving mode.

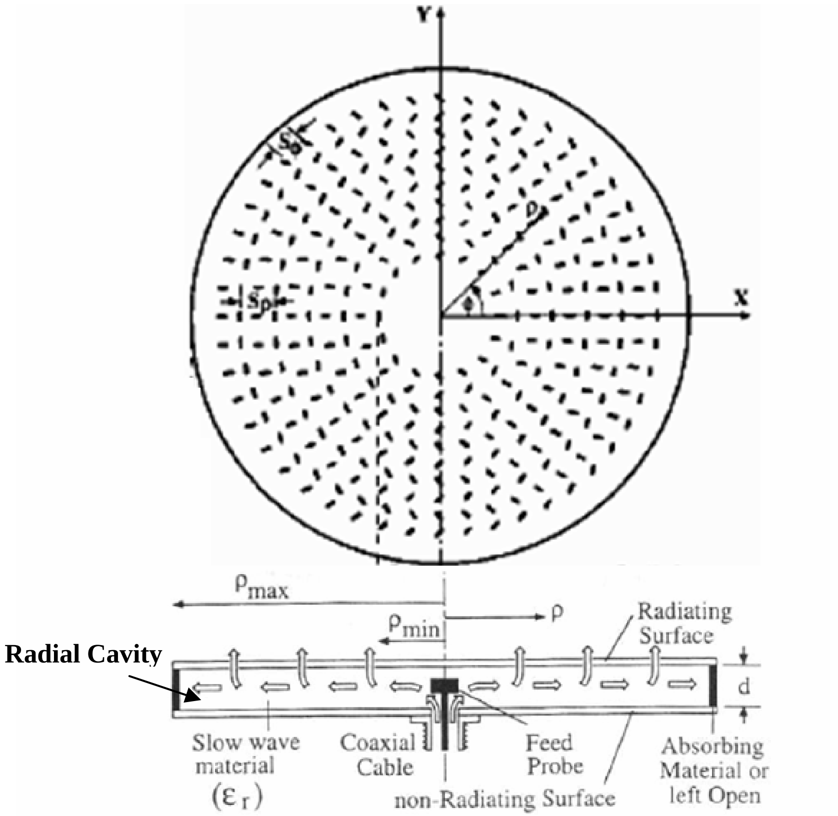

Figure 9.1 Power Flow Within the RLSA Radial Cavity

In the transmit mode, electromagnetic power is fed from a coaxial transmission line into the centre of the radial slow wave cavity by the disk ended feed probe. The feed probe is needed to convert power from the Transverse Electromagnetic (TEM) transmission line mode into a TEM cavity mode that travels axially outward wave inside the radial cavity. A region of radius is left devoid of slots, in order for the radial mode to stabilise within the guide before encountering the discontinuities related to the presence of the slots.

The slots arrangement on the upper plate was designed such that it couples as much of the cavity energy into the radiated pencil beam as possible, as energy not radiated is lost. The slots were designed to intercept the currents on the upper waveguide surface and produce radiation of the desired polarisation. The height of the radial cavity, d has to be limited to be less than one half of the guide wavelength.

$$d < \frac{\lambda_g}{2} \quad (9.1)$$

where d is the height of the radial guide, and λg is the wavelength inside the radial guide, here is referred to as the guide wavelength. Under these conditions, the only possible symmetric waveguide mode that can propagate within the radial cavity is a TEM mode.

9.3 THEORETICAL SURFACE SLOTS DESIGN

The design method for the placement and arraying of slots is similar to the approach adopted in. The geometry of unit radiator, which consists of adjacent pair slots as shown in Figure 9.2, is referred to in the design. To achieve linearly polarised radiation, the requirements as per below must be met:

i. The co-polar components must combine in phase.

ii. The cross-polar components must cancel each other out. These requirements can be expressed mathematically as follows:

co-polarisation:

$$\sin\theta_1 \sin(\theta_1 + \varphi) - \sin\theta_2 \sin(\theta_2 + \varphi) = 1 \quad (9.2)$$

cross-polarisation:

$$-\sin\theta_1 \cos(\theta_1 + \varphi) + \sin\theta_2 \cos(\theta_2 + \varphi) = 0 \quad (9.3)$$

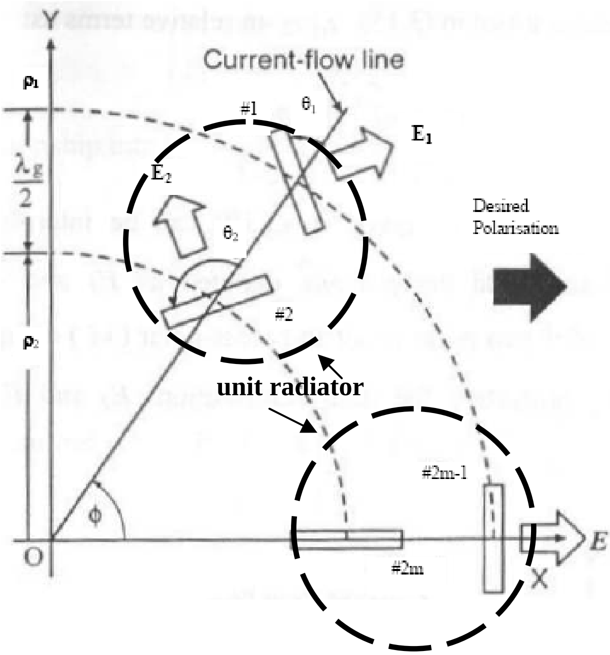

Figure 9.2: Slot Geometry for a Linearly Polarised Unit Radiator

To meet this prerequisite, θ_1 and θ_2 is selected to be

$$\theta_1 = \frac{\pi}{2} - \frac{\phi}{2} \qquad (9.4)$$

$$\theta_2 = \pi - \frac{\phi}{2} \qquad (9.5)$$

Via (4) and (5), unit radiators with suitable orientation are arrayed around a given ring of radius ρ. The angular spacing S_ϕ of the unit radiators placed on a ring of set radius is chosen arbitrarily.

The radial spacing, S_p, between consecutive unit radiators in the radial direction is made one guide wavelength, λ_g distance. This is to attain 0° phase shift for the successively arrayed slot rings, in order to obtain broadside radiation. This can be expressed as:

$$\rho_{odd} = \rho_1 \pm n\lambda_g \qquad \textit{for slot 2m-1} \qquad (9.6)$$

$$\rho_{even} = \rho_2 \pm n\lambda_g \quad \textit{for slot 2m} \tag{9.7}$$

where *n* and *m* are integers. *m* being the order of the unit radiator within the n^{th} ring. *m* will start from value 1, up to the number of unit cells in the current ring. *n* shall start from value 0, with *n*=0 represents the innermost ring, of radius $\rho_{\min}$.

In the design, the beam squinting technique is employed to improve the Return Loss characteristic. Referring to Figure 9.3, assuming that the desired squint angle is θ_T, ϕ_T in the respective planes shown, the contributions of co-phased slot radiation's superposition at the observation point produce the following expressions for new slot inclination angles θ_1, θ_2: when this technique is employed are

$$\theta_1 = \frac{\pi}{4} + \frac{1}{2}\left\{\arctan\left(\frac{\cos\theta_T}{\tan\phi_T}\right) - (\phi - \phi_T)\right\} \tag{9.8}$$

$$\theta_2 = \frac{3\pi}{4} + \frac{1}{2}\left\{\arctan\left(\frac{\cos\theta_T}{\tan\phi_T}\right) - (\phi - \phi_T)\right\} \tag{9.9}$$

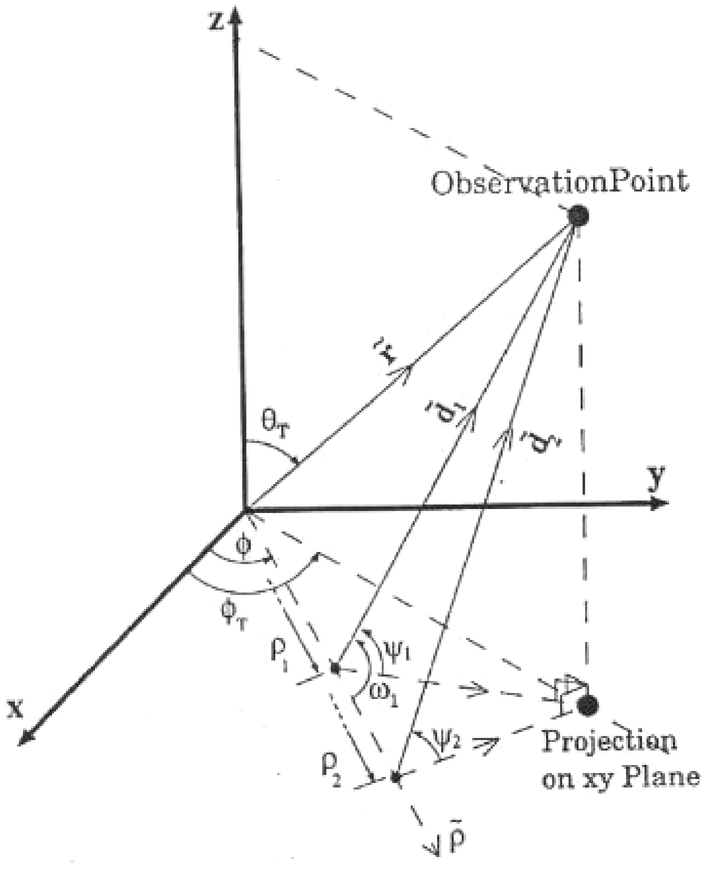

Figure 9.3 The beam squint geometry

The radial spacing between consecutive slot pairs, S_ρ would also be modified to become

$$S_\rho = \frac{\lambda_g}{1 - \xi \sin\theta_T \cos(\phi - \phi_T)} \qquad (9.10)$$

where, $\xi = 1 / \sqrt{\varepsilon_r}$

9.4 ANTENNA PROTOTYPE DEVELOPMENT

In this study, Teflon, Polycarbonate and FR4 are chosen to be the three dielectric materials to be used as the dielectric material in the RLSA antenna slow wave structure. The Dielectric Constant for the three materials are 2.1, 3.0 and 5.4 respectively. The values were acquired from each manufacturer.

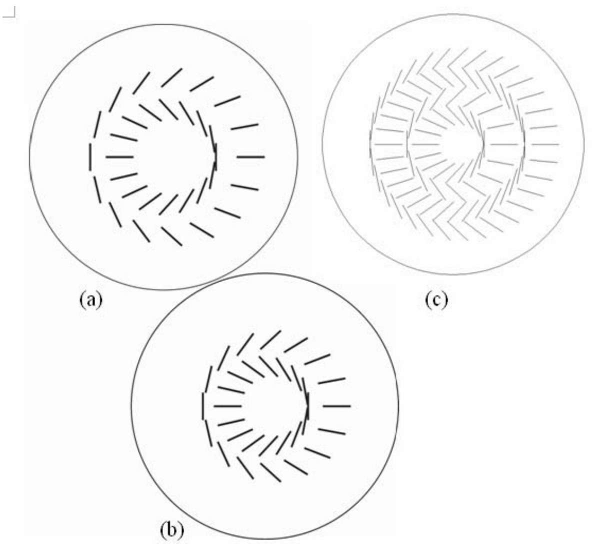

Figure 9.4 Generated slots patern for (a)teflon, (b)polycarbonate, & (c)FR4

The antenna diameter for each antenna is fixed at 150mm. The Teflon and Polycarbonate sheets acquired were of 6mm thickness. On the other hand, three pieces of thin FR4 sheets were stacked together, making up a thickness of 5mm. The number of radiating slots on the RLSA antenna depends on the antenna surface diameter and the dielectric constant of the slow wave material. The generated slots pattern is shown in Figure 9.4.

The radiating surface and ground plane for the antennas are made of copper and are of circular shape. The feed probe is attached and positioned at the centre of the ground plane. The feed probe's dimension is optimised to produce the best return loss at centre frequency 5.8GHz.

9.5 RESULTS AND DISCUSSION

Using the Marconi Instrument microwave test set 6204, the Return Loss measurement were acquired for the three antenna prototype. Figure 9.5 shows the results obtained.

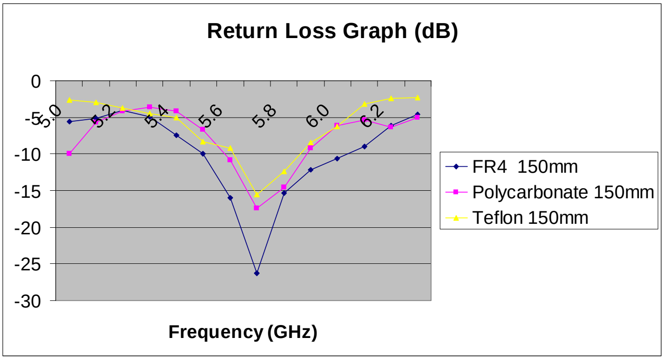

Figure 9.5 Return Loss graph for the three antenna prototypes

From the measurement, conducted all antenna prototypes have Return Loss value of below -14 dB, thus signifying signal reflection of maximum 5 %. The FR4 antenna prototype shows the best measured Return Loss value at centre frequency 5.8GHz.

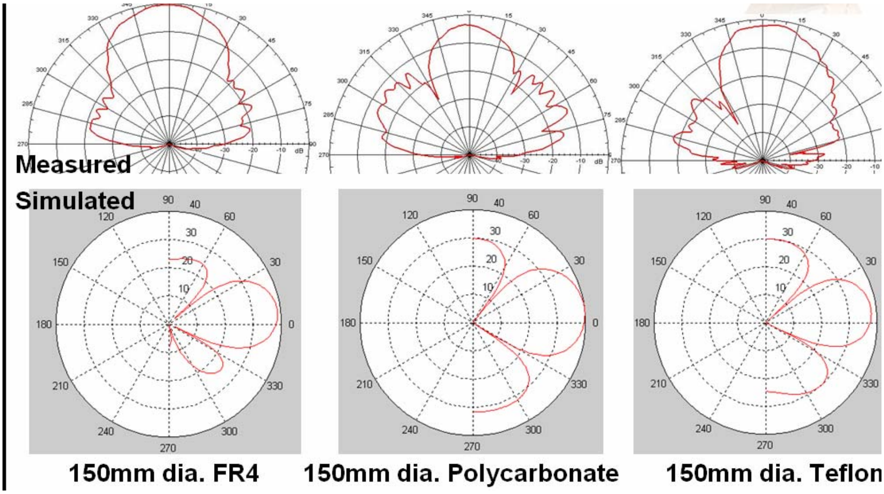

Figure 9.6 Comparison of Measured and Simulated Radiation Pattern

The Radiation Pattern characteristic was measured using an Anechoic Chamber. Figure 9.6 displays the simulated and the measured pattern. The Measured Radiation Patterns show agreement with the simulated one. From the measurement, it can be seen that FR4 antenna prototype exhibit less side lobes, thus indicating less loss. The main lobe of the FR4 shows that it can reach further distance compared to the other two antenna prototypes.

For Relative Gain measurement, the reference antenna used is a 5.8GHz unidirectional planar antenna, provided by Landasan Teknologi (M) Sdn. Bhd. which has a gain of 12 dBi. Using the Anechoic Chamber, the measured signal strength received from a transmitter source is compared between the reference antenna and the three antenna prototypes. Table 9.1 shows the measurements obtained. The results show that FR4 antenna prototype has the highest gain, followed by the Polycarbonate and Teflon antenna prototype.

Table 9.1 Measured signal strength and computed relative gain

Antenna	**Signal Strength (dB)**	Relative Gain (dBi)
Reference Antenna	-62.75	12
150 mm dia. Teflon	-60.03	14.72
150 mm dia. Polycarbonate	-54.93	19.82
150 mm dia. FR4	-51.52	23.23

9.6 CONCLUSIONS

Table 9.2 shows the overall design and measured parameters of the three Prototype antennas

Table 9.2 Comparison of the antenna prototypes

Parameter	**FR4 prototype**	**Polycarbonate prototype**	**Teflon Prototype**
Diameter (mm)	150	150	150
Thickness (mm)	5	6	6
Return Loss (dB)	-20.2	-15.8	-14.6
Dielectric Constant	5.4	3.0	2.1
Relative Gain (dBi)	23.23	19.82	14.72

From the studies conducted, FR4 antenna prototype shows the best performance in terms of the characteristics measured. This is followed by Polycarbonate and Teflon. If the dielectric constant is to be accounted for the acquired result from this study of three different materials, the higher the constant value is, the better the Return Loss and Relative gain would be. However, this need to be verified through further studies on a greater number of dielectric materials samples.

Since this study tried to simplify materials acquirement process, the dielectric materials acquired were of standard thickness as supplied by respective supplier. Thus, not all prototypes have similar thickness. This may also influence the measured results obtained. Thus further studies can work on to overcome this.

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