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ANALYSIS OF A CPW-FED SLOT RING ANTENNA

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A coplanar waveguide (CPW)-fed slot ring antenna is analysed by using a spectral domain moment method. The equivalent magnetic current on the slot is expressed by a set of global bases. Travelling wave type of bases are used on the CPW with linear basis functions near the junction of slot ring and CPW. Results of IE3D and experiment are compared to verify this approach. Other feed lines using microstrip and stripline are also studied. It is concluded that the CPW feed has better performance than the other two.

1 Introduction

Ring structures have been widely analyzed and designed for antenna applications. In [1], a rigorous analysis on the resonant characteristics of annular-ring microstrip antenna was performed using asymptotic expansions technique and perturbation approach. The relation between mode distribution and input impedance was studied by using cavity model and vector Hankel transform in [2]. Another approach including the effect of coaxial feed was presented in [3]. Furthermore, cavity model was applied to estimate the resonant frequency and the current distribution when operating in the higher order modes [4], [5].

In [6], the design and fabrication technique of a microstrip-fed slot ring antenna for mobile communication were presented. However, such antenna has high cross-polarization level [7]. Hence, an FET was added to suppress the cross-polarization level to lower than −12dB. A slot ring antenna fed by a stripline, which is suitable for mobile satellite systems, was discussed in [8].

All of the antennas mentioned above are implemented as multi-layered structures which require complicated fabrication process. A slot ring antenna fed by a CPW is easier to implement than the other feed lines [9]. The merit of CPW can also be utilized.

In all the slot ring antennas with different feed lines, only experiment results were presented. In this paper, we analyze the CPW-fed slot ring antenna using a spectral domain moment method, and the performance of these three feed lines are also compared.

2 Formulation

Fig.1 (a) shows the configuration of a CPW-fed slot ring antenna. The fields above and below the metal surface are first expressed as two-dimensional integrals in the spectral domain. Applying the equivalence principle on the slot, equivalent magnetic surface currents are defined, and all the field components can be expressed in terms of the magnetic surface currents. Applying the boundary conditions between each layer, two coupled integral equations can be obtained as

$$
\begin{aligned}
&\int\int_{-\infty}^{\infty} d\bar{k}_s e^{-j\bar{k}_s\cdot\bar{r}_s}\left[G_{xx}(\bar{k}_s)\tilde{M}_{sx}(\bar{k}_s)+G_{xy}(\bar{k}_s)\tilde{M}_{sy}(\bar{k}_s)\right]=0, \qquad \bar{r}_s \text{ on the slot} \\
&\int\int_{-\infty}^{\infty} d\bar{k}_s e^{-j\bar{k}_s\cdot\bar{r}_s}\left[G_{yx}(\bar{k}_s)\tilde{M}_{sx}(\bar{k}_s)+G_{yy}(\bar{k}_s)\tilde{M}_{sy}(\bar{k}_s)\right]=0, \qquad \bar{r}_s \text{ on the slot} \qquad (1)
\end{aligned}
$$

To solve these integral equations by method of moments, travelling-wave type of basis functions are used to expand the incident and the reflected equivalent magnetic currents associated with the fundamental mode on the CPW [9]. Linear basis are also placed on CPW near the junction with the antenna to account for the perturbation due to discontinuities.

On the slot ring, we choose a set of global basis functions to expand the magnetic surface currents as

$$M^a_{s\phi}(\rho,\phi)=\sum_{n=0}^{N_a-1}\sum_{m=0}^{M_a-1}A_{mn}\cos\left[\frac{n\pi}{\phi_t}\left(\phi+\pi/2-\alpha\right)\right]\frac{\cos\left[m\pi(\rho-a)/(b-a)\right]}{\rho\sqrt{(\rho-a)(b-\rho)}}$$

m is even, n is even

$$M^b_{s\phi}(\rho,\phi)=\sum_{n=1}^{N_b}\sum_{m=0}^{M_b-1}B_{mn}\sin\left[\frac{n\pi}{\phi_t}\left(\phi+\pi/2-\alpha\right)\right]\frac{\cos\left[m\pi(\rho-a)/(b-a)\right]}{\rho\sqrt{(\rho-a)(b-\rho)}}$$

m is even, n is odd (2)

where $\phi_t = 2(\pi-\alpha)$, the edge effects are considered, and the ρ^{-1} factor is used to simply the formulation when transforming (2) into the spectral domain. Next, Galerkin procedure is applied to convert the integral equations into a matrix equation from which the reflection coefficient can be obtained.

3 Results and Discussions

Figs.2 (a) and 2 (b) show the return loss of a CPW-fed slot ring antenna. Simulation results using IE3D and measurement results are also shown for comparison. The resonant frequency is around 2.5GHz. In the experiment, the antenna is fabricated on an FR4 substrate with ε_r=4.3 and thickness of 1.58mm. The S_{11} is measured by using HP8510C network analyzer, and the TRL calibration is used to set the reference plane at the junction of the transmission line with the slot ring. Reasonable agreement between our approach and experiment is observed. The measurement results favour our approach than the IE3D simulation, especially the phase of return loss. This deviation can be partially attributed to the segmentation approximation used in IE3D.

A thorough parameter study indicates that the return loss is mainly determined by the slot ring width, and the resonant frequency is mainly determined by the circumferential length of the slot ring. A bandwidth at 10 dB return loss is about 15% as shown in Fig.2 (a), much wider than those of CPW-fed rectangular slot loop antenna, annular ring, and circular patch antenna.

A microstrip-fed slot ring antenna and a stripline-fed slot ring antenna are shown in Figs.1 (b) and 1 (c). The magnitude of return loss of these three different feed lines are shown in Fig.3 (a). The bandwidth of the CPW-fed antenna is 15%, almost the same as that of the microstrip-fed antenna. And the stripline-fed structure has a narrow bandwidth of 2%.

Figs. 2 (c), 3 (b), and 3 (c) show the electric field distributions of these three structures on the slot ring. The magnetic current distribution of the stripline-fed structure is very different from that of the others. Since the stripline-fed slot ring antenna is backed by an additional ground plane, the effective wavelength in such structure is shorter than that of the other two. Hence, the circumference of the slot ring is about two wavelengths with a stripline feed, and about one and a half wavelengths for the other two feeding structures. The inner circular patch of the slot ring works like a microstrip patch. The electric current distribution on the inner patch with a backed ground is also similar to that of the circular patch antenna. Hence, its bandwidth is inherently narrow.

From the magnetic current distribution of the stripline-fed slot ring antenna, it is found that there is a null in the broadside direction, and the other structures have main beam in the broadside direction. Notice that for the microstrip-fed antenna, the electric field on the slot ring above the microstrip is strongly enhanced. Hence, the radiation pattern deviates from that of the resonant ring. Such phenomenon is not observed for the other structures. Near the CPW feed junction, the electric field on the CPW is almost perpendicular to that on the slot ring. Near the stripline feed junction, the electric field on the slot reaches its maximum. Hence the field on the slot ring is only slightly affected.

4 Conclusions

A coplanar waveguide(CPW)-fed slot ring antenna is analyzed by using a spectral domain moment method. The equivalent magnetic current on the slot is expressed by a set of global bases. Travelingwave type of bases are used on the CPW with linear basis functions near the junction of slot ring and CPW. Reasonable agreement between our approach and experiment is observed. The results of our approach are better than IE3D simulation comparing with the experiment. Moreover, the CPW-fed structure and microstrip-fed structure have wider bandwidth than the stripline-fed structure. Radiation pattern of the microstrip-fed structure is asymmetric due to the strong field excited near the microstrip. It is concluded that the CPW feed has better performance than the other two.

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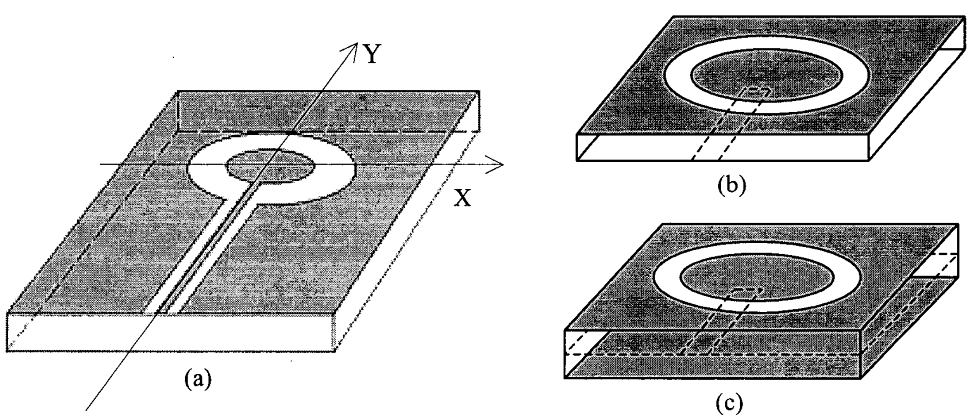
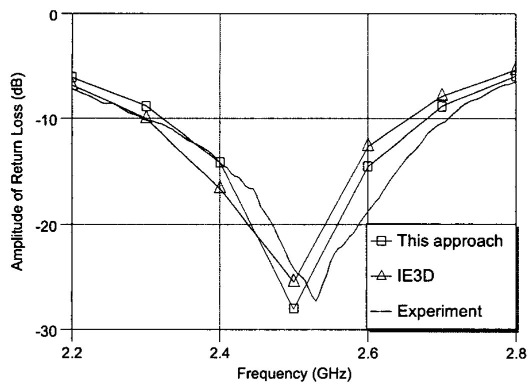
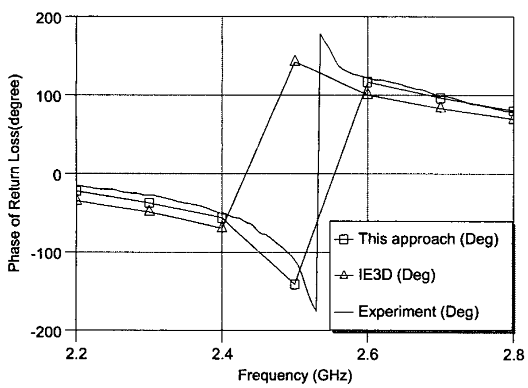


Fig.1 Configuration of a slot ring antenna fed by (a) CPW, (b) microstripline, and (c) stripline



(a)



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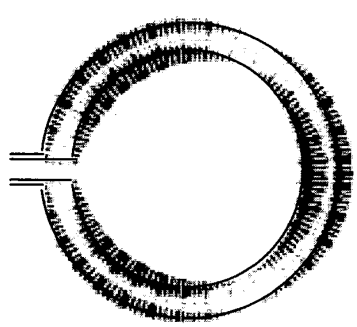
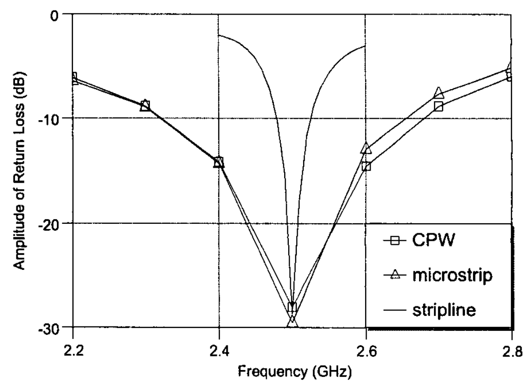
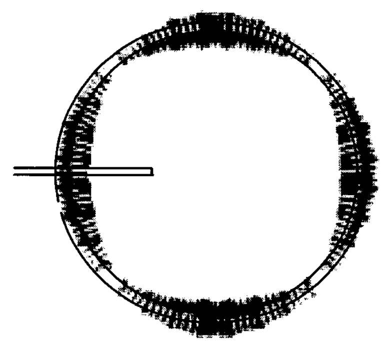


(c)

Fig.2 Return loss of a CPW-fed slot ring antenna, inner radius is 20mm, outer radius is 25mm, substrate thickness is 1.58mm, ε_r = 4.3, slot width is 0.3mm, and central strip width is 3mm on CPW, (a) magnitude of S_{11}, (b) phase of S_{11}, and (c) electric field distribution on the slot ring.



(a)



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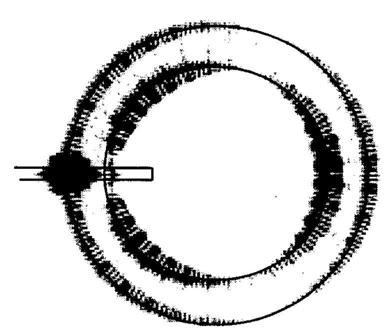

(c)

Fig.3 Comparison of three different feed lines, (a) return loss, (b) electric field distribution of a stripline-fed slot ring antenna (inner radius is 22mm, outer radius is 28mm, substrate thickness is 3.16mm, and ε_r = 4.3, strip width is 1.4mm;) (c) electric field distribution of a microstrip-fed slot ring antenna (inner radius is 21mm, outer radius is 29mm, substrate thickness is 1.58mm, ε_r = 4.3, and strip width is 3mm.)