FUNDAMENTAL SUPERSTRATE EFFECTS ON PRINTED CIRCUIT ANTENNA EFFICIENCY

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ABSTRACT

Printed circuit antennas integrated on typically used substrates such as quartz, GaAs or Si exhibit low radiation efficiency due to surface wave effects in the substrate (e.g., a GaAs substrate yields on optimum radiation efficiency of $e_s \simeq 28\%$). It is demonstrated in this paper that $e_s = 100\%$ is feasible with practical materials either by using a magnetic superstrate layer or by integrating the antennas on the lower side of a dielectric superstrate (such as GaAs), while in this case, the substrate is merely a supporting layer with lower dielectric constant. The effect of the composite layer is to eliminate surface waves, provided the layer thicknesses are chosen properly.

EFFICIENCY OPTIMIZATION

Printed circuit antennas are increasingly utilized in various microwave as well as millimeter wave applications. Although the typically used substrates such as GaAs, Si or quartz may be ideal for circuit integration in hybrid or monolithic form, they affect adversely the performance of an antenna integrated on the substrate. Amongst the various antenna design parameters, a significant one is the antenna radiation efficiency which, e.g., under optimum conditions for a GaAs substrate is $e_s \leq 28\%$ [1], i.e., most of the radiated power is absorbed in the substrate. The orientation of this paper is to determine methods which lead to the optimization of the performance of printed circuit antennas with emphasis on optimizing e_s and in fact to determine geometries which yield $e_s = 100\%$.

The total radiation efficiency of antennas is defined as [2]

$$e_t = \frac{P_r}{P_{in}} \tag{1}$$

where P_r is the total power radiated into free space and P_{in} the total power input in the antenna terminals. The overall radiation efficiency of printed circuit antennas can also be written as

$$e_t = e_c e_{sd} \tag{2}$$

where e_c is the efficiency factor due to ohmic losses in the antenna conducting structure. The factor e_{sd} is defined here as the overall substrate efficiency and is given as

$$e_{sd} = P_r/(P_r + P_d) \tag{3}$$

where P_d is the power loss due to the dielectric. If there are no ohmic losses in the dielectric, the power loss in the dielectric is due to unattenuated surface waves which propagate radially out from the antenna. If the dielectric is lossy, the surface waves attenuate as they propagate and the dielectric losses may be considered to be ohmic in nature only. If the dielectric material is only slightly lossy, the total power which is dissipated throughout the dielectric is essentially that which is initially launched into the surface waves, and treating the problem as completely lossless will give a good approximation to e_{sd}. That is,

$$e_{sd} \approx e_s = P_r/(P_r + P_{sw}) \tag{4}$$

where P_{sw} = power in surface waves for the lossless case. This factor e_s may prove to be the most critical one in lowering the overall radiation efficiency of printed circuit antennas, depending on substrate thickness and permittivity/permeability properties. For cases where $e_s = 100\%$ is not possible, geometries which maximize e_s will be presented.

A method which utilizes the concept of a superstrate layer and yields $e_s = 100\%$ has been developed. [3]. The substrate, under this scheme, merely serves the function of a supporting layer with the antennas actually printed on the bottom side of the superstrate with $\varepsilon_2\mu_2 > \varepsilon_1\mu_1$ (see Figure 1). A disadvantage of this approach for nonmagnetic layers is the fact that for substrate materials with only moderately ε_1 values ($\varepsilon_1 \gtrsim 2.10$) the maximum allowable substrate thickness is quite small, regardless of the ε_2 value used, if $e_s = 100\%$ is to be achieved. For example, if $\varepsilon_1 = 2.1$, then $\sqrt{\varepsilon_1}\, B_{max}/\lambda_o \approx .010$. Furthermore, as e_2 becomes large, the maximum substrate thickness decreases, so it would be necessary to use ε_1 values very close to 1.0 to achieve significant substrate thickness. For example, with a GaAs top layer ($\varepsilon_2 \approx 12.5$), it is necessary that $\varepsilon_1 \leq 1.0$ in order to achieve $\sqrt{\varepsilon_1}\, B_{max}/\lambda_o \geq .05$. For thin substrates, the radiation resistance is very low due to ground plane image effects and this tends to reduce the overall antenna radiation effect.

These undesirable properties of low radiation resistance or impractically low ε_1 values may be eliminated by using a magnetic superstrate layer.

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It is then possible to achieve e_s = 100% with reasonable radiation resistance and a wide variety of substrate dielectric constant.

The governing equations for the elimination of wave modes and e_s = 100% have been determined to be

$$\cot\left[2\pi\left(\frac{n_2 t_c}{\lambda_o}\right)\sqrt{1-\left(\frac{n_1}{n_2}\right)^2}\right] = \frac{\sqrt{n_2^2 - n_1^2}}{\varepsilon_2\sqrt{n_1^2-1}} \tag{5}$$

and

$$\frac{1}{\sqrt{n_2^2-1}}\tan^{-1}\frac{\mu_1\sqrt{n_1^2-1}}{\mu_2\sqrt{n_2^2-1}}\cot\left[2\pi\frac{n_1 B_{max}}{\lambda_o}\sqrt{1-\frac{1}{n_1^2}}\right] =$$

$$= \frac{1}{\sqrt{n_2^2-n_1^2}}\tan^{-1}\left[\frac{\varepsilon_2\sqrt{n_1^2-1}}{\sqrt{n_2^2-n_1^2}}\right] \tag{6}$$

where t_c is the critical superstrate thickness, B_{max} the maximum allowable substrate thickness, $n_1^2 = \varepsilon_1$ and $n_2^2 = \varepsilon_2$ and μ_1, μ_2 the permeability of the substrate and superstrate respectively.

By utilizing Equations (1) and (2), the critical dimensions for e_s = 100% will be presented for a variety of practical substrate and superstrate materials with an example being shown in Figure 2. In addition, for cases where practical dimensions cannot be realized for e_s = 100%, various schemes will be presented which maximize e_s considerably beyond published data as in [1].

CONCLUSION

A combination of superstrate-substrate materials is determined which yields radiation efficiencies of 100% for printed circuit antennas. Various schemes are also presented which maximize radiation efficiencies considerably beyond published data, for those cases where e_s = 100% is not realizable.

REFERENCES

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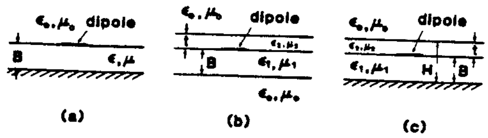

Figure 1

Geometry of (a) Microstrip ,(b)Asymmetric Layers and (c) Microstrip with a Superstrate.

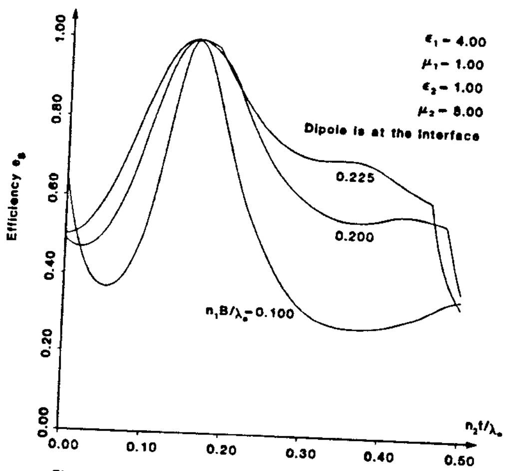

Figure 2 Efficiency vs. n_2t/λ_o

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