BROADBAND ANALYSIS OF RADIATING, RECEIVING AND SCATTERING CHARACTERISTICS OF MICROSTRIP ANTENNAS AND ARRAYS

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1. Introduction.

This paper presents an analysis of microstrip antennas and arrays. The cases considered are a single patch with pin feed, an array of patches fed by pins and an array of microstrip dipoles, all above a ground plane. In each case, the solution is obtained via an inverse Fourier transform Green's dyadic Galerkin's method formulation. The solution is potentially exact over frequency ranges of 3 to 1 or more, including higher-order resonances. An attachment current distribution which provides for continuity at the feed pin-patch junction, and for which the spatial Galerkin's method integrals are integrable in closed form, is introduced

2. Single circular patch antenna with post feed.

The patch is located on a layer of dielectric, situated above a ground plane, as shown in Figure 1. A thin feed pin spans the thickness of the dielectric between the patch and the ground plane. Three cases are considered. In the scattering case, the feed pin is attached to both the patch and the ground plane. The structure is illuminated by a plane wave and the currents on the patch and feed pin are obtained. In the transmitting case, a voltage source is inserted between the feed pin and the ground plane. No plane wave is assumed here, so the voltage source is the only source for driving the antenna. In the receiving case, an arbitrary load impedance replaces the voltage source and a plane wave again serves to drive the structure. This case is found as a combination of the first two cases, with the voltage in the transmitting case chosen so as to be equal to the voltage across the load impedance due to the currents flowing through it.

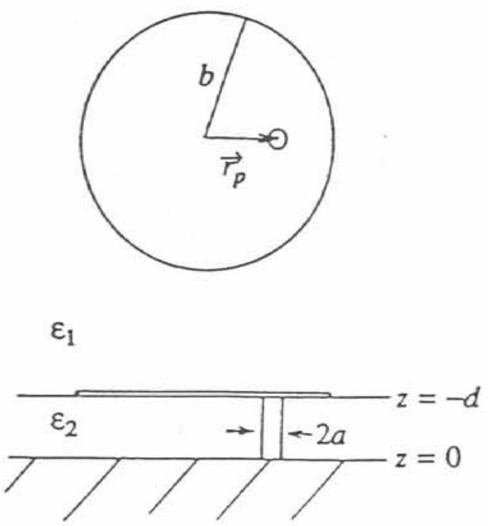

Figure 1. Single patch with feed pin.

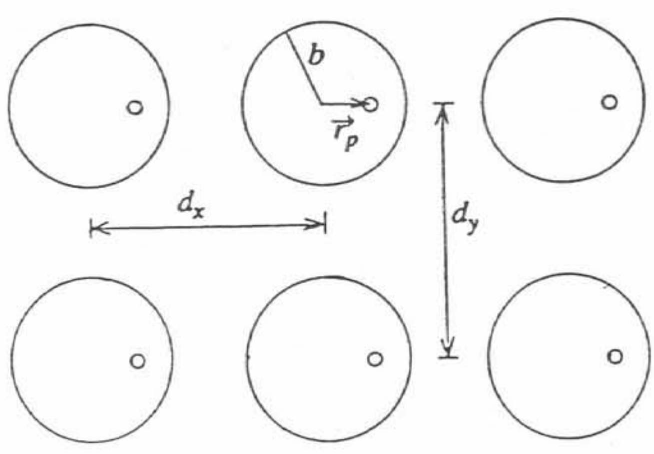

Figure 2. Infinite array of patches.

In all cases, the antenna behavior is obtained over a wide frequency band. The behavior of higher-order resonances, along with the behavior away from resonance, is then important and needs to be accurately determined.

To facilitate this, the current on the patch surface is expanded as a summation over a set of smooth continuous currents. These current distributions are either purely radial or purely azimuthal. In the azimuthal direction, they vary sinusoidally, and in the radial direction they vary as Tchebychef polynomials, modified by the appropriate edge factor. The feed pin current distribution has two components. The first component flows along the feed pin surface with no variation along or around the feed pin. The second component flows across the patch surface radially away from the patch-feed pin junction. The feed pin current distribution is constructed so that current flows continuously from the feed pin onto the patch with no charge build-up at the patch-feed pin junction. Also, the patch component of the feed pin current away from the junction is smooth and continuous, and its divergence is continuous. Thus, there are no line or point charges produced.

The tangential component of the electric field at the surfaces of the feed pin and patch is obtained via an inverse Fourier Green's dyadic formulation. For currents flowing parallel to the ground plane at the dielectric-cover interface, the component of the electric field Green's dyadic normal to the ground plane is found for the dielectric region, and the electric field Green's dyadic components parallel to the ground plane are obtained at the interface. Likewise, for current flowing normal to the ground plane within the dielectric region, the same Green's dyadic components are found. The necessary dyadic components are

$$g_{\alpha\alpha}(z{=}0, x, y \mid z'{=}0, x', y', \vec{k}) = \frac{1}{(2\pi)^2}\iint_{-\infty}^{\infty} \frac{e^{j\vec{k}\cdot(\vec{r}-\vec{r}\,')}}{j\omega\varepsilon_1} \times \frac{(k_1^2\varepsilon_r - k_\alpha^2)p_1 + (k_1^2 - k_\alpha^2)p_2\tanh(p_2 d)}{\left[p_1 + p_2\coth(p_2 d)\right]\left[\varepsilon_r p_1 + p_2\tanh(p_2 d)\right]}\, d^2k \tag{1}$$

$$g_{xy}(z{=}0, x, y \mid z'{=}0, x', y', \vec{k}) = g_{yx}(z{=}0, x, y \mid z'{=}0, x', y', \vec{k}) = \frac{1}{(2\pi)^2}\iint_{-\infty}^{\infty} \frac{e^{j\vec{k}\cdot(\vec{r}-\vec{r}\,')}}{j\omega\varepsilon_1} \frac{-k_x k_y\left[p_1 + p_2\tanh(p_2 d)\right]}{\left[p_1 + p_2\coth(p_2 d)\right]\left[\varepsilon_r p_1 + p_2\tanh(p_2 d)\right]}\, d^2k \tag{2}$$

$$g_{z\alpha}(\vec{r} \mid \vec{r}\,') = \frac{1}{(2\pi)^2}\iint_{-\infty}^{\infty} \frac{e^{j\vec{k}\cdot(\vec{r}-\vec{r}\,')}}{j\omega\varepsilon_1}\, e^{-p_1 z'} \frac{jk_\alpha p_1\cosh(p_2(d+z))}{\cosh(p_2 d)\left[\varepsilon_r p_1 + p_2\tanh(p_2 d)\right]}\, d^2k \tag{3}$$

$$g_{\alpha z}(\vec{r} \mid \vec{r}\,') = \frac{1}{(2\pi)^2}\iint_{-\infty}^{\infty} \frac{e^{j\vec{k}\cdot(\vec{r}-\vec{r}\,')}}{j\omega\varepsilon_1}\, e^{-p_1 z} \frac{-jk_\alpha p_1\cosh(p_2(z'+d))}{\cosh(p_2 d)\left[\varepsilon_r p_1 + p_2\tanh(p_2 d)\right]}\, d^2k \tag{4}$$

$$g_{zz}(\vec{r} \mid \vec{r}\,') = \frac{1}{(2\pi)^2}\iint_{-\infty}^{\infty} \frac{e^{j\vec{k}\cdot(\vec{r}-\vec{r}\,')}}{j\omega\varepsilon_2} \times \left\{\delta(z - z') + \left[\frac{k_2^2 + p_2^2}{p_2}\right]\frac{\cosh(p_2(z^< + d))}{T_m}\left[\frac{p_2}{p_1}\cosh(p_2 z^>) - \varepsilon_r\sinh(p_2 z^>)\right]\right\} d^2k \tag{5}$$

where α represents either x or y, and where

$$z^> = \max\,(z, z') \qquad z^< = \min\,(z, z'). \tag{6a,b}$$

The boundary conditon of zero tangential electric field at the patch and feed pin surfaces is enforced via Galerkin's method. The current distributions have been chosen so that all spatial integrations arrising from Galerkin's method, including those involving the patch component of the feed pin current, can be performed in closed form. The spectral integrations are then obtained via real-line integration.

3. Infinite array of circluar patch antennas with feed pins.

The set-up for each patch is as described above for a single patch. The patches are arranged in a rectangular array, as shown in Figure 2., infinite in both direction. The solution is again approached via a Green's dyadic formulation. Because this is for an infinite array, the inverse Fourier transforms of the single patch Green's dyadic become infinite summations, thus avoiding the spectral integrations. The summation may be truncated after a sufficient number of terms. The corresponding spatial integrations arrising from Galerkin's method may still be performed closed form. The infinite array Greens dyadic components are obtained from the corresponding ones for an isolated current element with the following transformation:

$$\int\int_{-\infty}^{\infty} d^2k \rightarrow \frac{(2\pi)^2}{d_x\, d_y} \sum_{p,q=-\infty}^{\infty} \tag{7}$$

where $\vec{k}$ is now

$$\vec{k} = (k_1\, u + p\, \frac{2\pi}{d_x})\, \hat{x} + (k_1\, v + q\, \frac{2\pi}{d_y})\, \hat{y} \tag{8}$$

Received power is obtained for an arbitrary load impedances. Below, the received power is shown as a function of frequency for load impedances set equal to the complimentary impedance of the input impedance, and matched to the input impedance.

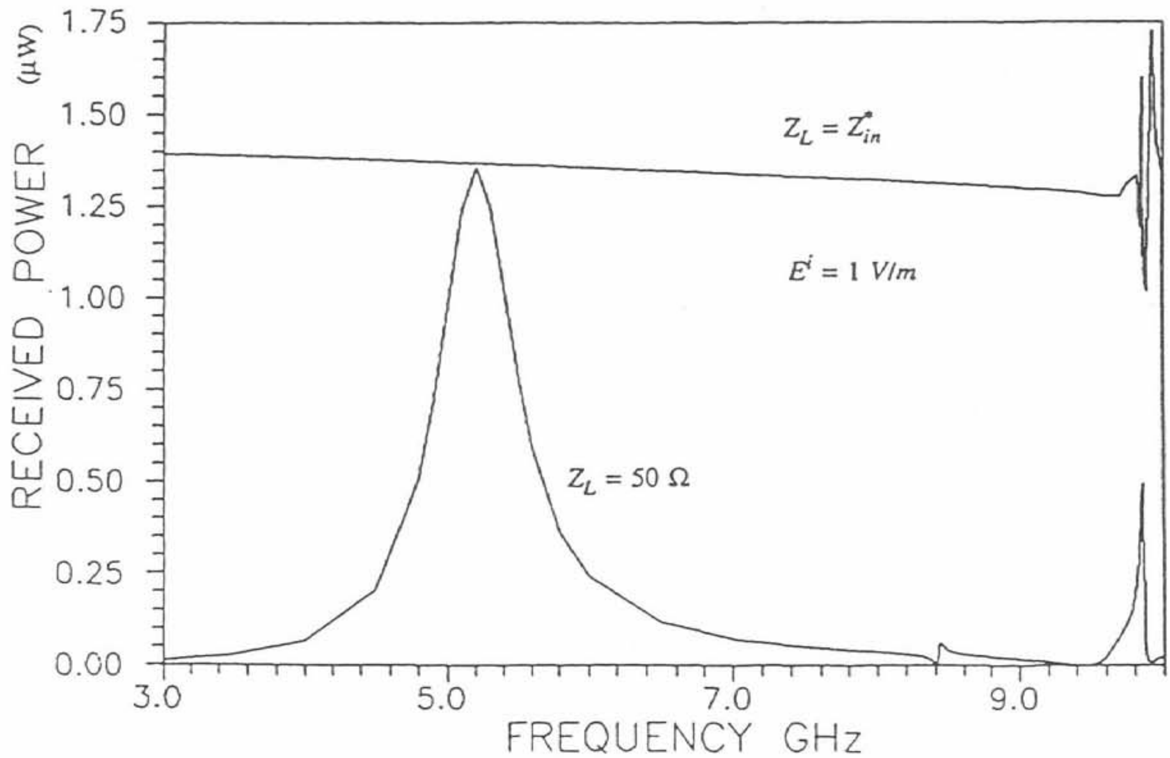

Figure 3. Received power for patch array.

4. **Infinite array of microstrip dipole antennas.**

The dipoles are located on a layer of dielectric, situated above a ground plane. Again, three cases are considered. In the scattering case, there is only an array of strip dipoles, with no voltage sources or impedances present. The structure is illuminated by a plane wave and the currents on the dipoles are obtained.

In the transmitting case, a voltage source is inserted at the center of each dipole. This voltage source is the only source for driving the array.

In the receiving case, an arbitrary load impedance replaces the voltage source and a plane wave again serves to drive the structure. Again, this is found as a combination of the first two cases, with the voltage in the transmitting case chosen so as to be equal to the voltage across the load impedance due to the currents flowing through it.

Only currents flowing along the length of the dipole are assumed, and the electric field component along this same direction is the only component tested and set to zero, so only a single Green's dyad component is needed. For dipoles whose length is in the x-direction, the $\hat{x}$-$\hat{x}$ component is the one needed.

Below, the received power received is shown for load impedance set equal to the input impedance, equal to the complimentary impedance, and matched

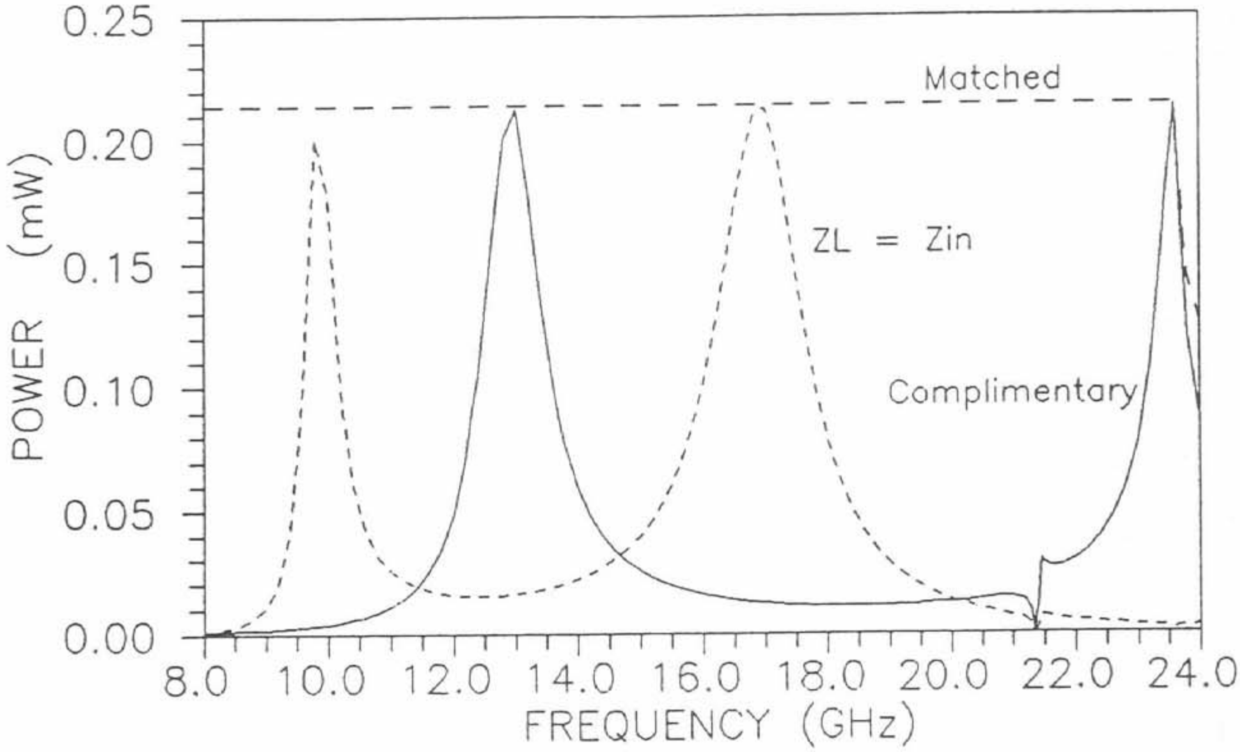

Figure 4. Received power for an infinite array of microstrip dipoles.