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A RIGOROUS ANALYSIS OF ELECTROMAGNETICALLY COUPLED MICROSTRIP PATCH ANTENNAS, A DYADIC GREEN'S FUNCTION APPROACH

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ABSTRACT

A moment method solution to the problem of input impedance and mutual coupling of microstrip patch antenna elements excited by a coax transmission line is presented.From the reciprocity theorem a reaction integral equation is formulated by treating the coaxial aperture as a part of the antenna.The formulation uses the dielectric coated conductor dyadic Green's function to account rigorously for the presence of substrate and surface waves.This accurate technique is suitable for the evaluation of mutual coupling and the interactions between feed and element in millimeter wave printed antennas.The method has been applied to obtain the input impedance and mutual coupling of two coupled patches fed by coax transmission line.Comparison with experimental results shows excellent agreement.

I.INTRODUCTION

The extensive use of microstrip antenna technology requires analysis methods capable of accurately predicting the input impedance, mutual coupling and radiation of these antennas [1]. Recently, a moment method solution to the coax fed microstrip antenna problem was proposed[2], From the reciprocity theorem an integral equation is formulated, which is used to solve for the current distributions on the patch and the feed probe.This approach uses the exact dyadic Green's function for the grounded dielectric slab,and thus rigorously accounts for surface waves and coupling to adjacent antenna elements.Suitable types of expansion functions are considered,which account for the singularity of current distribution at the edges of the patch,and fast convergence of the method.The accuracy of the latter calculations is confirmed by comparison with experimental data.

II.THEORY

The geometry under consideration is shown in fig.1, in order to obtain the current distributions along the probes and the surface current distributions on the patches, an integral equation is formulated considering the reciprocity theorem.it can be written as[2]:

$$\iint (\bar{J} \cdot \bar{E}^{t})ds=\iint (\bar{M} \cdot \bar{H}^{t})ds \quad (1)$$

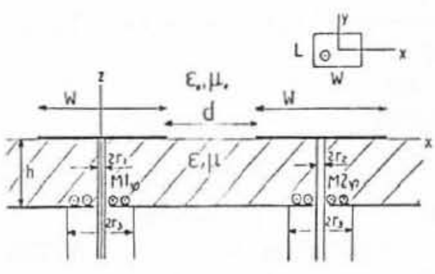


fig.1.Geometry for two coupled microstrip antenna elements fed by coax line

where $\bar{E}^t$ and $\bar{H}^t$ are due to the test sources.The right-hand side takes into account the effect of coaxial apertures, while the left-hand side accounts for the current distributions on each patche and along its corresponding probe.It should be noted that the analysis is simplified by assuming that only the transverse electromagnetic (TEM) mode is allowed to propagate in the coaxial line.

Two types of current distributions exist , vertical current distributions along the probes and horizontal current distributions on the patches,therefore we need two different types of dyadic Green's function. The elementry sources can be either a vertical electric dipole(VED) or a horizontal electric dipole (HED) [2] The dyadic Green's functions are given by the following expressions[1],[3] ($\exp(j\omega t)$ time dependence is omitted):

$$\bar{\bar{G}}(r|r')=G_{xx}\hat{x}\hat{x}+G_{zx}\hat{z}\hat{x} \quad \text{for a x-oriented HED} \qquad (2)$$

$$\bar{\bar{G}}(r|r')=G_{yy}\hat{y}\hat{y}+G_{zy}\hat{z}\hat{y} \quad \text{for a y-oriented HED} \qquad (3)$$

$$\bar{\bar{G}}(r|r')=G_{zz}\hat{z}\hat{z} \quad \text{for a z-oriented VED} \qquad (4)$$

for a HED[1]:

$$G_{xx}=-\frac{j\omega\mu}{2\pi K_m^2}\int_0^\infty \frac{\sin(k_1 z)\beta}{D_e(\beta)}J_0(\beta R)\,d\beta \qquad (5)$$

$$G_{zx}=-\frac{\omega\mu}{2\pi K_m^2}\cos(\phi)\int_0^\infty (\epsilon_r-1)\frac{\sin(k_1 h)\cos(k_1 z)\beta^2}{D_e(\beta)D_m(\beta)}J_1(\beta R)\,d\beta \qquad (6)$$

similar expressions can be obtained for G_{yy} and G_{zy} by coordinate transformation.The field point is at (x,y,z) ; the source point is at (x_o,y_o,h).In the above expressions $K_m=k_o$ in the air region and $K_m=\sqrt{\epsilon_r}k_o$ in the dielectric region,while the other parameters are defined as:

$$D_e(\beta)=k_1\cos(k_1 h)+jk_2\sin(k_1 h) \qquad (7)$$

$$D_m(\beta)=\epsilon_r k_2\cos(k_1 h)+jk_1\sin(k_1 h) \qquad (8)$$

$$k_1^2=\epsilon_r k_o^2-\beta^2 \quad (\mathrm{Im}(k_1)<0)\ ;\ k_2^2=k_o^2-\beta^2 \quad (\mathrm{Im}(k_2)<0) \qquad (9)$$

$$k_o^2=\omega^2\mu_o\epsilon_o \qquad (10)$$

note that dielectric loss is easily included by replacing ϵ_r by $\epsilon_r(1-j\tan\delta)$ in(10),where $\tan\delta$ is the loss tangent of the substrate material.The Green's function pertinent to the problem of the radiation by a Hertzian vertical electric dipole located at$(0,0,z')$where $0\le z'\le h$,is obtained as follows[3]: when the source and field point are within the substrate

$$G_{zz}(r|r')=-\frac{60j}{\epsilon_r k_o}\int_0^\infty \frac{\Omega}{uF_{TM}}\cosh(uz')\cdot[u\cosh(u[h-z])+\epsilon_r u_o\sinh(u[h-z])]J_o(\Omega R)\,d\Omega \qquad z'\le z\le h \qquad (11)$$

$$G_{zz}(r|r')=-\frac{60j}{\epsilon_r k_o}\int_0^\infty \frac{\Omega}{uF_{TM}}\cosh(uz)\cdot[u\cosh(u[h-z'])+\epsilon_r u_o\sinh(u[h-z'])]J_o(\Omega R)\,d\Omega \qquad 0\le z\le z' \qquad (12)$$

when $z\ge h$ and $z'\le h$ then

$$G_{zz}(r|r')=-\frac{60j}{k_o}\int_0^\infty \frac{\Omega}{F_{TM}}\cosh(uz')e^{-u_o(z-h)}J_o(\Omega R)\,d\Omega \qquad (13)$$

where $u^2=(\Omega^2-k^2)$; $uo^2=(\Omega^2-ko^2)$; $k^2=\epsilon r ko^2$
while $F_{TM}=(\epsilon r)uo.\cosh(uh)+u\sinh(uh)$ (14)

by superposition principle the electric field generated by a collection of infinitesimal radiation elements is expressed as[5]:

$$\bar{E}(r|r')=\sum_i \iint (Km^2\bar{\bar{I}}+\bar{\nabla}\ \bar{\nabla}).\bar{\bar{G}}_i(r|r').\bar{J}_i(r')ds' \qquad (15)$$

where $J_i(r')$ is Jx1,Jy1 or Jz1 and G_i's are the appropriate Green's function. in order to solve(1)for the unknowns,current distributions must be expanded in suitable basis functions:

$$\bar{J}_1=Jx1\ \hat{x}+Jy1\ \hat{y}+Jz1\ \hat{z}\quad ;\quad \bar{J}_2=Jx2\ \hat{x}+Jy2\ \hat{y}+Jz2\ \hat{z} \qquad (16)$$

where Jxi,Jyi (i=1,2) are surface current distribution on the patch No 1 and 2 repectively and Jzi is the current distribution along the feed probe No1 and 2 repectively:

$$\bar{J}x1=\sum_n^N I_{1n}\ Jxn\ \hat{x}\ ;\ \bar{J}x2=\sum_k^K I_{2k}\ Jxk\ \hat{x}\ ;\ \bar{J}y1=\sum_l^L I_{3l}\ Jyl\ \hat{y} \qquad (17)$$

$$\bar{J}y2=\sum_m^M I_{4m}\ Jym\ \hat{y}\ ;\ \bar{J}z1=\sum_p^P I_{5p}\ Jzp\ \hat{z}\ ;\ \bar{J}z2=\sum_r^R I_{6r}\ Jzr\ \hat{z} \qquad (18)$$

for patch No 1:

$$Jxn(x,y)=\frac{\sin(2\pi ux/W)\quad \sin[(2v-1)\pi y/L]}{[(W/2)^2-x^2]^{1/2}\ [(L/2)^2-y^2]^{1/2}} \qquad (19)$$

$$Jyl(x,y)=\frac{\cos[2(u-1)\pi x/W]\quad \cos[(2v-1)\pi y/L]}{[(W/2)^2-x^2]^{1/2}\quad [(L/2)^2-y^2]^{1/2}} \qquad (20)$$

where u=1,2,... and v=1,2,... any combination of u and v provides a specific basis function ■. The expressions for Jzp when the body of the probe is divided into N subsections are given by [3]:

$$Jz1(z)=\frac{\sin[k(l1-z)]}{\sin(kl1)} \qquad 0\le z\le l1 \qquad (21)$$

$$Jzp(z)=\frac{\sin[k(z_{p+1}-z)]}{\sin(kl1)} \qquad z_p\le z\le z_{p+1}$$

$$Jzp(z)=\frac{\sin[k(z-z_{p-1})]}{\sin(kl1)} \qquad z_{p-1}\le z\le z_p$$

where l1 is the length of each subsection.The corresponding results for Jxk ,Jym and Jzr can be obtained by coordinate translation. substituting (16) through (21) into (1) and performing the reaction integrals lead to the following matrix equation:

$$[Z]=\left(\begin{array}{c|c|c|c|c|c} Z^{P1x,P1x} & Z^{P1x,P1y} & Z^{P1x,P2x} & Z^{P1x,P2y} & Z^{P1x,P1z} & Z^{P1x,P2z} \\ \hline \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \hline Z^{P2z,P1x} & Z^{P2z,P1y} & Z^{P2z,P2x} & Z^{P2z,P2y} & Z^{P2z,P1z} & Z^{P2z,P2z} \end{array}\right)$$

$$[Z][I]=[V] \qquad (22)$$

where the submatrices $[Z^{P1x,P1x}]$, $[Z^{P1x,P1y}]$,... represent the element-element and feed-element interactions.For the evaluation of the self and mutual impedances of the structure shown in fig.1, one can write [4]:

$$Z11=-\frac{1}{I^2}\sum_i \iint (\bar{J}_i^1 \cdot \bar{E}^1 - \bar{M}^1 \cdot \bar{H}^1)ds \qquad (23)$$

where I is the total input current, J_i is $Jx1$, $Jy1$ or $Jz1$ and $\bar{E}^1$, $\bar{H}^1$ are total fields due to these current distributions. $\bar{M}^1$ is the magnetic frill current distribution due to coax aperture No 1. Similar expression exists for mutual impedance as follows:

$$Z21=-\frac{1}{I1.I2}\sum_i \iint (\bar{J}_i^1 \cdot \bar{E}^2 - \bar{M}^1 \cdot \bar{H}^2)ds \qquad (24)$$

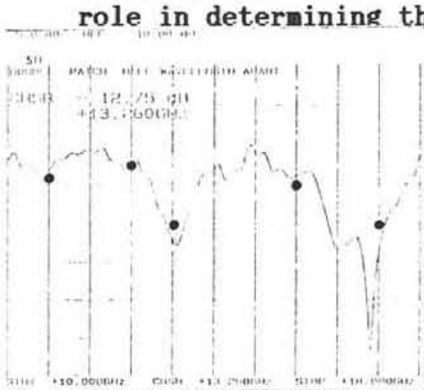
where I1 and I2 are input currents at terminals "1" and "2" and $\bar{E}^2$, $\bar{H}^2$ are total fields due to the current distributions on the patch No 2.

III. NUMERICAL RESULTS

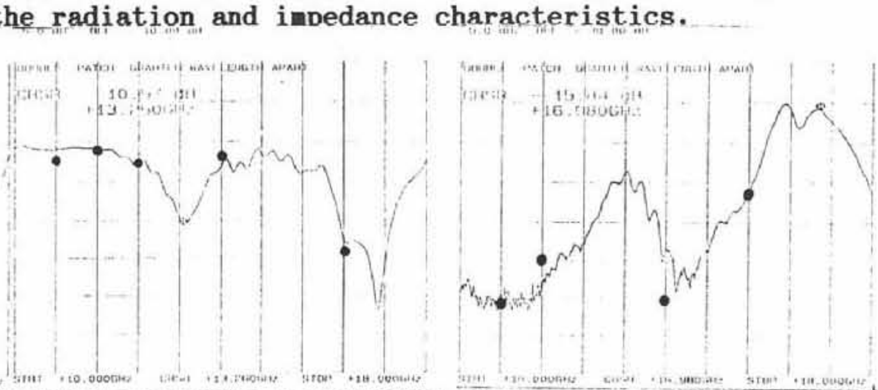
In order to evaluate the accuracy of our theoretical models, we have applied our method to several cases of practical interest. The dielectric substrate was Duroid with $\epsilon r=2.33$ and a thickness of h=0.7874 mm, other parameters were: W=10.759 mm, L=6.484 mm, 10GHz $\leq f \leq$ 18GHz, r1=0.2 mm and r2=0.225 mm. Fig. 2 compares calculated scattering coefficient |S11| with measurments for two different values of separating parameter d. Also fig.3 shows measured and calculated scattering coefficient |S12|.

IV. CONCLUSION

This paper has presented a moment method solution for the evalution of input impedance and mutual coupling in microstrip patch antennas fed by coax transmission line using the rigorous grounded dielectric slab dyadic Green's function. The good agreement between calculated and measured parameters demonstrates the accuracy and versatility of the method. The study may find applications for millimeter-wave printed antennas where the surface waves and feed-element interactions will play an important role in determining the radiation and impedance characteristics.



3. scattering coefficient s12 versus frequency calculated(■) experimental(-)



2. comparison of experimental(-) and calculated(■) results of scattering coefficient s11 versus frequency.

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■ Note: The index n for the basis functions is given by a combination of u,v