RESONANT BEHAVIOR OF SLOT COUPLED MICROSTRIP ANTENNAS

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INTRODUCTION

The present paper deals with the linear slot excitation of rectangular patches using a cavity model;the results of the cavity analysis are in good agreement either with exact Green functions and Galerkin moment solutions[1,2,3],or with measurements.Among all the parameters the slot length effects have been analysed carefully;one of the most interesting result concerns two opposite resonant behaviors of the slot coupled patches which can exhibit impedance curves of serie's R-L-C circuit[3] or the more usual parrallel's R-L-C [1,2] properties.The proposed cavity model gives a simple explanation of these two aspects.

1-CAVITY MODEL OF SLOT COUPLED PATCHES

As far as thin dielectric substrate are used only one component E_z of the electric field can be considered over the main volume under the patch(fig.1).However strong variations of the fields occur in the area near the slot;therefore a special attention has been devoted to the calculations of the E_x local field of the slot line assuming that the radiation is related to the E_z field under the patch.Moreover the back side radiation is usually negligible and has been neglected here; it can be added if necessary.The analysis needs four steps:

- the first one is the calculation of the internal field of a cavity bounded by four perfect magnetic walls and two electric walls in z=0 and t (fig.1).The field distribution in the volume V above the slot(fig 2.2)shows qualitatively that E_z remains the main component outside V. Then an equivalent magnetic current source(equal to the magnetic current of the slot) is assumed to be uniformly distributed in V(fig2.1).The current density is:

$$\boxed{\vec{J}_m = \frac{2V_0}{t\,Wa}\,\frac{\sin k^{a}(La/2 - |y-y_0|)}{\sin(k^{a}La\,'2)}\,\vec{y}} \quad \begin{array}{l} x_0 - Wa/2 \le x \le x_0 + Wa/2 \\ \qquad\qquad\qquad\qquad 0 \le z \le t \\ y_0 - La/2 \le y \le y_0 + La/2 \end{array}$$

where:- k^a <u>has been determined by COHN'S method</u> [4],taking into account the two dielectric substrates and the near metallic top plane (patch).

-V_0 is the slot voltage.

- When the internal field is known,a magnetic current source located at the edges of the cavity can be defined;therefore the radiated power Prad, dielectric (Pd) and metallic losses (Pcu) can be computed in the same iterative algorithm than the stored electric (Welec) and magnetic (Wmag) energy of the E_z component(and the related $\vec{H}$ components).The patch admittance Yant is:

$$\boxed{Y_{ant} = [P_{rad} + P_{cu} + P_d + 2j\omega(W_{elec} - W_{mag})]\,|V_o|^{-2}}$$

• However the local fields around the aperture exhibits E_x components (and the associated $\vec{H}$) which do not couple to the radiated fields but contributes to the stored energy of the cavity.A shunt susceptance Y_{ap} must be added to Y_{ant};its value equals the susceptance of two short-circuited slot lines(length=$L_a/2$).It must be noticed that the characteristic impedance and the wavenumber($k^a=2\pi/\lambda_{gsl}$) of the slot line are strongly dependent of the near metallic patch;these values have been carefully computed using a COHN'S method[4] taking into account the various dielectric constants,the thicknesses,the resonant length of the patch.

• The input impedance on the microstrip line(fig.3) needs the computation of the modal voltage discontinuity ΔV due to the slot cut in the ground plane[5].The final impedance including the open stub(impedance Z_c,length L_s) is:

$$\boxed{Z_{in} = \frac{\left(\Delta V / V_o\right)^2}{Y_{ant}+Y_{ap}} - j\, Z_c \operatorname{cotg}\left(k^1 L_s \right)}$$

2-IMPEDANCE VERSUS SLOT LENGTH

Two kinds of impedance curves have been shown in previous publications,namely the RLC parallel's type[1,2]which is the more usual and the RLC serie's type[3] which displays a large bandwith.

2-1-RLC parallel type.

The antenna parameters are those given in ref.[1].The results of both methods have been plotted on fig.4-a,4-b.In each case as the slot length is reduced the radius of the impedance circle decreases and moves toward the short circuit location.The agreement is good for impedance values and resonant frequencies.Similarly as in [1] fig.4-c shows that the resonant frequency decreases slightly with an increasing slot length while the input resistance increases.A very good match can be obtained from the cavity curves for a slot length of 1.12 cm at the resonant frequency of 2.233 Ghz(instead of 1.09 cm and 2.233 Ghz in [1]).The resonant frequency of the cavity model given in [1] for comparison was 2.306 Ghz;the large discrepancy between our results(2.233 Ghz) and the previous value comes from the fact that the slot excitation plays a fundamental role both on impedance values and resonant frequency.To give an idea on this effect the admittances Y_{ant} (patch alone) ,Y_{ap} and Y_{total} are plotted on fig.5.a;transformer and stub contribution have been omitted .It is very clear on fig.5-b,5-c that the slot coupled patch has not the same resonant frequency than the patch alone(whose resistance at resonance is also very small).

2-2-RLC serie's type

The previous RLC parallel properties of slot coupled patch are strongly related to the reactive power of the slot itself.Some paper[3] described slot coupled patches exhibiting typical RLC serie's impedance.Theoretical and experimental have been plotted on fig.6.The shapes of the curves are in good agreament while a frequency shift remains.The cavity model uses the James [6] effective length well suited for low dielectric constant.A physical understanding of the RLC serie's properties is easily obtained with the cavity model.It must be noticed first,that the slot length is longer than previously(nearly equal to the width of the patch).Fig.7 shows that the slot length reaches a half guided slot wavelength in the frequency range 4.2 to 4.45 Ghz.This means that the parallel reactive susceptance Y_{ap} equals zero or keeps very small values.Then the frequency variation of Z_{in} looks like the Z_{ant} of the cavity excited with a magnetic current;as explained in [7] this cavity will exhibit RLC serie's impedance.

CONCLUSION

A new analysis of slot coupled patches have been proposed. Despite its mathematical simplicity the cavity model yields good results which agree with previous theoretical and experimental datas.Moreover the model gives a physical insight and explains two opposite electrical properties(serie's or parallel circuit) of the same type of radiating element.

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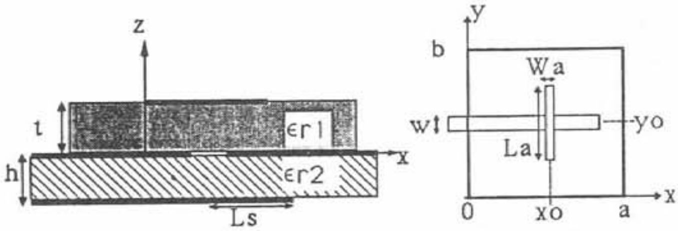

fig. 1: Aperture coupled microstrip antenna

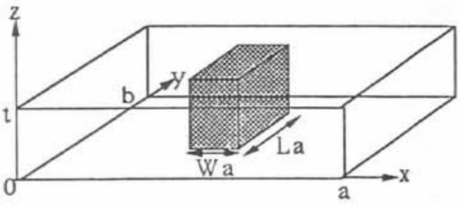

fig. 2-1: Modelisation of magnetic current density in the cavity

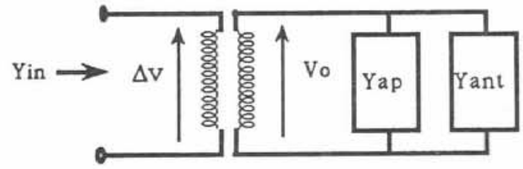

fig. 3: Equivalent transformer of the transition microstrip line / slot line

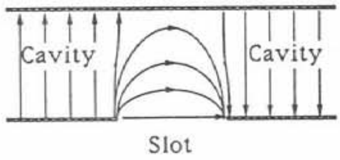

fig. 2-2: Electric field distribution near the slot

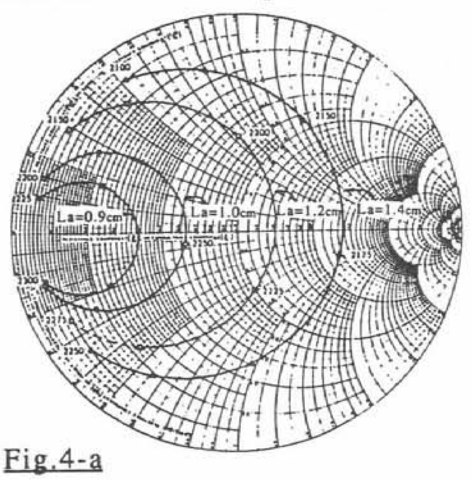

Fig.4-a

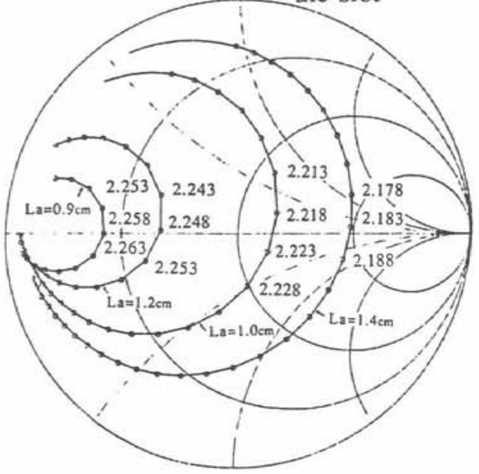

Fig.4-b

fig. 4:Input impedance versus frequency for different slot length (Parallel equivalent circuit)

$a=4.0$ cm,$b=3.0$cm,$\varepsilon_{r1}=2.54$,$t=0.16$ cm

$w=0.495$ cm,$\varepsilon_{r2}=2.54$, $h=0.16$ cm

$L_s=2.0$ cm, $x_o=a/2$,$y_o=b/2$, $W_a=0.11$ cm.

a) THEORY OF [1] ; b) CAVITY METHOD

c) Resonant frequency and input resistance at resonance versus slot length

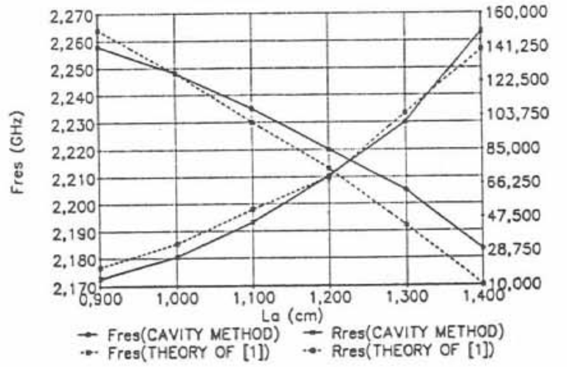

Fig.4-c

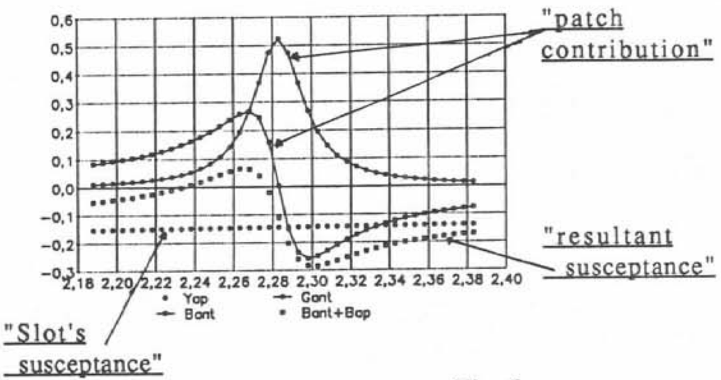

Fig.5-a

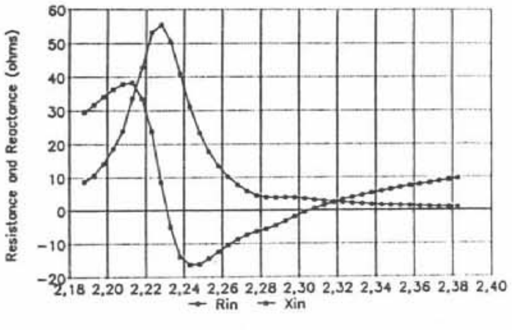

Fig.5-b

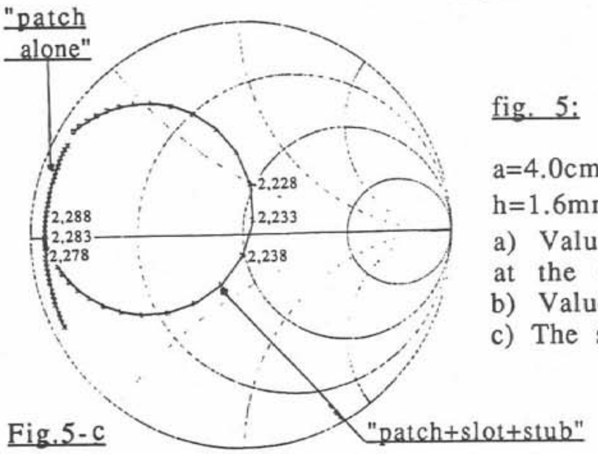

Fig.5-c

fig. 5: Antenna characteristics behavior before and after addition of aperture susceptance
$a=4.0cm, b=3.0cm, \varepsilon r1=2.54, t=1.6mm, w=4.42mm, \varepsilon r2=2.54$
$h=1.6mm, L_S=2cm, x_O=a/2, y_O=b/2, La=1.12cm, Wa=1.55cm$
a) Values of conductance and susceptance of patch at the slot(with and without slot contribution)
b) Values of the input impedance on microstrip line
c) The same values as in a) and b)on a Smith Chart

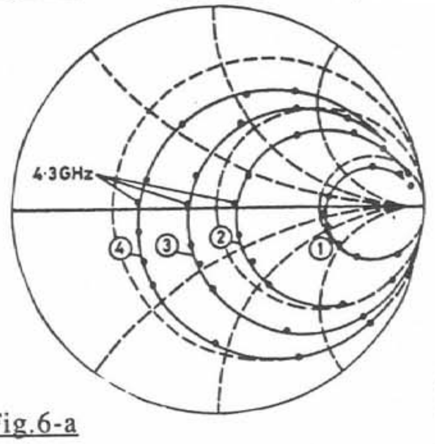

Fig.6-a

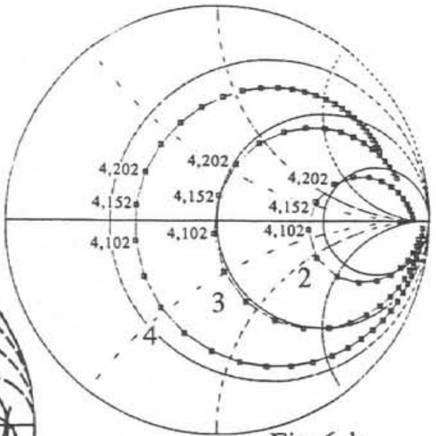

Fig.6-b

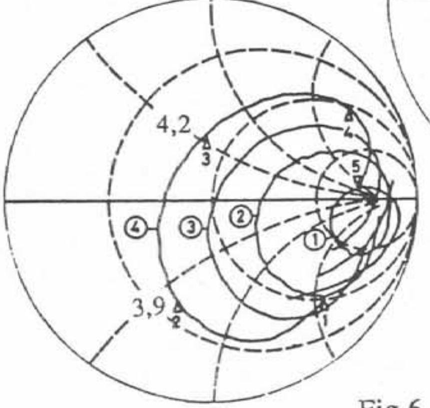

Fig.6 c

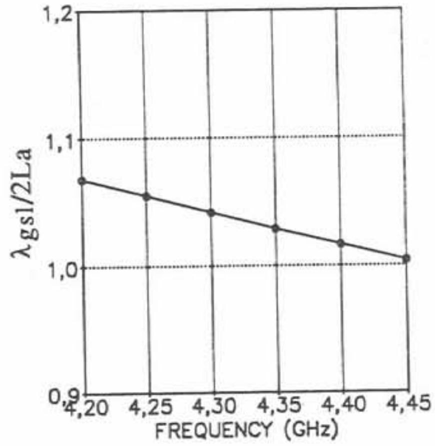

fig. 7: The behavior of $\lambda gsl/2La$ versus frequency (data from fig.6)

fig. 6: Input impedance variations versus frequency for different slot positions **(Serie's equivalent circuit)**
$a=2.8\ cm, b=3.0cm, \varepsilon r1=1., t=3.15\ mm$
$W=0.92\ mm, \varepsilon r2=6., h=0.635\ mm$
$L_S=8\ mm, y_O=b/2,\ La=26.5\ mm, Wa=1\ mm.$
$1):x_O=0mm, 2):x_O=3mm, 3):x_O=5mm, 4):x_O=8mm$
a) THEORY OF [3] ; b) CAVITY METHOD
c) MESURED OF [3]