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AUTOMATIC REFLECTION METHOD FOR ANTENNA GAIN DETERMINATION UNDER MISMATCHED CONDITION

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INTRODUCTION

Purcell has proposed a gain measurement method using only one antenna in the presence of a metallic reflecting plane as shown in figure 1, [1]. In this method, the antenna being supposed well matched, the gain G can be obtained with the Friis transmission formula, which relates the received power P_R to the transmitted power P_T :

$$(1) \qquad P_R = P_T \left(\frac{G\lambda}{8\pi x}\right)^2$$

where λ is the free space wavelength and x is the distance from the antenna aperture to the reflecting plane.

Introducing Γ, the reflection coefficient in the waveguide, it leads to :

$$(2) \qquad |\Gamma| = \frac{G\lambda}{8\pi x}$$

A modification of this method has been proposed [1], [2] to take account the re-radiation on reception and Wu [3] has introduced the effect of a mismatch between the antenna and the waveguide. With those two phenomena the resultant field reflection coefficient in the waveguide is :

$$(3) \qquad \Gamma = \Gamma_0 + \frac{\left(1-|\Gamma_0|^2\right).\Gamma_r.\left(\frac{\sigma G}{16\pi x^2}\right)^{\frac{1}{2}}.\ e^{-2jkx}}{1-\Gamma_r.\left(\frac{\sigma' G'}{16\pi x^2}\right)^{\frac{1}{2}}.\ e^{-2jkx}}$$

where Γ_r is the reflection coefficient of the reflecting plane (equal to -1), k is the free space propagation constant, σ is the absorption cross section, G is the transmission gain and σ' and G' are respectively the cross section and the power gain for re-radiation .

Measuring Γ for different positions of the reflecting plane, and also Γ_0, one can obtain the gain [3], [4].

We propose a modified method substituting the distance variation by a suitable frequency variation. In this way we avoid mechanical problems due to reflection plane displacement, and also we obtain an automated measuring method.

ANALYSIS AND RESTRICTIONS OF THE CLASSICAL METHOD

For variable distance x, from (3) we have :

$$(4) \qquad \frac{1}{|\Gamma - \Gamma_0|} = \frac{1}{1-|\Gamma_0|^2} \cdot \frac{x}{\alpha} \cdot \left(1 + \frac{\beta^2}{x^2} - 2 \cdot \frac{\beta}{x} \cdot \cos\phi \right)^{\frac{1}{2}}$$

with : $\alpha = \left(\frac{\sigma G}{16\pi}\right)^{\frac{1}{2}} = \frac{G\lambda}{8\pi}$, $\quad \beta = \left(\frac{\sigma' G'}{16\pi}\right)^{\frac{1}{2}}$, $\quad \phi = \pi - 2kx$

Equation (4) is an oscillatory function of x whose curve is bounded by the two parallel straight lines corresponding to the maximum values and minimum values of the function :

$$(5) \qquad \text{Max} : \frac{1}{|\Gamma - \Gamma_0|} = \frac{1}{1-|\Gamma_0|^2} \cdot \left(\frac{x}{\alpha} + \frac{\beta}{\alpha} \right) \qquad \text{Min} : \frac{1}{|\Gamma - \Gamma_0|} = \frac{1}{1-|\Gamma_0|^2} \cdot \left(\left|\frac{x}{\alpha} - \frac{\beta}{\alpha}\right| \right)$$

and which are equidistant from the straight line $\frac{1}{1-|\Gamma_0|^2} \cdot \frac{8\pi x}{G\lambda}$ whose slope contains the unknown gain G.

In practice one obtains first the straight line of $1/|\Gamma - \Gamma_0|$ versus x from experimental data and then extracts G. In order to get a good precision a sufficient number of oscillations is necessary. The minimum distance between two extrema being $\lambda/4$, at high frequencies the necessary displacement Δx of the reflecting plane may cause mechanical problem and make a restraint to the method. ($\Delta x_{min} \approx 2.5$ mm at 30 GHz)

MODIFIED METHOD

In order to set free from this problematic displacement and to make the measurement at fixed distance, we have decided to vary the frequency. The equation (4) which is this time oscillatory versus the frequency f, is now put to the following form :

$$(7) \qquad \frac{1-|\Gamma_0|^2}{|\Gamma - \Gamma_0|} \cdot \frac{C}{8\pi x f} = \frac{1}{G} \cdot \left(1 + \frac{\beta^2}{x^2} - 2 \cdot \frac{\beta}{x} \cdot \cos\left(\frac{4\pi x f}{C} - \pi \right) \right)^{\frac{1}{2}}, \quad \text{C is the light velocity .}$$

So we plot first the function g from the experimental data of Γ and Γ_0 versus f:

$$(8) \qquad g(f) = \frac{1-|\Gamma_0|^2}{|\Gamma - \Gamma_0|} \cdot \frac{C}{8\pi x f}$$

According to (7) this experimental curve should be identified to the theorical curve given by the following expression in order to obtain the unknown gain G :

$$(9) \qquad \frac{1}{G} \cdot \left(1 + \frac{\beta^2}{x^2} - 2 \cdot \frac{\beta}{x} \cdot \cos\left(\frac{4\pi x f}{C} - \pi \right) \right)^{\frac{1}{2}}$$

One notes that the maxima and minima of g correspond to the theorical values : $\frac{1}{G} \cdot \left(1 + \frac{\beta}{x} \right)$ and $\frac{1}{G} \cdot \left(\left| 1 - \frac{\beta}{x} \right| \right)$. The average of these values is simply 1/G.

So after plotting g(f) we look for representative lines corresponding to minima and maxima of g(f). The middle-line between them gives directly 1/G.

The period θ_f of the oscillations is : (10) $\theta_f = C/2x$

The frequency variation has to be sufficiently high to give enough number of periods. However the frequency sweeping should not exceed the antenna bandwidth in order to consider the antenna gain quasi-constant in this band. We may move the reflecting plane sufficiently away in order to reduce the sweeping range (according to eq.10). But for a large distance x, the measurements may become less accurate. There is then a compromise to find between the frequency range and the reflecting plane position. In addition to this, one should respect the following radiation criterion [1] :

$$\frac{2d^2}{\lambda} \leq 2x \leq \frac{dh}{2\lambda} \quad (11)$$

where d is the antenna maximum dimension and h the edge length of the reflecting plane.

MEASUREMENT RESULTS

Measurements have been carried out on one pyramidal horn and two microstrip antennas arrays taken from ref. [5] in the Ka band (26,5-40 GHz). From (8), the function g is directly plotted versus the frequency, and the value of 1/G is extracted from the data points as explained above. Best precision in this method is around the central frequency of the range.

Table 1 gives an example of results obtained with this method for two microstrip antennas.These results are compared with measurements realized using the well known gain comparaison technique. The discrepancy is about 0.2 dB at the central frequency .
Figure 2 shows the experimental graph of the function g, obtained for the first microstrip antenna array. The value found for 1/G is .0362 at the central frequency. It gives G=14.41 dB.
Table 2 gives results obtained for the pyramidal horn and compare them with constructor specified gain. The difference is about 0.4 dB at the central frequency.

CONCLUSION

We have proposed an automatic method of gain measurement which replace the tedious mechanical displacement by simple frequency sweeping. The antenna gain obtained by this method has a good precision (about 0,5 dB at the central frequency) if an appropriate choice of the frequency sweep range and of the reflecting plane position is made. Furthermore the method becomes very interesting for gain measurements at high frequencies.

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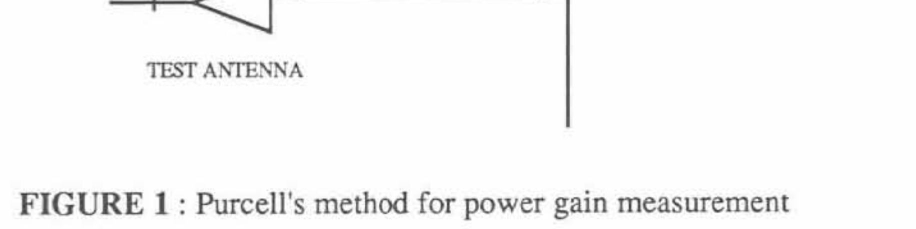

FIGURE 1 : Purcell's method for power gain measurement

ANTENNA	CENTRAL FREQUENCY	X (cm)	GAIN WITH OUR METHOD (dB)	GAIN WITH THE COMPA- -RAISON TECHNIQUE (dB)
1 st	33.16 GHz	58	14.41	14.3
2 nd	32.06 GHz	32	12.97	13.17

TABLE 1 : Results obtained for two microstrip antennas arrays of ref. [5].

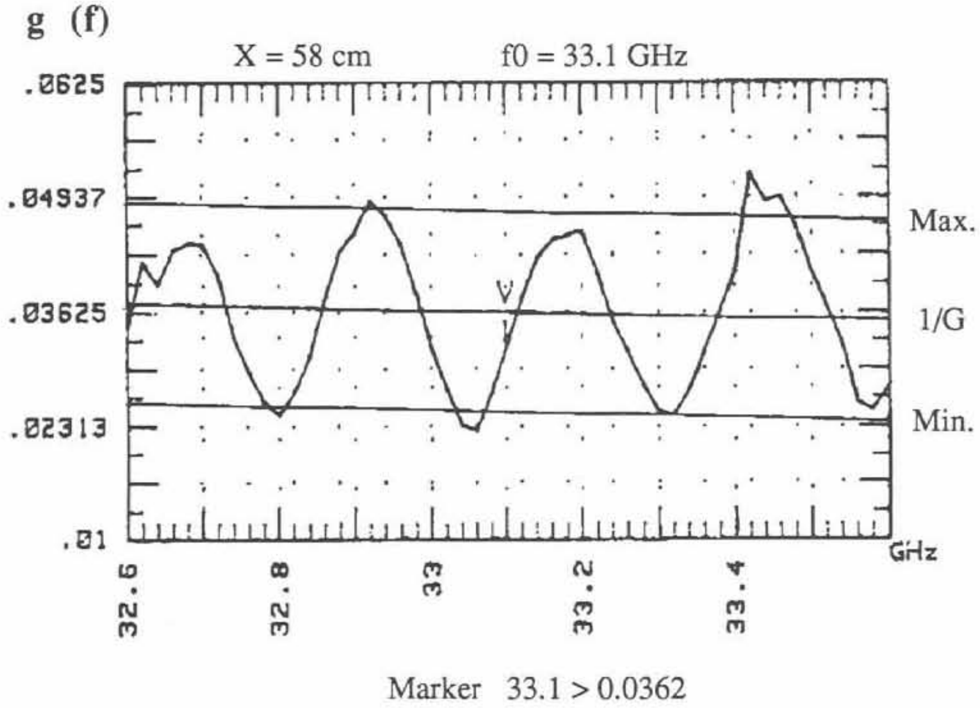

FIGURE 2 : Experimental graph of the function g for the first microstrip antenna array.

CENTRAL FREQUENCY	X (cm)	GAIN WITH OUR METHOD (dB)	CONSTRUCTOR SPECIFIED GAIN (dB)
32 GHz	55	20.02	19.85
38 GHz	55	20.47	20.8

TABLE 2 : Results obtained for a pyramidal horn.