Y JUNCTION CIRCULATOR ANALYSIS

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Abstract

We bring to evidence the operation of partially magnetized below resonance Y junction circulators. We elaborate a complete computer program taking into account this state as well as the material dielectric and magnetic losses. We call for your attention upon the prevailing importance of the ψ parameter in the definition of narrow and wide band circulators, whether they be of the classical or composite type.

Introduction

The design of stripline and microstrip Y junction circulators is generally based on the works of BOSMA [1] and Fay, and Comstock [2]. Their works essentially concern magnetized ferrites saturation and consider lossless materials. The direct use of these results in the below resonance Y junction circulator often leads to a disagreement between theory and experience.

No systematic exploitation was made for the case of circulators operating in zones where the ferrite is partially magnetized, which represents most of the uses of current circulators (frequences higher than 1 GHz).

In this paper, we study the structures which need a weak applied magnetic field for which it is fitting to use the permeability tensor of the partially magnetized ferrite given by Green, Schlomann and al [3] We also indicate the structure operating at saturation state. We shall give the physical limitations of the narrow and wide band circulators, insisting on the importance of the ψ parameter. We finally analyze the composite junction circulators and we give the results.

Text

Y Junction stripline circulator

The study of the operating conditions of a stripline Y junction circulator led us to elaborate a complete computer program which takes into account the dielectric and magnetic losses of the materials, but also the state of the ferrite magnetization. The same hypothesis as those given by Bosma [1] have been used to describe the boundary conditions; the equations system which comes out of it is then (reference [4])

C = 0 (1) and (B) = 1 (2) when **A** = 1. Relation (1) expresses the maximum isolation and relation (2) the minimum of insertion losses. Generally, equation (1) only is resolved. In fact it is fitting to resolve both relations at the same time, for the solutions of (1) do not necessarily verify equation (2).

The resolution of the circulation equation leads to such relations as :

$$F(x,\ \psi,\ f_o,\ \varepsilon_d\ H_i) = 0 \qquad (3)$$

with $x = \dfrac{2\,\Pi\, f_o}{C}\sqrt{\varepsilon_f}\ \sqrt{\mu_e}\,R$; $\sin\psi = \dfrac{W}{2\,R}$

f_o : central frequency — w : width of the transmission lines

R : ferrite radius — H_i : internal field

μ_e : $\dfrac{\mu^2 - K^2}{\mu}$ — ε_d : dielectric permittivity

The research of the zeros coming from (3) is possible, by the use of a subroutine program for the complex equations established in our laboratory [5] such as : F(z) = 0

This research is achieved inside a closed contour, the limits of which are given by the solutions of the singular points equation $[\,d_n\,] = 0$ (reference 4)

The resolution of equations (3) gives us the values of x when the ferrite parameters, f_o, ψ, ε_d are known. We take from it the value of the ferrite disc radius to be used. In our calculation x is a complex quantity as well as μ_e and ε_f. When the circulation conditions are set, the imaginary part of the quantity R becomes negligible in front of the real part and we find again the notion of the ferrite radius, a term which is essentially real. It is then easy to obtain the isolation and insertion losses curves of the circulator created in that way.

If now, we consider the curves $x = f(K/\mu)$ (fig.1) obtained for different values of ψ, we can observe that for $\psi \leqslant 15°$, the values of x exist only for the ratio $|K/\mu| \leqslant 0{,}4$. On the contrary, if ψ is superior to 15°, the $|K/\mu|$ ratio varies from 0 to 1

Let us consider now the operation of real narrow band and below resonance circulators. Bosma indicated that the optimum operating of the devices took place for H_i equal to zero. In these conditions, the minimum value of $|K/\mu|$ is equal to m ($m = \gamma\, 4\,\Pi\, M_s / f_o$) Generally, for the circulators beyond 1 GHz, this value of m, is always superior to 0,5, because of the magnetization state of the used ferrites. We can conclude that these devices can only operate with partially magnetized ferrites.

Using this new notion of the ferrite magnetization state and using our computer program, we obtain a good agreement between the theoretical and experimental definitions of the ferrite disc radius.

Let us consider for example, the L.T.T. circulator with a frequency range 3,7 to 4,2 GHz, constituted by a $4\,\Pi\, M_s$ ferrite equal to 800 g, $\varepsilon'r = 14{,}8$; $tg\delta_f = 5.10^{-4}$, by a dielectric $\varepsilon'_d = 17$; $tg\delta_d = 3.10^{-4}$ The disc-dimensions are R = 6,5 mm and the value of ψ equal to 8°. At the central frequency 3,95 GHz, our program gives us the following results :

$|K/\mu| = 0{,}156$; x = 1,90 R = 6.4 mm

It is the same for a good number of below resonance circulators operating with a small ψ. With our computer program we can also precise the characteristics of the circulators.

When using Fig. 1 and 2, we notice that for $\psi = 10°$, for example, the impedance ratio curve coming from the boundary conditions can interfer with the ferrite impedance curve in only one point. This supposes a narrow band operation, very easily tuned by quarter wave filters.

On the contrary, when $\psi = 29°$, the two preceding curves present an overlapping zone. This zone corresponds to an inherently broad-band circulator, operating range from $|K/\mu| = 0,5$ to $|K/\mu| = 1$. The bandwidth of such a circulator may reach the octave band. These results have, already, been given by Rosenbaum [6] and verify by our computer program. We also notice that the physical limitations of the broad-band process are, on the one hand limited at the inferior frequency by the ratio $|K/\mu| = 1$, and on the other hand, at the superior frequency by the ratio $|K/\mu| = 0,5$. It is fitting to point out that in this last point, there is a degeneracy of the modes of the circulator and that the circulation phenomenon is destroyed. The large absorption of insertion losses which then appears cannot be imputed to "radiation from the top magnet" as Rosenbaum suggested [6]

Composite Y junction circulator

We have moreover studied the composite junction circulators detailed in Fig. 3 In this paper, we only examine the case of the A structure which we think is the only interesting case. All the calculations and results of the A, B, C structure are given in reference [7] .

For A structure, we looked for the values of R_1 which preserves the circulation condition, taking x_2, ψ, εd_1, εd_2 as parameters (Fig.3) Otherwise we look for the ferrite filling factor R_1/R_2 in terms of the ratio $|K/\mu|$ (Fig. 4). We also draw the variations of the normalized impedances Z_{eff}/Z_d in terms of the ratio $|K/\mu|$ for different values of ψ_2 and x_2 (fig. 5) The indicated areas correspond to solution zones which guarantee a good isolation and small insertion losses.

We find again, as for the classical structure, an overlapping zone, when $\psi = 30°$ and x_2 varies from 0 to 2 which correspond to a broad band operation. On Fig. 6 we give the theoretical results for a 2150 g magnetization ferrite. We obtain an isolation with values superior to 20 dB from 10,5 to 13,2 GHz and average values far superior to 15 dB and insertion losses lower than 1 db, on all the band from 6 to 13,5 GHz.

On the other hand, for small values of ψ, the R_1/R_2 ratio is higher than 0,5. We find theoretically the case exposed by Helszajn [8] who had put in evidence experimentally a narrow band operation with small insertion losses (0,15 db) by using a R_1/R_2 ratio equal to 0,65 and by using a lossless dielectric ($\varepsilon d_1 = 9$)

Conclusion

Our studies allowed to clarify the circulation conditions of narrow and broad band devices in classical or composite structure.

On the other hand, for the first time, the notion of partially magnetized ferrite allowed to find again the theoretical definition of the weak field circulator, namely the ferrite radius and the main performances. It is now possible to begin an optimization study of such devices in terms of the frequency bands, materials and of the choice of the matching technics.

An optimization of the composite junction still remains to do as a function of the different parameters and components. The works of our laboratory go on about the study of the composite junction circulators using ferrite associations, of different magnetization, associations of ferrites and materials with large dielectric or magnetic losses.

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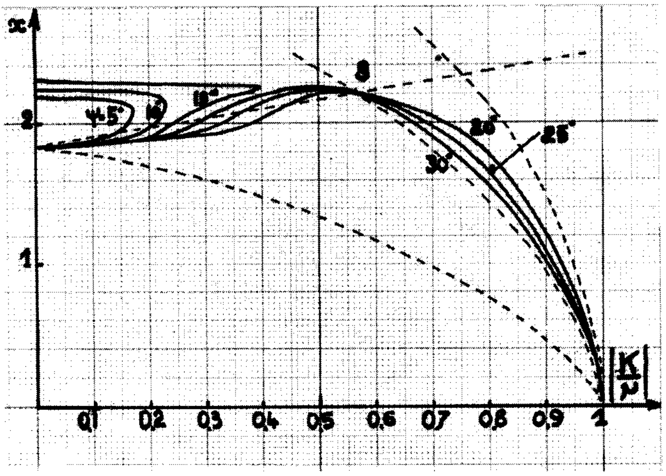

Fig. 1 : Circulation roots of the circulation conditions for different ψ versus | K / μ |

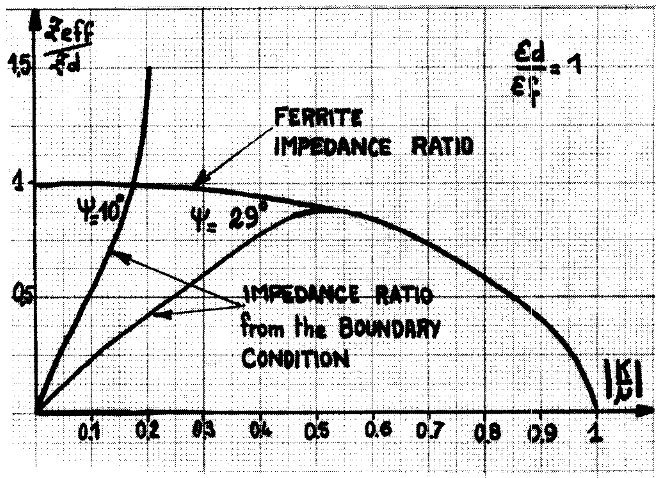

Fig. 2 : Junction wave impedance ratio from the ferrite and from the circulation conditions versus | K / μ |

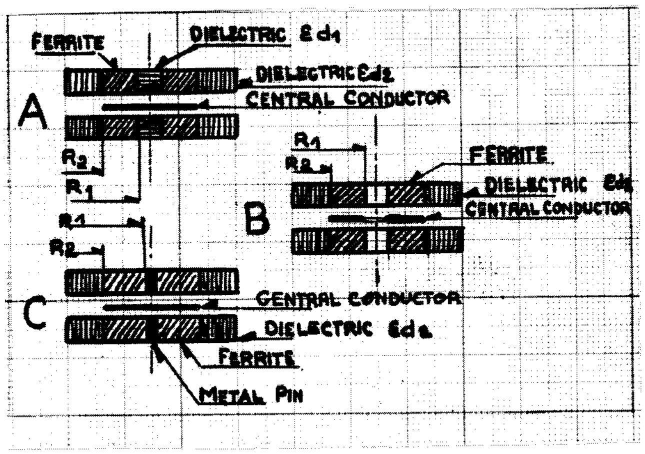

Fig. 3 : Schematic of different composite junction circulators

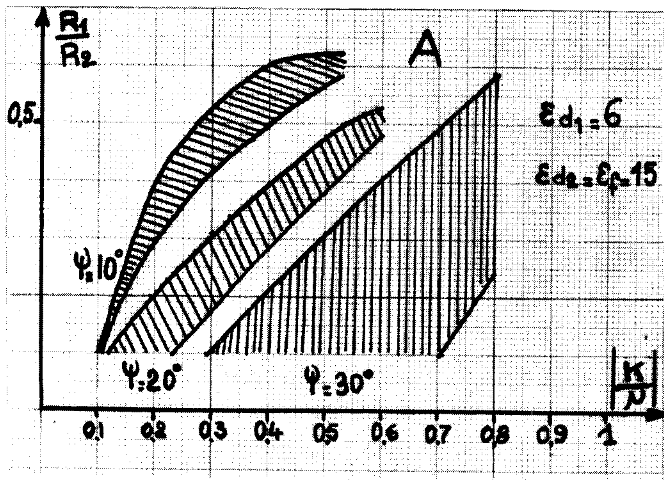

Fig. 4 : Theoretical ratio R_1/R_2 versus $|K/\mu|$ and different ψ

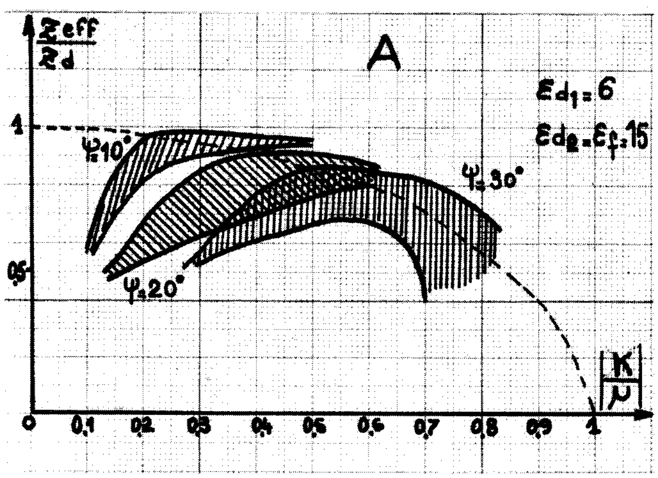

Fig. 5 : Junction wave impedance ratio versus | K / μ |

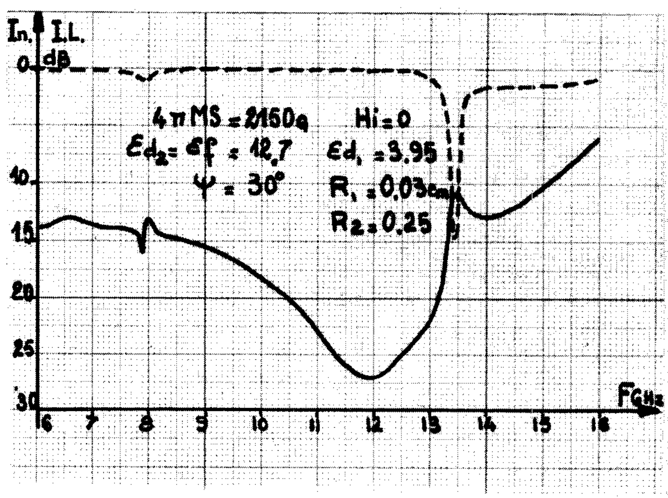

Fig. 6 : Theoretical performance of a composite junction circulator.