BANDWIDTH ENLARGEMENT OF A MILLIMETER WAVE Y-CIRCULATOR WITH HALF WAVELENGTH LINE RESONATORS

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Abstract

Half wavelength line resonators are employed to enlarge the bandwidth of a 50 GHz Y-circulator. The resonator has a very simple structure that a rectangular metal block is placed in a waveguide. The bandwidth is enlarged from 3.5 GHz to 5.5 GHz.

Introduction

Relative bandwidth of a circulator is narrower at mm-wave frequencies than at lower frequencies, on account of lack of ferrites with higher saturation magnetization.

Efforts have been made to enlarge the bandwidth of the mm-wave Y-circulator. B. Owen and C. E. Barnes[1] used an inphase eigen excitation resonator and obtained a very wide band Y-circulator at 50-GHz band. This resonator has, however, a complicated structure to construct at higher frequencies and field analyses to obtain design formulas are difficult.

Dielectric filled half wavelength line resonators had been used for a 2 GHz band stripline Y-circulator.[2]

In this paper, half wavelength line resonators are employed to enlarge the bandwidth of a 50-GHz Y-circulator. The resonator has a very simple structure wherein a rectangular metal block is placed in the terminal waveguide. It is easy to theoretically obtain the center frequency and the external Q-factor.

Theoretical Consideration on Bandwidth Enlargement with Resonators

When the performance of a circulator is not much deteriorated from the ideal performance, the scattering matrix is given by as,

$$S=\begin{pmatrix} \Delta\alpha & 1+\Delta\beta & \Delta\gamma \\ \Delta\gamma & \Delta\alpha & 1+\Delta\beta \\ 1+\Delta\beta & \Delta\gamma & \Delta\alpha \end{pmatrix} \quad (1)$$

where $|\Delta\alpha|, |\Delta\beta|, |\Delta\gamma| << 1$, and the wave travels as $3\to2\to1$. It has been known that the following equation holds[3]

$$\Delta\alpha = -\Delta\gamma^* \quad (2)$$

Suppose terminal impedances are changed slightly from Z_0 to Z_i (i=1,2,3,), i.e., $|Z_i-Z_0|<<1$, then the scattering matrix is approximated as,[4]

$$S=\begin{pmatrix} \Delta\alpha-r_1^* & 1+\Delta\beta-j\,\mathrm{Im}(r_1+r_2) & \Delta\gamma+r_2 \\ \Delta\gamma+r_3 & \Delta\alpha-r_2^* & 1+\Delta\beta-j\,\mathrm{Im}(r_2+r_3) \\ 1+\Delta\beta-j\,\mathrm{Im}(r_3+r_1) & \Delta\gamma+r_1 & \Delta\alpha-r_3^* \end{pmatrix} \quad (3)$$

where $r_i=(Z_i-Z_0^*)/(Z_i+Z_0)$.

To illustrate the meanings of Eq.(3), consider the case when conjugate match is made at port 1 and wave goes into from port 2. In this case, it is known from Eqs.(2) and (3) that no wave comes out from port 3, i.e., isolation is infinite.

Input impedance of a circulator exhibits a resonance characteristic because of the ferrite resonance. Therefore, the bandwidth can be enlarged by loading resonators in each terminal. The design theory has been established.[5] A low external Q-factor is required for the resonator.

Half Wavelength Line Resonator

Input impedance of the half wavelength line constructed as shown in Fig.1 is easily obtained on the Smith Chart. Figure 2 shows the input admittance of the half wavelength line resonator for the case where the characteristic admittance ratio (Y_1/Y_0) is 1.42. It is known from Fig.2 that the half wavelength line behaves like a parallel resonator. The resonator behaves as a series resonator when $Y_1<Y_0$.

Input admittance of n-times the half wave length line, normalized by the terminal waveguide admittance, is approximated around the center frequency as :

$$y=1+j(Y_1/Y_0-Y_0/Y_1)\frac{\partial x}{\partial\omega}\Delta\omega \quad (4)$$

where x is the electrical angle. For the dominant mode of the waveguide, x is given by

$$x=\sqrt{\omega^2\epsilon\mu-(\frac{\pi}{a})^2}\,\ell \quad (5)$$

where a is the width of the waveguide and ℓ is the length of the resonator. Using Eqs. (4) and (5) and $x=n\pi$ at the center frequency, the external Q-factor is given by,

$$Q_L=\frac{1}{2}\omega\frac{\partial}{\partial\omega}(y)=\frac{1}{2}(Y_1/Y_0-Y_0/Y_1)\frac{n\pi}{1-(\frac{\pi}{ka})^2} \quad (n=0,1,2,---) \quad (6)$$

where $k=\omega\sqrt{\epsilon\mu}$. The calculated and measured Q-factors obtained by measuring V S W R as a function of frequency are shown in Fig.3.

Construction and Performance of the Circulator

A photograph of the circulator is shown in Fig.4. A triangular ferrite post, triangular metal plates and teflon spacers are used. Ferrite constants are as follows :

Saturation magnetization	5300 gauss
Relative dielectric constant	14.2

Input admittance looking into the Y-junction from the near face of the resonator is shown Fig.5. Although the locus is distorted from that of an ideal resonator, the higher frequencies part of the input admittance well represents the series resonance property. This part of the input admittance may be matched to the parallel resonance property of the half wavelength line resonator.

The center frequency, f,is some 20% higher than the frequency calculated from Eq. (7) by assuming the TM(1,-1,0)1 mode and assuming that ferrite post surfaces are open-circuited.[6] f is given by

$$f=\frac{1}{2\sqrt{\epsilon\mu}}\sqrt{\left(\frac{4}{3a}\right)^2(m^2+mn+n^2)+\left(\frac{p}{L}\right)^2} \qquad (7)$$

where a is the length of the sides of the triangle, L is the length of a ferrite post and m,n and p are integers.

Transmission losses of the circulator before loading the resonator are shown in Fig.6 by broken lines. Transmission losses after loading the resonators are shown in Fig.6 by solid lines. The rectangular metal block dimensions are 4.77x3.55x0.7(mm). The external Q-factor of the resonator is chosen to be 2.2. The bandwith where isolation loss is greater than 20 dB is enlarged from 3.5 GHz to 5.5 GHz.

Conclusion

It has been shown that half wavelength line resonators are effective to enlarge the bandwidth of a mm-wave Y-circulator. It is also expected that they will be effective to enlarge the bandwidth of a circulator having an inphase eigen-excitation resonator.

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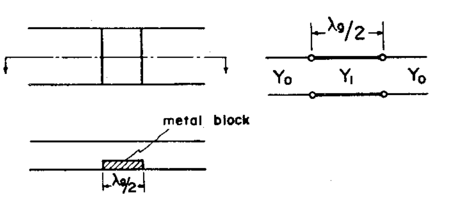

Fig.1 Construction and equivalent circuit of a half wavelength line resonator

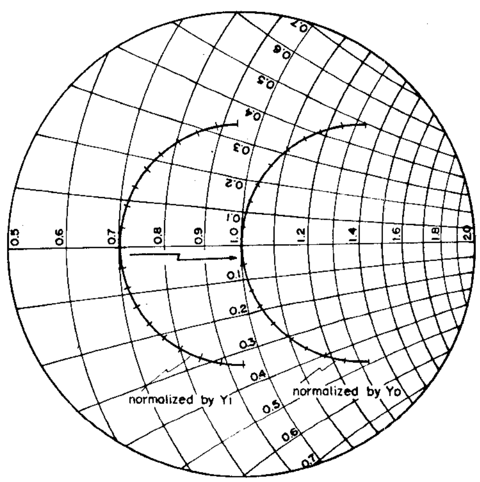

Fig.2 Input admittance of a half wavelength line resonator (Y_1/Y_0=1.42)

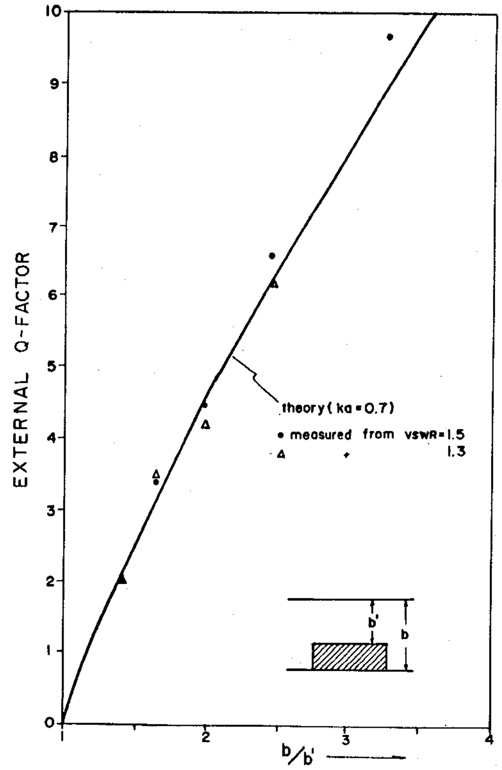

Fig.3 Calculated and measured external Q of half wavelength line resonators.

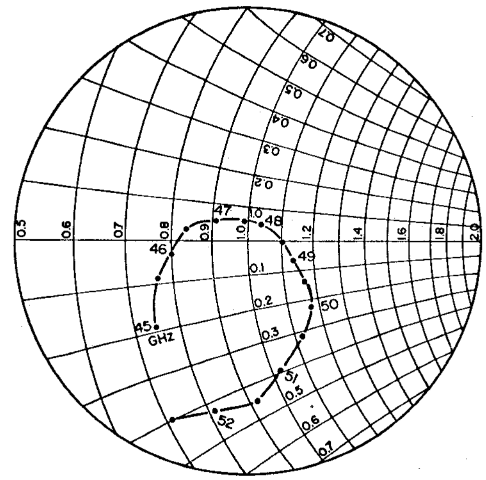

Fig.5 Input admittance of circulator looking 5.8 mm away from the center of circulator before loading resonators.

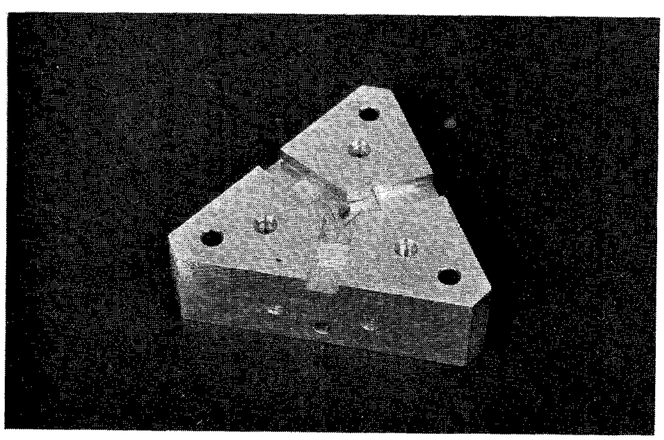

Fig.4 Internal view of 50-GHz Y-circulator with half wavelength line resonators.

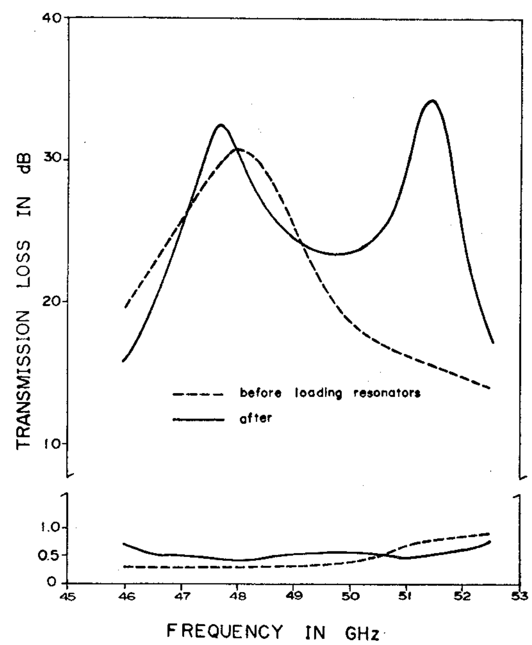

Fig.6 Transmission losses of circulator before and after loading resonators.