7.3: FERRITE SWITCHES IN COAXIAL OR STRIP TRANSMISSION LINE

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In many microwave systems there is need for a fast-acting switch which has negligible insertion loss in its "On" condition and substantial attenuation in its "Off" condition. Ferrite switches can in general be made fast-acting by thinning waveguide walls to a few skin depths, using low inductance coils and applying pulse circuitry techniques. Switches in rectangular or circular waveguide have been either of the Faraday rotation[1, 2, 3] or the waveguide-beyond-cutoff variety[4]. Some coaxial or stripline structures have been described which show interesting properties[5, 6, 7]. Early work at Bell Telephone Laboratories on ferrite loaded coaxial lines[8] indicated that large amounts of attenuation could be obtained with axial magnetic fields. The high attenuation is the result of a cutoff condition in the ferrite loaded line, and/or ferromagnetic resonance in the ferrite. The applied field may be switched to bring the line into a propagating and low loss condition.

The object of this paper is to describe some design considerations for the performance of the coaxial or stripline type of ferrite switch and to present data on the operation of a stripline switch in the L band.

The coaxial transmission line operates normally in the TEM mode and its dimensions are usually such that other modes are well beyond cutoff at its operating frequency. For purposes of analysis, it is convenient to "unroll" the coaxial line to parallel conducting planes with a ferrite filling between them, Figure 1. Suhl and Walker[9] have considered this

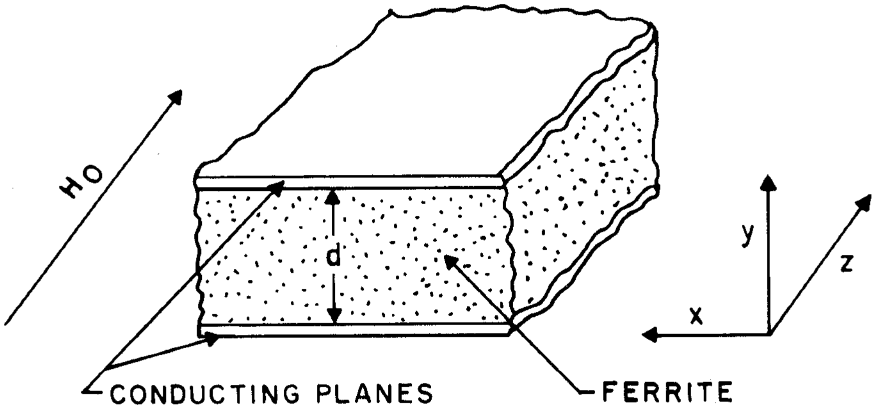


Fig. 1. Parallel-plane transmission line.

case with longitudinal magnetization of the ferrite and shown that the line behaves as though the ferrite had a scalar permeability $\mu_e = \frac{\mu^2 - \kappa^2}{\mu}$ where μ and κ are the components of the Polder permeability tensor and are given by:

$$\mu = 1 + \frac{4\pi M_s \gamma \omega_o}{\omega_o^2 - \omega^2} \quad \text{and} \quad \kappa = \frac{4\pi M_s \gamma \omega}{\omega_o^2 - \omega^2} \qquad \text{where:}$$

$4\pi M_s$ = saturation magnetization of the ferrite

γ = gyromagnetic ratio of the electron

ω = operating angular frequency

ω_o = γH_o

H_o = internal biasing field in the ferrite.

We also need to define

β_o = $\omega\sqrt{\mu_o \varepsilon_o}$ = the free space phase constant

β = $\beta_o \sqrt{\mu_e \varepsilon}$ = the phase constant in the ferrite line

ε = the relative permittivity of the ferrite.

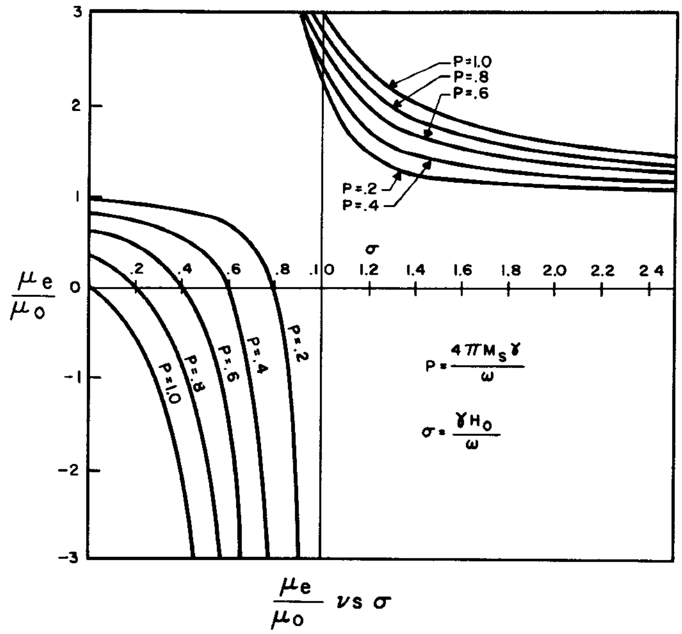
Waves propagate in the line according to the relation $E = E_o \exp j(\omega t - \beta z)$. As biasing field, H_o, is applied, μ_e changes and hence β as well as the characteristic impedance,

$$Z_o \sqrt{\frac{\mu_e}{\varepsilon}} .$$

A plot of μ_e versus applied biasing field is shown in Figure 2, where reduced variables are used to remove frequency as a parameter. Following the notation of Suhl and Walker [9], these are:

$$P = \frac{4\pi M_s \gamma}{\omega} \quad \text{for the saturation magnetization}$$

$$\sigma = \frac{\gamma H_o}{\omega} \quad \text{for the applied biasing field.}$$



$\frac{\mu_e}{\mu_o}$ vs σ

Fig. 2.

With reference to Figure 2, we see a region where μ_e is negative extending from $\mu_e = 0$ to $\mu_e = -\infty$ (neglecting loss in the ferrite). This represents a region where β is imaginary and the line is cutoff. The degree of cutoff depends on the value of μ_e and is a maximum at the point

$\sigma = \sqrt{1 + \frac{P^2}{4}} - \frac{P}{2}$ (again neglecting loss in the ferrite). For higher values of σ the line again propagates with large values of β at first, gradually dropping to approach $\beta = \beta_o \sqrt{\epsilon}$ for $\sigma = \infty$. At the point $\sigma = 1$, which is ferromagnetic resonance, the ferrite loss will be high and it will also be considerable on either side of this point to an extent determined by the magnetic line width of the material. Thus the high loss region of the switch should encompass the high cutoff point and the point of ferromagnetic resonance. A useful approximate expression for the high loss bandwidth then would be,

$$BW = 1 - \sqrt{1 + \frac{P^2}{4} + \frac{P}{2}} \; .$$

The possibility of other propagating modes where μ_e is large and positive should not be overlooked. Suhl and Walker [9] show that both a TE and a TM mode are possible here, depending on the separation d, Figure 1. As a practical matter, since these could propagate only near ferromagnetic resonance, their effect should be negligible in the presence of the resonance absorption.

The low loss or transmitting condition must be far enough from resonance that the absorption is negligible. With reference to Figure 2, this point might be either at σ near zero or at $\sigma > 1$ with the latter looking attractive from the standpoint of small impedance change with σ.

The construction of a switch built for L-band operation in stripline is shown in Figure 3. It is designed to be biased to the high loss condition by means of permanent magnets and to be switched to the low loss condition by means of a solenoid. The design parameters are:

$P \simeq 0.67$, σ for low loss condition $\simeq 2.25$.

Typical performance of the switch is shown in Figure 4. It will be noted that it operates over a 13 per cent band with insertion loss of about 0.1 db and isolation of 45 db, which provides the very attractive ratio of 450 to 1. In addition the VSWR in the transmitting condition is seen to be excellent. The matching for this condition is accomplished by the use of quarter-wave sections of alumina-loaded line at each end of the ferrite section. The design can be moved in the 1 to 2 Gc/s frequency range with substantially the same performance. The ferromagnetic material used in this switch was a low saturation (~ 350 gauss) aluminum-substituted yttrium-iron-garnet. Its magnetic linewidth in L band was approximately 50 oersteds.

Figure 5 shows the behavior of the switch at its midband frequency as a function of the biasing field. With zero field the loss is low, being considerably dependent upon the impedance match. With application of field, the loss goes through a minimum and then increases sharply along with the VSWR as the device goes into the cutoff condition. The VSWR levels off and then shows a sharp peak in the vicinity of ferromagnetic resonance. Above ferromagnetic resonance the attenuation and VSWR drop rapidly and then level off at quite low values in the region where the structure is matched.

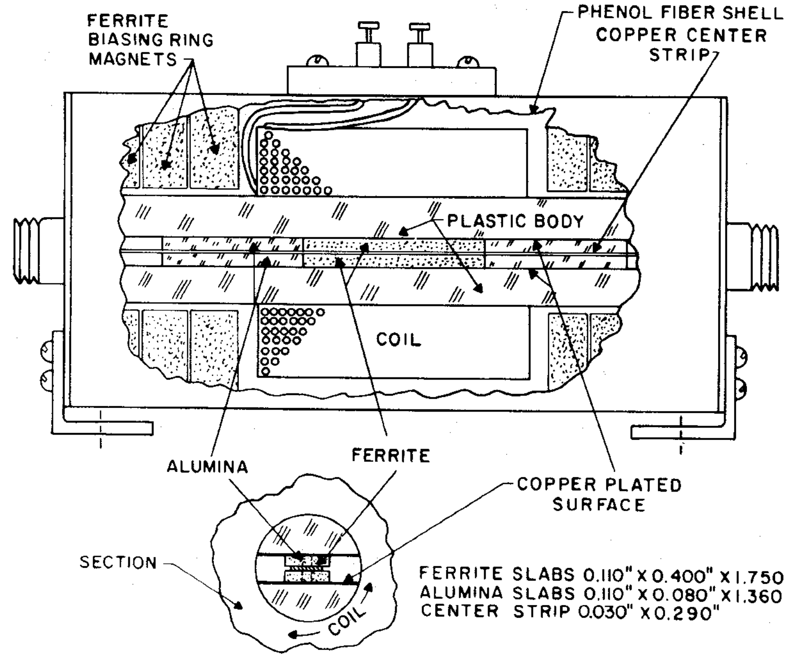


Fig. 3. Stripline switch.

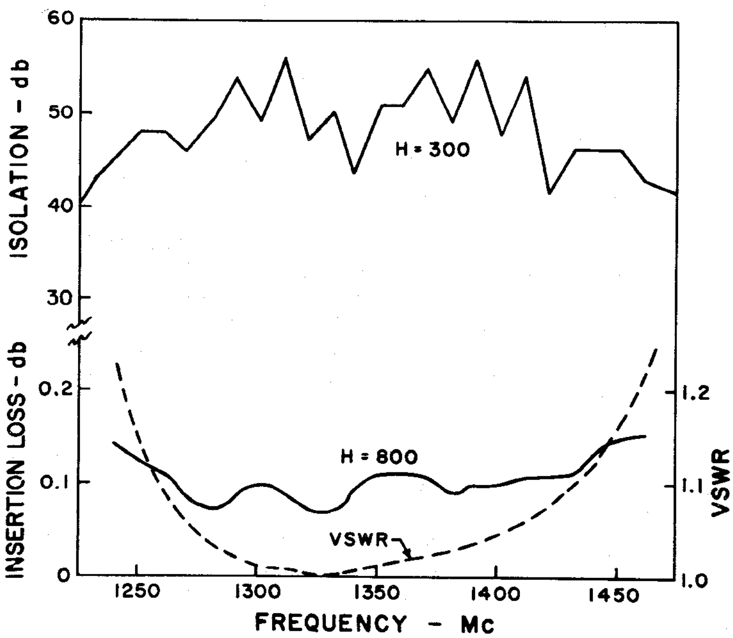


Fig. 4. Performance of stripline switch.

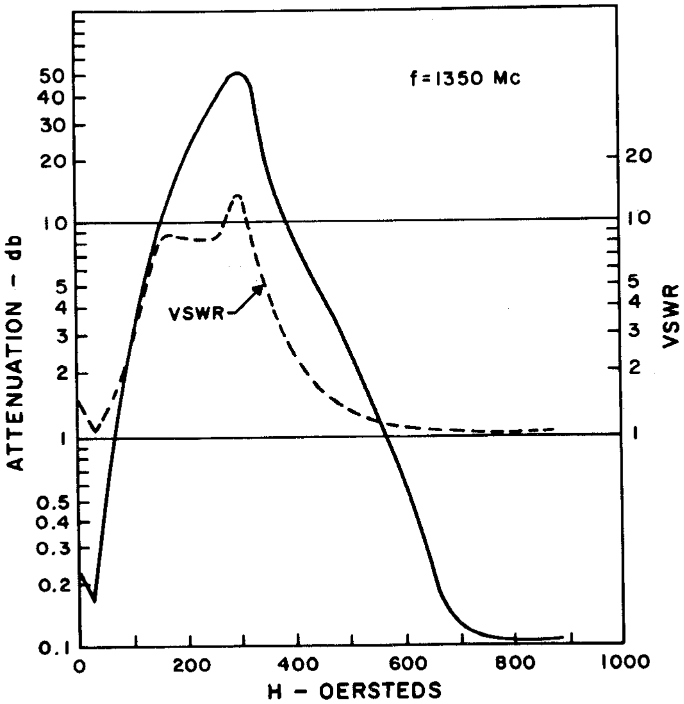


Fig. 5. Attenuation vs. H.

In conclusion, the coaxial or strip transmission line switch has been shown to provide very high ratios of isolation to insertion loss over a reasonable bandwidth. Its principal disadvantage is the high switching field required, particularly when it is operating at the higher frequencies. However, this field is required over a relatively small volume so the total energy involved is not excessive.

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