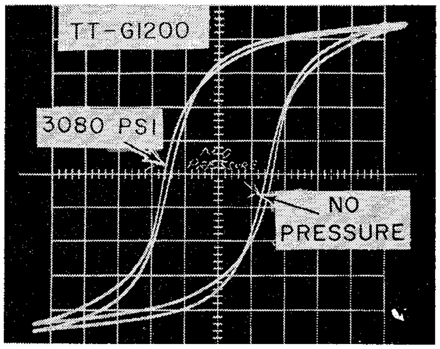

Fig. 1. Change in the *B-H* loop with applied stress.

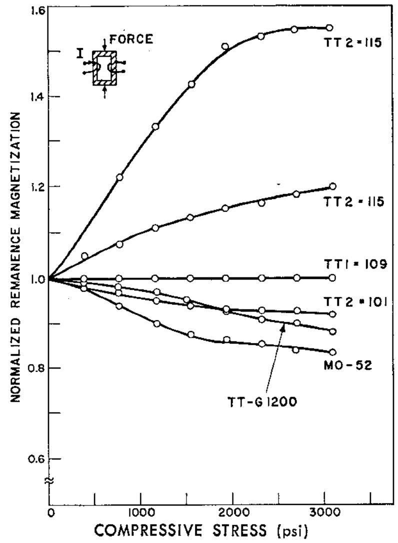

Fig. 2. Typical remanence magnetization characteristics vs. compressive stress.

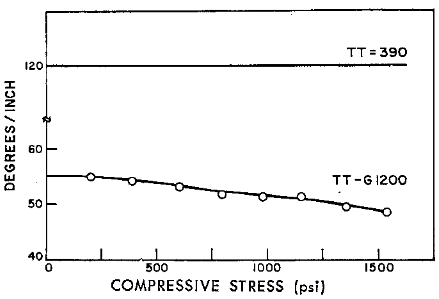

Fig. 3. Differential phase shift vs. compressive stress in ferrite.

The remanent magnetization, the coercive force, and the shape of the B-H loop of ferrites and garnets[2] are altered by compressive stress. A typical effect of pressure on the B-H loop of a toroid of garnet is shown in Fig. 1. Since the phase shift is directly related to the remanence magnetization,[3] a variation in stress alters the insertion and differential phase. Such variations are inimical to phased array radars, and to other applications. The variation of remanent magnetization with compressive stress is shown in Fig. 2 for some typical microwave ferrites with a toroid shape, as shown. On Table I are listed the maximum variations of a number of ferrites and garnets at a stress of 3000 psi.

TABLE I
MAGNETOSTRICTIVE PROPERTIES OF FERRITES

	Material	$4\pi M_s$ Gauss	$B_R/B_{R(0)}$** at 3000 psi
Mg-Mn	TT1-414*	680	1.0
	TT1-109	1250	1.0
	TT1-105	1700	1.0
	TT1-390	2150	1.0
	GE 42L	860	1.0
Ni-Co	TT2-116	1400	1.55
	TT2-115	1600	1.21
	TT2-101	3000	0.93
	M-52*	3150	0.84
Garnets	TTG-1002	1000	0.84
	TTG-1001	1200	0.88
	TTG-1200	1200	0.88
	TTG-113	1780	0.95
	SP 286*	1250	0.95

* Prefixes: TT—Trans Tech, M—Motorola, SP—Sperry.
** $B_R/B_{R(0)}$ is the ratio of remanence moment at 3000-psi compression over the remanence moment without stress.

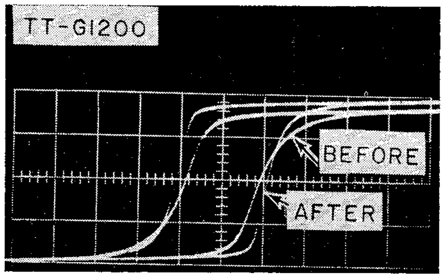

Fig. 4. Change in the *B-H* loop by annealing.

It appears evident from these data that at remanence magnesium-manganese ferrites are not magnetostrictive, and that garnet and nickel ferrites are strongly magnetostrictive.

The differential phase shifts of garnet and magnesium-manganese ferrite phase shifters are plotted as a function of compressive stress in Fig. 3. Note the stability of the magnesium-manganese ferrite and sensitivity of the garnet device. A measurement of the remanence magnetization of the garnet showed that the phase shift decreased proportionally with the remanence magnetization.

We believe that magnetostriction is also responsible for the effects of machining on the shape of the B-H loop of garnets observed by Harrison.[4] He has observed that the squareness ratio of the hysteresis loop of machined garnet toroids is increased by a heat treatment (annealing) process.

We have verified Harrison's observations with garnets and have also observed the effect in nickel ferrites. However, heat treatment of magnesium-manganese ferrites does not affect the B-H loop characteristics.

It appears that machining introduces local stresses into the ferrite and garnet, especially near the surface. If the ferrite is magnetostrictive, the local B-H loop response is altered near the surface, and the effect is readily observable in the loop of the whole toroid. Annealing the toroid relives the stresses and the B-H loop characteristics are restored (see Fig. 4).

The hypothesis that machining mainly effects the surface material of the toroid has been supported by two experiments. Fifteen mils of the surface of a machined toroid were etched away; the resultant shape of the hysteresis loop was similar to an annealed toroid. Secondly, the squareness ratio of the hysteresis loop should increase as the surface to volume ratio of a toroid is decreased in machined toroids. This has been observed.

CONCLUSION

Considerable caution should be employed in the handling of magnetostrictive microwave ferrites, such as garnets and nickel ferrites, for remanence applications. The toroids should be annealed prior to insertion into the device, and care should be taken to avoid stress buildup in the toroid, if optimum performance is desired. Structures should be designed to maintain a constant mechanical stress on the toroid, or a method of flux stabilization, such as a composite loop[5] design, should be employed to compensate for these effects.

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[2] J. Smit and H. P. J. Wijn, *Ferrites*. New York: Wiley, 1959.
[3] W. Ince and E. Stern, "Waveguide nonreciprocal remanence phase shifters," *Proc. IEE Internat'l Conf. on the Microwave Behavior of Ferrimagnetics and Plasmas*, no. 13, p. 1.
[4] G. R. Harrison, et al., "Microwave 'square loop' ferrimagnetic materials for application in fast switching phased array components," Rome Air Dev. Ctr., N. Y., Tech. Rept. RADC-TDR-64-225, vol. 1, p. 252, July 1964.
[5] E. Stern and W. J. Ince, "Temperature stabilization of unsaturated microwave ferrite devices," presented at the 1965 Conf. on Magnetism Magnetic Materials, San Francisco, Calif.
[6] Operated with support from the U. S. Air Force.

Comparison of Two Low-Loss Semiconductor Switches

The semiconductor waveguide switch discussed in these TRANSACTIONS in 1965[1] is similar to a switch reported in 1961,[2] and yet the authors of the recent paper were not aware of earlier work,[3] approaching their project from a different point of view. The earlier switch offers advantages over the latter, with switching specifications (isolation, insertion loss, power limitations, bandwidth, etc.) that are strikingly similar.

In comparing the two, it must be noted that the result in Fig. 6 of the recent article, i.e., single cavity switching, most nearly parallels the previous work. Several cascading experiments reported in 1961 implied a behavior similar to that in the recent article for a multielement switch.

Manuscript received May 14, 1965.
[1] H. J. Peppiatt, A. V. McDaniel, Jr., and J. B., Linker, Jr., "A 7-Gc/s narrow-band waveguide switch using *p-i-n* junction diodes," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-13, pp. 44–47, January 1965.
[2] D. L. Rebsch, "A low-loss semiconductor microwave switch," *IRE Proc.* (*Correspondence*), vol. 49, pp. 644–645, March 1961.
[3] Confirmed by communication with the authors.

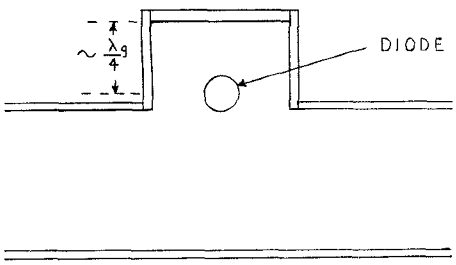

Fig. 1. Layout of H-plane switch.

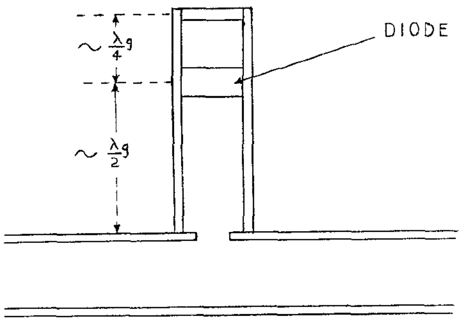

Fig. 2. Layout of recent switch.

A valid comparison also requires the use of similar diodes. The IN419 seems to be no longer available in the configuration used in 1961, but Philco switching diodes which are still available yielded similar results.

Because of its simplicity (Fig. 1) the earlier switch offers the advantages of 1) comparatively little measurement data or calculation required for its design; 2) good matching almost everywhere in the band for the "pass" condition, which comes about from the close placement of the diode to the junction (wider bandwidth of attenuation, as much as 2 per cent, can also be obtained from this feature); and 3) the ability to attenuate any frequency in the band, as determined solely by the position of the short. This switch is, in fact, most often used with a sliding short, so that the operating frequency can be changed at will. Diode placement favors the use of an H-plane tee for this switch, while the recent switch (Fig. 2) could supposedly be built equally well in the E or H plane.

An evident disadvantage is that the early switch must operate into a better match because of its close involvement in the junction. But because of these considerations, it is recommended that this switch be considered in applications using the recent design, especially in laboratory work, where flexibility is often desirable.

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Author's Comment[4]

Although our narrow-band waveguide switch[1] is of the same generic type (a band reject design in waveguide using diodes) as the one previously described, it is difficult to envisage any two switches in this category as different as these, both electrically and mechanically. The most striking difference in performance is evident from our Fig. 6, where it is shown that the isolation curve shifts by about 120 Mc/s for a change in diode state. According to Rebsch's correspondence of 1961,[2] the isolation of his switch is only present when the diode is forward biased. Perhaps Rebsch can be more specific about the electrical similarity he sees in these switches.

The central aim of our paper was to present a switch design which parallels the synthesis of passive band reject filters, and which therefore could be used in the design of switches for a wide variety of applications. By this procedure many of the difficult impedance matching problems associated with other types of switches are avoided. The degree to which this aim has been achieved is evident from our Figs. 6 to 8 which show a comparison of measured and computed responses as an example of the effectiveness of the synthesis procedure. It is significant that our design procedure is quite insensitive to the precise nature of the diode (and mount) impedance in either of the two states.

We agree that Rebsch's design presents matching problems, especially in the design of cascaded stages for the pass condition.

His other comments are rather general and therefore difficult to answer specifically, but we suggest that most engineers do not mind making calculations and measurements if the results are predictable. As a matter of fact, to be able to do so, is a rather delightful experience not encountered as often as one would like.

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[4] Manuscript received June 25, 1965.

Acceptable Mode Types for Inhomogeneous Media

This correspondence is prompted by Holmes's paper[1] in which he presented a study of the use of the WKB approximation for the solution of the wave equations in a rectangular waveguide inhomogeneously and continuously loaded across the broad dimension. I would like to point out the form of the acceptable mode types in such a waveguide.

Maxwell's equations are

$$\overline{E} = -j\omega\mu\overline{H} \tag{1}$$

$$\overline{H} = j\omega\epsilon\overline{E}. \tag{2}$$

Assume that μ and ϵ are functions of position. Taking the curl of (2) and substituting (1) we get

$$\nabla\times\nabla\times\overline{H} = \nabla\ln\epsilon\times(\nabla\times\overline{H}) + k^2\overline{H} \tag{3}$$

Manuscript received February 23, 1965.

[1] D. A. Holmes, "Propagation in rectangular waveguide containing inhomogeneous, anisotropic dielectric," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-12, pp. 152–5, March 1964.

where

$$\nabla\ln\epsilon = \frac{\nabla\epsilon}{\epsilon} \tag{4}$$

and

$$k^2 = \omega^2\mu\epsilon. \tag{5}$$

Since

$$\nabla\cdot\overline{B} = \nabla\mu\cdot\overline{H} + \mu\nabla\cdot\overline{H} = 0, \tag{6}$$

then

$$\nabla\cdot\overline{H} = -\overline{H}\cdot\nabla\ln\mu \tag{7}$$

with

$$\nabla\ln\mu = \frac{\nabla\mu}{\mu}\cdot \tag{8}$$

As a result, the left-hand side of (3) may be written

$$\nabla\times\nabla\times\overline{H} = \nabla(\nabla\cdot\overline{H}) - \nabla^2\overline{H} = -\nabla(\overline{H}\cdot\nabla\ln\mu) - \nabla^2 H \tag{9}$$

and (3) becomes

$$(\nabla^2 + k^2)\overline{H} = (\nabla\times\overline{H})\times\nabla\ln\epsilon - \nabla(\overline{H}\cdot\nabla\ln\mu). \tag{10}$$

Similarly,

$$(\nabla^2 + k^2)\overline{E} = (\nabla\times\overline{E})\times\nabla\ln\mu - \nabla(\overline{E}\cdot\nabla\ln\epsilon). \tag{11}$$

Equations (10) and (11) are the wave equations for inhomogeneous media.

Consider now a rectangular waveguide in which μ and/or ϵ are functions of y only. As a result,

$$\nabla\ln\epsilon = \bar{u}_y\frac{\partial}{\partial y}\ln\epsilon \tag{12}$$

$$\nabla\ln\mu = \bar{u}_y\frac{\partial}{\partial y}\ln\mu. \tag{13}$$

Equations (14), (15), and (16) are the components of (10) when expanded in the rectangular coordinate system.

$$(\nabla^2 + k^2)H_x = \frac{\partial}{\partial y}H_x\frac{\partial}{\partial y}\ln\epsilon - \frac{\partial}{\partial x}H_y\frac{\partial}{\partial y}\ln(\mu\epsilon) \tag{14}$$

$$(\nabla^2 + k^2)H_y = -\frac{\partial}{\partial y}H_y\frac{\partial}{\partial y}\ln\mu - H_y\frac{\partial^2}{\partial y^2}\ln\mu \tag{15}$$

$$(\nabla^2 + k^2)H_z = \frac{\partial}{\partial y}H_z\frac{\partial}{\partial y}\ln\epsilon - \frac{\partial}{\partial z}H_y\frac{\partial}{\partial y}\ln(\mu\epsilon). \tag{16}$$

Expressions for the components of (11) are identical in form and, with the obvious substitutions, the following argument holds for electric fields as well.

Take x and y as the transverse coordinates and z as the direction of propagation. We now look for modes in which one of the components of magnetic field is nonexistent. The possibilities are as follows.

$H_z = 0$

From (16),

$$\frac{\partial}{\partial z}H_y\frac{\partial}{\partial y}\ln(\mu\epsilon) = 0. \tag{17}$$

This can occur when

1) $\mu\epsilon$ = constant, being a trivial case.
2) $H_y \neq f(z)$. Impossible for a wave