matching the guide. (Values shown give $\sqrt{L/C}=55$.) This equivalent circuit cannot be altogether satisfactory and Fig. 10 in [1] clearly shows a change in effective varactor inductance which may be indicative of some transformation of junction impedance.

With the more common types of varactor package, the tolerances are frequently so serious that there would be considerable variations in correction factors necessary to deduce the junction values from the impedance close to resonance.

The use of the series resonant condition does not necessarily make it easier to measure varactors by insertion loss than by reflection methods, although commonly used impedance values are not very suitable for the latter. Blake and Dominick [2] have used the transmission-loss method because of the physical separation of their equipment from the mount, since, at a fixed frequency, measurement of loss is simpler. When the frequency is varied, the changes in generator output, in line losses, and in detector sensitivity complicate the measurement of transmission loss unless a balancing path which includes the reference attenuator is used. In such circumstances, for a limited range of frequencies, there is little or no economy in equipment compared with a reflection technique using two balanced paths connected to a precision directional coupler. Phase information is helpful in detailed analysis, and data such as obtained by Roberts is desirable.

There is need for much further work on evaluation of varactors and especially for the development of methods suitable for routine testing, and which can provide useful data on tolerances in packages and junction characteristics.

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[1] B. C. DeLoach, "A new microwave measurement technique to characterize diodes and an 800-Gc cut-off frequency varactor at zero volts bias," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-12, pp. 15–20, January 1964.
[2] C. Blake and F. Dominick, "Transmission test method for high-Q varactors," *Microwaves*, vol. MTT-4, pp. 18–23, January 1965.
[3] D. A. E. Roberts, "Measurements of varactor diode impedance," *IEEE Trans. on Microwave Theory and Techniques (Correspondence)*, vol. MTT-12, pp. 471–475, July 1964.

Submillimeter Wave Harmonic Mixing

The difference frequency between harmonics of millimeter wave oscillators has been observed at submillimeter wavelengths using a crossed-waveguide harmonic generator[1] as a harmonic mixer.

Figure 1 shows the experimental setup

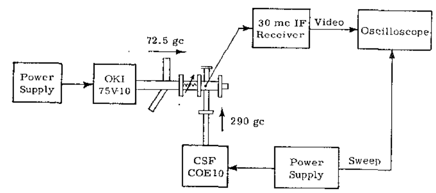

Fig. 1. Harmonics of 72.5-Gc/s klystron mixing with 290-Gc/s carcinotron output and its harmonics.

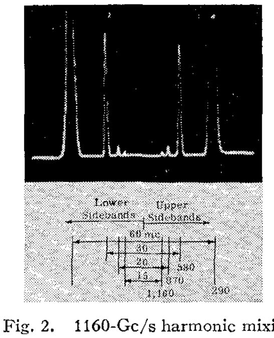

Fig. 2. 1160-Gc/s harmonic mixing.

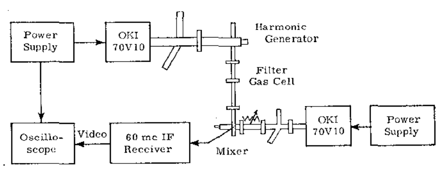

Fig. 3. Harmonic mixing using two 70V10 klystrons.

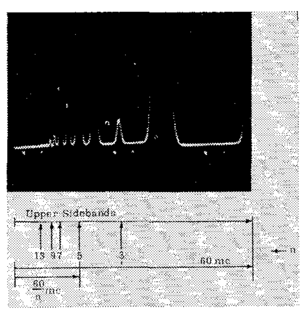

Fig. 4. 950-Gc/s harmonic mixing.

used in mixing the 290-Gc/s output of a carcinotron with the 72.5-Gc/s output of a klystron. The carcinotron was swept about 100 Mc/s and the klystron was operated CW. The difference frequency signals were amplified in a 30-Mc/s IF amplifier and the detected video output was displayed on an oscilloscope. Figure 2 shows the receiver output. Upper and lower sidebands are displayed. The nth harmonic of the carcinotron mixes with the 4 nth harmonic of the klystron to produce IF signals. The upper and lower sidebands are separated by $60/n$ Mc/s on the carcinotron sweep. The highest harmonic observed was the fourth at 1160 Gc/s.

Figure 3 shows the experimental arrangement used in mixing the output from a 72.9-Gc/s klystron with harmonics of a second 72.9-Gc/s klystron. In this case, one crossed-waveguide device was used as a harmonic generator and an identical unit was used as a harmonic mixer. Figure 4 shows the upper sidebands of the receiver output. Thirteen harmonics were observed. A narrow-band receiver is needed to resolve adjacent harmonics. For example, the tenth and twelfth harmonics are separated by 1 Mc/s at the fundamental with a 60-Mc/s IF. In order to determine how many of these harmonics were generated in the multiplier and propagated to the mixer and how many were generated in the mixer, a waveguide filter cutting off the second harmonic was inserted between the multiplier and the mixer. Only the third through sixth harmonics were observed. These were shown to be generated by the multiplier by observing absorptions in a gas cell with carbonyl sulfide, OCS. The signals corresponding to $n=1$ and $n=7$ through 13 were generated in the mixer.

In another experiment, both 72.9-Gc/s klystron outputs were fed in the RG-98 waveguide input of a mixer. One tube was connected to the regular input and the tuning short was removed to accept the second input. In this case so many harmonic beats were observed that the higher harmonics were not resolved. More than 20 harmonics of the 72.9 input were observed.

Harmonic mixing experiments similar to these have been reported by Murai[2] who observed beats as high as 750 Gc/s using a IN53 crystal. A millimeter wave superhetrodyne system using similar techniques was used by Johnson[3] for spectroscopy in the 100- to 150-Gc/s region.

Since 70-Gc/s klystrons can be phase locked to crystal oscillator harmonics, this harmonic mixing technique can be used for accurate measurement of the frequency of submillimeter oscillators (far-infrared lasers) and for phase (or frequency) stabilization of these sources.

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[1] Devices of this type were first used by spectroscopists to generate millimeter waves from centimeter klystrons. For example, see W. C. King and W. Gordy, *Phys. Rev.*, vol. 93, p. 407, 1954. The units used in these experiments have RG-98 and RG-135 waveguides.

[2] A. Murai, "Heterodyne beat between submillimeter components generated in a crystal detector," presented at the 1964 Internat'l Conf. on Microwaves, Cur ent Theory, and Information Theory, Tokyo, Japan.

[3] C. M. Johnson, "Superheterodyne receiver for the 100 to 150-kmc region," *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-2, pp. 27–32, September 1954.

Magnetostriction Effects in Remanence Phase Shifters

One type of remanence phase shifter[1] consists of a microwave ferrite toroid located in a waveguide. Close mechanical fit between ferrite and waveguide is desirable to eliminate reflection spikes, and to provide an adequate thermal path. Such structures typically develop mechanical pressure on the ferrite, and this pressure may vary with temperature, due to the unequal expansion of the waveguide and ferrite with temperature.

Manuscript received May 25, 1965.

[1] L. Levey and L. Silber, "A fast switching X-band circulator utilizing ferrite toroids," *1950 IRE Wescon Conv. Rec.*, pt. 1, pp. 11–20.

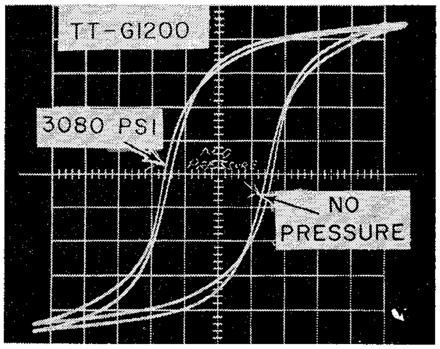

Fig. 1. Change in the *B-H* loop with applied stress.

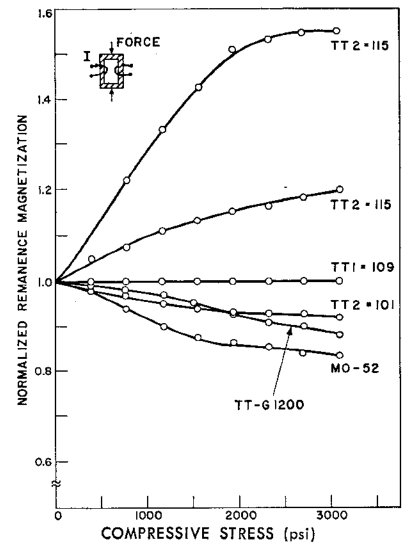

Fig. 2. Typical remanence magnetization characteristics vs. compressive stress.

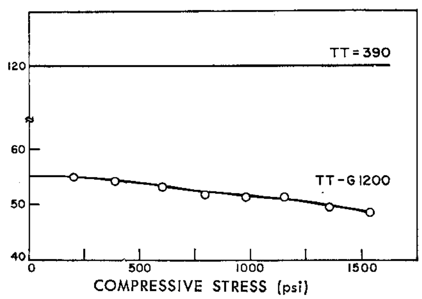

Fig. 3. Differential phase shift vs. compressive stress in ferrite.

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.

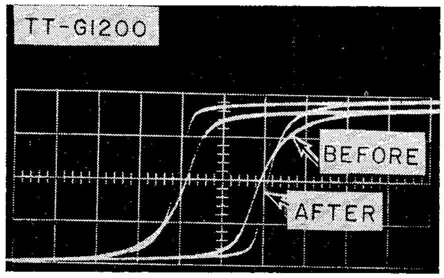

Fig. 4. Change in the *B-H* loop by annealing.

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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[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.
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[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.