about 10 hr per fill. The waveguide interior is copper-plated and gold-flashed to reduce the microwave insertion loss. The upper section of waveguide is filled with polystyrene foam plastic to provide a "gas-tight" seal. The VSWR of the termination at the input flange is better than 1.05 to 1 from 2270 to 2350 Mc at both ambient and liquid helium temperatures. The minimum VSWR of 1.02 to 1 occurs at 2300 Mc at 4.2 °K.

The calculation for noise temperature at the input flange of the helium-cooled termination assumes a linear temperature distribution between the 4.2°K bath and ambient (294°K) section of waveguide. The insertion loss for the cooled section of waveguide was measured to be 0.009 db.[2] The insertion loss for the upper section (at constant ambient temperature) is 0.008 db. The noise temperature of the liquid helium termination referred to the input flange is calculated to be 5.0°K.[3] The resistive loss of the waveguide connecting the termination to the maser adds 0.4°K.

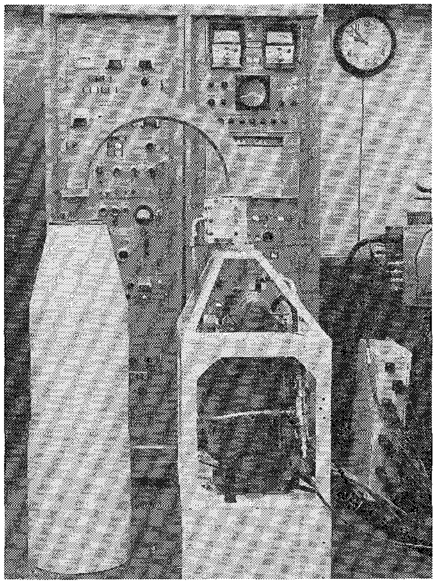

Fig. 1—Traveling wave maser system (JPL photo No. 333-2681).

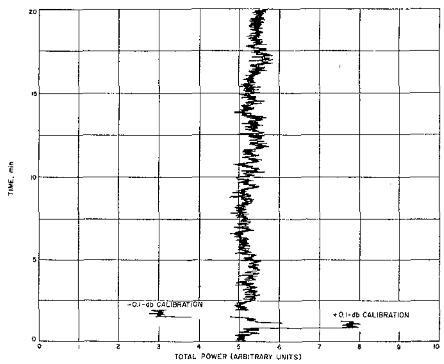

Fig. 2—Maser gain 37 db, system temperature ≈15°K, detector bandwidth ≈8 Mc, time constant ≈1 sec, chart speed =24″/hr, May 5, 1964.

System noise-temperature measurement errors are introduced by gain instability, precision-attenuator inaccuracy, system nonlinearity, and the tolerances assigned to reference termination temperatures. An analysis of these sources of errors indicates that the system temperature measurement described herein has an absolute accuracy of ±0.4°K. Fig. 2 is an example of the stability which has been achieved with this maser system in the laboratory. Since 0.1 db represents a 0.35°K system temperature change, the minimum detectable system temperature change is approximately 0.03°K. This sensitivity has enabled a meaningful series of noise temperature measurements to be made while cooling the refrigerator from 4.5 to 3.9°K.

The system temperature measured 15.6 and 14.3°K at refrigerator temperatures of 4.5 and 3.9°K, respectively. The reduction in system temperature at 3.9°K is the result of two changes. The increased maser gain at the lower temperature reduced the second-stage contribution from 0.72 to 0.07°K. The equivalent input noise temperature of the maser varied from 9.48 to 8.83°K. This represents a change in maser noise temperature of 0.65°K.

The maser noise temperature is predicted by the expression[4]

$$T_m \simeq T_0 \frac{\rho + \beta}{1 - \beta}, \tag{1}$$

where

T_0 = refrigerator temperature
$\rho = f_s/(f_p - f_s)$
f_s = signal frequency
f_p = pump frequency
$\beta = \alpha_0/\alpha_p$
α_p = gain coefficient per unit length of TWM
α_0 = loss coefficient per unit length of TWM.

Since $G = e^{(\alpha_p - \alpha_0)L}$ = net gain for a TWM of length L, it can be shown that

$$\beta = \frac{\alpha_0}{\alpha_p} = \frac{\text{forward loss in db of TWM}}{\text{electronic gain in db of TWM}} \cdot \tag{2}$$

The change in maser noise temperature while cooling the refrigerator is predicted by the expression

$$\Delta T_m T_{0_1}\left(\frac{\rho - \beta_1}{1 - \beta_1}\right) - T_{0_2}\left(\frac{\rho + \beta_2}{1 - \beta_2}\right), \tag{3}$$

where

$T_{0_1} = 4.5°K$
$T_{0_2} = 3.9°K$
$\rho = 0.222$
$\beta_1 = 0.204$
$\beta_2 = 0.168.$

The predicted change in maser noise temperature of 0.58°K and the measured value of 0.65°K differ by 0.07°K. The accuracy achieved is the result of a low system temperature (15°K), good gain stability, and accurately calibrated thermal terminations. This accuracy is believed to represent a milestone in the precise measurement of low-noise receiving systems. Previous methods have used inaccurate cooled terminations or have relied on shorting the input[5] of the traveling wave maser for the cold reference.

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Quick Coaxial Phaseshifter for 150 Watts

In some RF and microwave systems it might be necessary to arrange a sudden phase jump of the RF power. For this purpose we have developed a phase shifter which switches an energy of 150 w at 500 Mc for any angle between 0 and 360°. With semiconductor diodes the energy will be switched from one path in the coaxial line to the other. The system remains matched in any case.

The shifter can be described by Fig. 1. If the diode S_1 is open it transforms into an open circuit at B. The energy can pass the unloaded line ABC. In the same time the open diodes $S_2(S_3)$ transform into a short circuit at $E(D)$ and an open circuit at $A(C)$. No energy flows through $AEDC$. So far the switching is ideal, no mismatch occurs. Similarly, when shorting the switching diodes S_1, S_2, and S_3, the transformation causes the energy to flow through $AEDC$ and closes the path ABC. By adjusting the

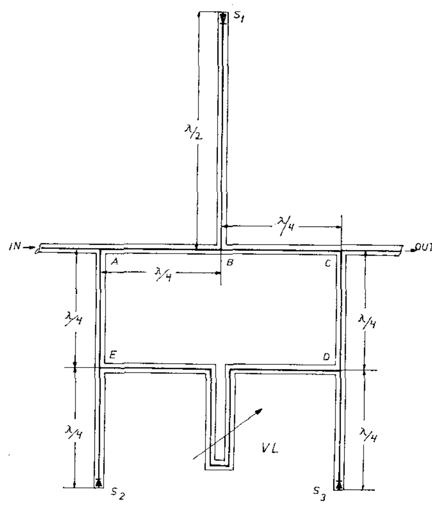

Fig. 1—Principal circuit of the phaseshifter.

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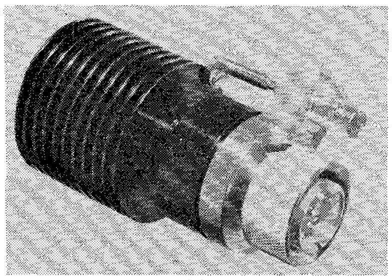
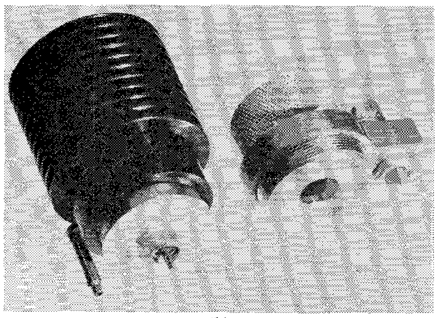


(a)



(b)

Fig. 2—(a) mounted diode switch with connector for the triggering. (b) Diode switch screwed off, showing the mounted semiconductor diode in the cooling cylinder.

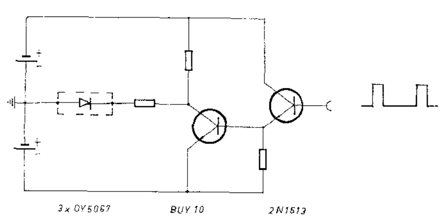


Fig. 3—Principal circuit of the trigger unit.

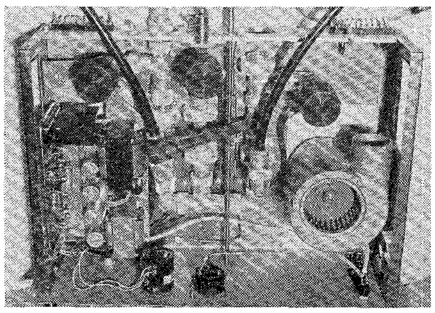


Fig. 4—The apparatus, showing the trigger unit and the 3 semiconductor diode switches without cooling channel.

variable line *VL* we can obtain any amount of phase jump.

The most critical parts of the shifter are the diode switches. They limit the switching time as well as the switched energy. They also determine how far we approach the ideal short or open circuit. We built selected semiconductor diodes OY 5067 in a coaxial elenent (Fig. 2), compensating the stray capacitance as much as possible.

Care has been taken to conduct the terminal energy from the diodes by a blackened brass cylinder which is forced air cooled. So we are able to shift an energy of 150 w in less than 1.5 μsec. A diode element itself has an open to closed ratio of 25 db. With special RF diodes we hope to reach better switching times.

The diodes will be triggered in parallel by the power stage shown in Fig. 3, having a rise time of less than 200 nsec. The apparatus itself is seen in Fig. 4.

In a similar way this switching principle could be used in switching from one transmitter to two different loads or from two different transmitters to the same receiver. We think that it would be possible to build similar switches for rectangular waveguide systems.

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Recent Linewidth Measurements with a Cross-Guide Coupler

The continued interest in both narrow and broad linewidth ferromagnets for microwave applications motivates studies directed toward measuring their pertinent parameters. Two of the more important parameters are the linewidth and the effective *g* factor. These quantities are ordinarily measured in a resonant cavity where quite often it is necessary to use two different cavities for materials whose line widths differ by several orders of magnitude. Although the procedure for using this method is unnecessarily involved when one desires to measure only the linewidth and the *g* factor, the cavity technique is considered the standard.

The purpose of this communication is to present measurements that show that the cross-guide coupler technique is satisfactory for both narrow and broad linewidth materials using the same coupler and that it is also possible to perform these measurements over a wide frequency range. The theory and operation of the cross-guide coupler method has been presented before[1] so only some of the more recent results will be given here.

Since it was suggested that the coupler method might not be satisfactory for extremely narrow linewidth samples,[2] it was of interest to determine experimentally whether such a supposition were true. Initially, attempts were made to polish several YIG single crystals using the method described by Carter, *et al.*[3] Linewidths as narrow as 1.5 Oe at *X*-band[4] were obtained in this manner although it was found necessary to line the tube constraining the ferrite above the grinding wheel with a plastic insert in order to avoid chipping the surface of the sphere during its random bouncing. Because of the difficulties encountered in polishing spheres and obtaining one without inclusions, it was decided to purchase a polished sphere from Microwave Chemicals Lab., Inc., New York, N. Y. The linewidth and *g* factor of this sphere were measured over the frequency range from 2–17 Gc.[5] Two cross-guide couplers constructed from $\frac{7}{8}$ inch and $\frac{5}{8}$ inch coax were used for frequencies to 6 Gc and 9 Gc, respectively, and ordinary *X*-band and K_u-band waveguides were used for the other two couplers. The behavior of the linewidth as a function of the normalized field for resonance is shown in Fig. 1. Since the *g* factor was constant at a value of 2, the abscissa may be converted to frequency in Gc by multiplying by 5. The increase in linewidth at the lower frequencies is caused by the sample becoming unsaturated whereas the increase in linewidth at frequencies near 3 Gc is caused by the uniform mode entering the spin wave manifold. A considerable scattering of points occurred for frequencies above 8 Gc with some frequency bands from 100–500 Mc wide where the uniform mode did not possess a clean resonance but was coupled to various magnetostatic modes. Since the linewidth and the coupled power were very sensitive to the incident power level, sufficient attenuation was always inserted in the primary line to produce the minimum linewidth. A comparison of our data with that reported by Masters, *et al.*,[2] Douthett and Kaufman,[6] and Microwave Chemicals[7] is also noted in Fig. 1. It is interesting to observe that the linewidth is less than 0.5 Oe over the entire frequency range from 3.4–6 Gc with the narrowest linewidth of about 0.2 Oe at 4.38 Gc. However, no attempt was made to obtain either extreme accuracy or to seek a minimum linewidth since our interest was in the general behavior of the linewidth as a function of frequency. Two linewidth values taken at different times at a frequency of 10 Gc are shown in Fig. 1 with a vertical dotted line between them to give an idea of the repeatability of the measurements. The accuracy in measuring linewidths was estimated at ±15 per cent for linewidths of 1 Oe. It was found necessary to add several turns of wire to the yoke of the magnet[2] in order to measure linewidths below 2 Oe. The YIG sample was not glued in the coupling hole but was placed in a hollow cylindrical cavity in a dielectric rod and the rod was glued in the coupling hole. The axes of the coupling hole, the dielectric rod, and the cylindrical cavity were all parallel. However, considerable difficulty was experienced with the YIG sample moving about in the coupling hole. This problem was solved by placing the sphere in a cylindrical cavity whose axis was perpendicular to the axis of the dielectric rod.

The linewidth behavior of the single crystal YIG sphere in Fig. 1 was typical of

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