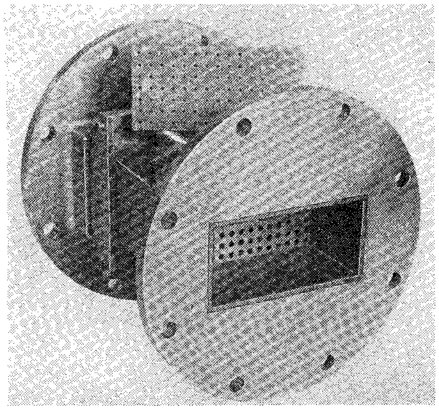

Fig. 1—Two-resonator quasi-optical filter.

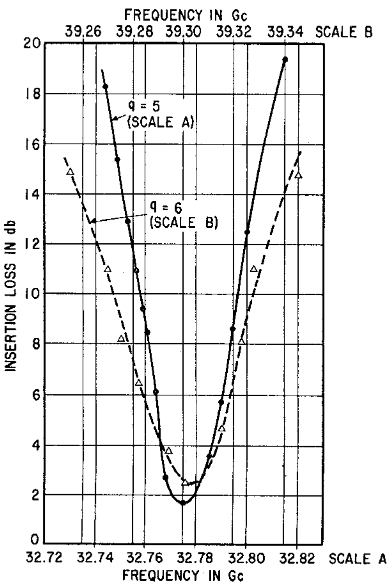

Fig. 2—Insertion loss vs frequency of quasi-optical two-resonator filter.

fied for the case of constant separation and varying frequency. At present, we have inferred proper filter action from the single-frequency data that will be described in the following paragraphs.

Taub, *et al.* [1] gives curves that describe the single-frequency operation for one and two pairs of slabs for materials with various dielectric constants. These curves indicate that the transmitted power rises and falls with a periodicity of 127 electrical degrees; this is approximately a 12-db attenuation range for a single pair of quartz slabs. Thus, such a structure is limited to low coupling ratios—that is, it is limited in its maximum insertion loss when used as a filter. To obtain a greater range of insertion loss, the multiple-slab structure using two pairs of slabs was used. This device has a theoretical range of 27 db.

An analysis of the dissipation loss in this multiple-slab filter has been made and appears in Taub and Hindin [6]. The purpose of the analysis was to estimate the dielectric losses of the device. The analysis is valid for any number of slabs. Since quartz slabs are used, we can estimate the loss by using measured values of ϵ_r and $\tan\delta$. At 0.9 mm, $\epsilon_r = 3.9$ and $\tan\delta = 0.0043$ [7]. Using [6] we

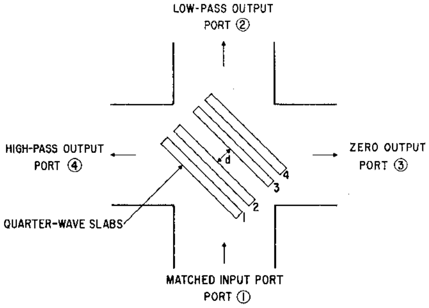

Fig. 3—High-pass and low-pass directional filter.

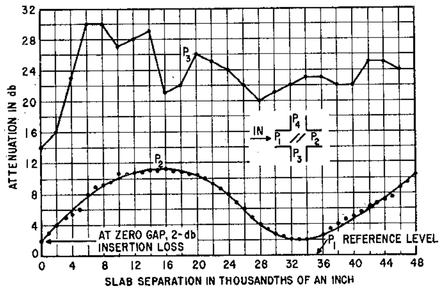

Fig. 4—$n = 2$ multiple-slab test data.

obtain a theoretical insertion loss of 0.65 db. The filter was tested at 0.9 mm using a CSF COE 10 carcinotron. Fig. 4 shows the data obtained.

This is in reasonable agreement with the theoretical characteristics shown in Taub and Hindin [6]. There was sufficient range in the slab separation to permit the periodicity and the filter response attenuation characteristics to be shown. The device had only 2 db of insertion loss. This value is higher than predicted and it is felt that the discrepancy is mainly due to nonperfect alignment of the slabs, which causes a leakage of power into the perpendicular arm. This accounts for about 1 db. Wall losses, loss in the quartz slabs, and the imperfect directivity (matching) of the device account for 0.2 to 0.3 db more.

The separation between peaks of the filter characteristic should be 127° and is measured to be 126°. This again verifies the quasi-optical design theory. The only failure in this device is its inability to obtain the theoretical maximum attenuation for a given slab separation. We believe this discrepancy is related to the apparent higher insertion loss. The directivity of the filter is also shown in Fig. 4. It varies between 10 and 20 db, but will probably be improved when the cause of the decreased attenuation range is determined.

The data presented indicate the feasibility of the techniques for constructing quasi-optical filters. Work is continuing on these devices and will be reported in a future publication.

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Total System Noise Temperature: 15°K

Laboratory evaluation of an operational maser system has led to interesting results, particularly in regard to accurate noise temperature measurements.

The maser is a ruby loaded comb structure designed for operation at 2295 Mc. It is normally operated with 37 db gain and 18 Mc of 3-db bandwidth, at a refrigerator temperature of 4.5°K. The maser is conduction cooled for hard-vacuum operation in a closed-cycle helium refrigerator.[1]

The package containing the maser and refrigerator weighs 450 pounds. A 180-pound magnet supplies a 2500 gauss field. The package also contains a klystron pump oscillator, a noise calibration package, directional couplers for gain and noise temperature measurements, heaters, and a thermistor to maintain constant package temperature (see Fig. 1).

Several components affect the equivalent input temperature of the maser. A 26-db crossguide coupler and a transition to a $\frac{7}{8}$ coaxial line precede the maser. A $\frac{7}{8}$ inch 50 ohm coaxial feeds the input signal through the vacuum jacket into the maser. Careful construction techniques have resulted in a combination of low insertion loss and good thermal isolation.

In order to accurately measure the equivalent input temperature of the maser, a standard neon noise source is used in conjunction with terminations at liquid helium, liquid nitrogen, and ambient temperatures. The liquid-helium-cooled termination has been constructed in WR 430 S-band waveguide. The thin wall (0.025 inch) stainless steel waveguide gives adequate thermal isolation and results in a useful operating life of

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[1] The traveling wave maser was purchased from Airborne Instruments Laboratory. The "Cryodyne" helium refrigerator was purchased from Arthur D. Little, Inc., Cambridge, Mass.

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.

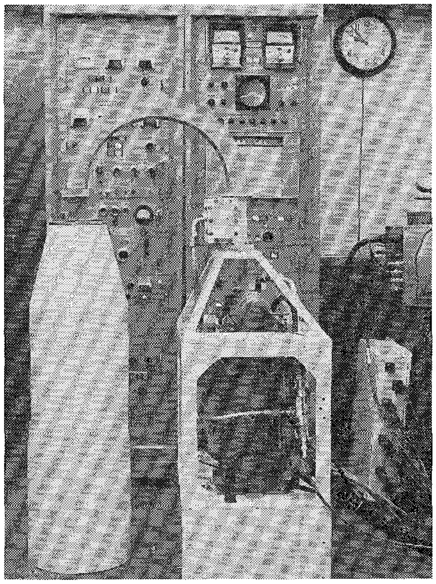

Fig. 1—Traveling wave maser system (JPL photo No. 333-2681).

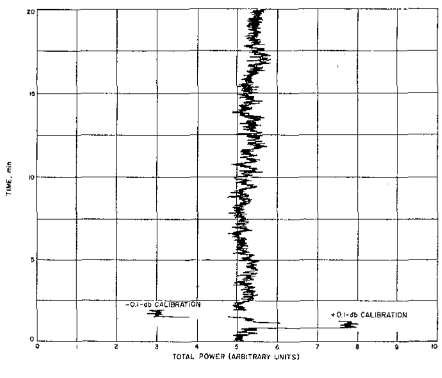

Fig. 2—Maser gain 37 db, system temperature ≈15°K, detector bandwidth ≈8 Mc, time constant ≈1 sec, chart speed =24″/hr, May 5, 1964.

[2] C. T. Stelzried and S. M. Petty, "Microwave insertion loss test-set," IEEE TRANS. ON MICROWAVE THEORY AND TEHCNIQUES (*Correspondence*), vol. MTT-12, pp. 475–477; July, 1964.

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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]

$$T_m \simeq T_0 \frac{\rho + \beta}{1 - \beta}, \quad (1)$$

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

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

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

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

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

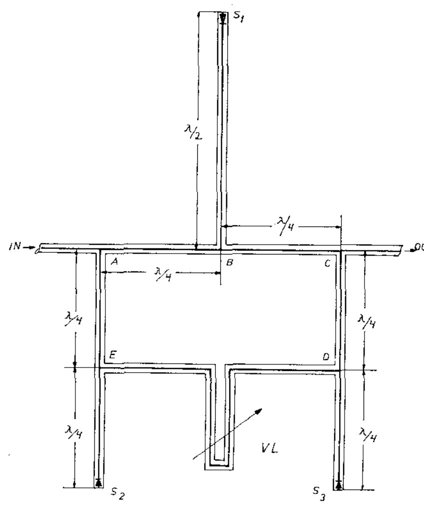

Fig. 1—Principal circuit of the phaseshifter.

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