This shows that the attenuation constant is sensitive to changes in loss tangent.

The normalized impedance z in the air-filled portion of waveguide at the interface of the soil sample is equal to the ratio of the propagation constant in the air-filled guide to that in the soil-filled guide and is thus written as

$$z = \frac{\gamma_0}{\gamma} = \left[\frac{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}{\epsilon_r(1-j\tan\delta)-\left(\frac{\lambda_0}{\lambda_c}\right)^2}\right]^{1/2}. \quad (4)$$

In turn, the VSWR S in the air-filled guide is related to z by

$$S = \frac{|z+1|+|z-1|}{|z+1|-|z-1|}. \quad (5)$$

Substitution of (3) and (4) in (5) yields an expression for S containing ϵ_r, the measured quantity α/k_0 and waveguide parameters. For the special case when $\epsilon_r \geq 2$ and $\tan\delta \leq 0.1$, (5) simplifies to

$$S \approx \frac{1}{z} \approx \left[\frac{\epsilon_r-\left(\frac{\lambda_0}{\lambda_c}\right)^2}{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}\right]^{1/2}. \quad (6)$$

This shows that measurement of VSWR is sensitive to changes in dielectric constant.

Eqs. (3), (4) and (5) are plotted in Figs. 3 and 4 as a function of α/k_0 for an operating frequency of 8.6 kMc. Thus, for a given measured α/k_0 and S, the corresponding dielectric constant may be read from Fig. 3 and then the value of $\tan\delta$ may be taken from Fig. 4. Not only has this technique proved useful for measuring the properties of soil, but it has also been used with great success in a bio-medical research program for measuring the properties of fatty tissue at L- and S-band frequencies.

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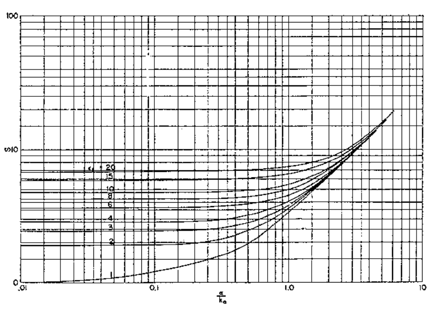

Fig. 3—VSWR as a function of α/k_0 for $f = 8.6$ kMc.

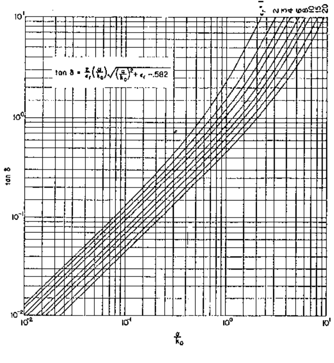

Fig. 4—Loss tangent as a function of α/k_0 for $f = 8.6$ kMc.

Investigation of Millimeter Wave Reflex Klystron Amplifiers*

It has been shown that reflex klystrons are usable for microwave[1–2] and millimeter wave amplification.[3–5] The purpose of this communication is to report that a VA-99 fixed-cavity reflex klystron performed well as a negative-resistance amplifier in the "difficult" millimeter wave region and that the amplifier was operated not by loading it so that it was incapable of oscillation as has been previously reported,[2,4,6] but by adjusting voltages and impedances so that it was on the edge of a mode of oscillation. All measurements were made using the set-up shown in Fig. 1. In the amplifier section, the reflex klystron was connected to the main waveguide line with an H-plane tee with an EH tuner, each at the input and output end of the colinear arm of the H-plane tee.[5] The repeller and anode voltages, and the circuit impedance were adjusted so that the oscillation stopped at the signal frequency.

In general when the amplifier was adjusted so the signal frequency existed at the outside edge of the oscillation range of the repeller voltage, stable amplification was easily accomplished. Thus, the most suitable frequency for amplification exists at the edge of oscillation region of repeller voltage. For the fixed-frequency klystron the signal frequency must be chosen to meet these conditions. The same thing is true for the anode voltage adjustments.

When the output circuit impedance of the reflex klystron is such that it can oscillate and the input signal frequency is in frequency range of oscillation of the amplifier, it is difficult to control the oscillation to obtain stable amplification. On the other hand if the signal frequency is just outside the oscillation region and the impedances and voltages are such that oscillation does not exist, stable amplification is easily obtained.

Thus it can be seen that the output impedance of the amplifier had a great effect on its performance. As an example, with a -70 dbm 70.35 kMc input signal to the VA-99, strong oscillation appeared approximately 30 Mc off the signal. When one of the EH tuners adjacent to the VA-99 was adjusted, the oscillation weakened as it moved to within 18 Mc of the signal which was now being amplified. By further adjustment of the EH tuner, oscillation disappeared near the signal frequency and the signal alone remained, amplified 27 db.

When the VA-99 was oscillating strongly

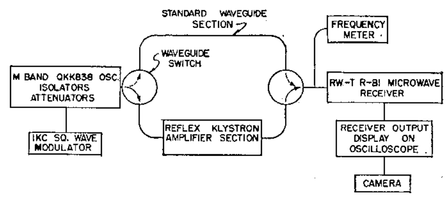

Fig. 1—Test circuit configuration.

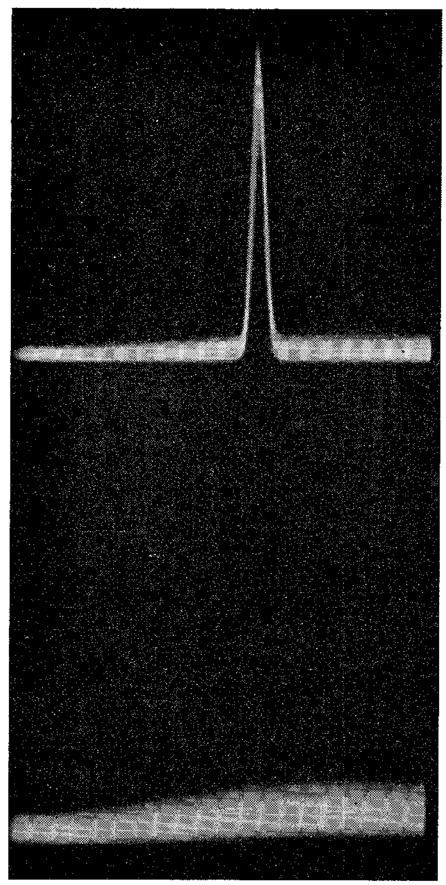

Fig. 2—Pulse amplification (frequency sweep display). Top: Output of VA-99 Amplifier, 30 db gain 70.35 kMc carrier. Bottom: 1-μsec pulse input to VA-99 amplifier, pulse repetition rate, 1000 cps.

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[1] K. Ishii, "X-Band receiving amplifier," *Electronics*, vol. 28, pp. 202–210; April, 1955.

[2] C. F. Quate, R. Kompfner, and D. A. Chisholm, "The reflex klystron as a negative resistance type amplifier," IRE Trans. on Electron Devices, vol. ED-5, pp. 173–179; July, 1958.

[3] K. Ishii, "Using reflex klystron as millimeter wave amplifiers," *Electronics*, vol. 33, pp. 71–73; March, 1960.

[4] D. M. Makurat, R. C. Hertel and K. Ishii, "The reflex klystron as an amplifier at 73 kMc," Proc. IRE (*Correspondence*) vol. 50, pp. 210–211; February, 1962.

[5] K. Ishii, D. E. Schumacher and K. R. Kelly, "Interesting behavior of VA-99 as a millimeter wave amplifier," Proc. IRE (*Correspondence*) vol. 50, p. 2510; December, 1962.

[6] I. Thomas and L. Bounds, "The Investigation of the Characteristics of the KS9-20A Reflex Klystron When Used As an Amplifier," The Mullard Radio Valve Co. Ltd. England, D.V.T. Rept. No. U231; 1961.

it was difficult to control the oscillation merely by the circuit impedance adjustment as Quate, *et al.*,[2] Makurat, *et al.*[4] and Thomas, *et al.*[6] experienced. They tried to amplify signals whose frequency was located right at the center of the strong oscillation region of repeller voltage. They loaded the tube down until it stopped oscillating and then placed an input signal to be amplified at the original oscillation frequency. In such cases the amplifiers were often noisy.[2,4,6]

Note that in the method explained in this communication the oscillation frequency was always electrically shifted until the oscillation died out at the signal frequency and the tube was not simply overloaded to stop oscillation without shifting its frequency.

For small signals (almost the noise level of the RW-T R-BI receiver 1-μs pulse modulated, (Fig. 2, bottom) the amplifier showed a gain of 30 db at 70.35 kMc (Fig. 2, top).

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Still Another Method for Transforming Impedances Through Lossless Networks*

The input impedance $\boldsymbol{Z}_A$ and the terminating impedance $\boldsymbol{Z}_L$ of a symmetrical lossless four-terminal network are related by an equation which contains only one additional parameter; namely, the input impedance $\boldsymbol{Z}_1$ when the network is terminated in any known resistance R_0. Let $\boldsymbol{\Gamma}_A=(\boldsymbol{Z}_A-R_0)/(\boldsymbol{Z}_A+R_0)$, $\boldsymbol{\Gamma}_L=(\boldsymbol{Z}_L-R_0)/(\boldsymbol{Z}_L+R_0)$, $\boldsymbol{\Gamma}_1=(\boldsymbol{Z}_1-R_0)/(\boldsymbol{Z}_1+R_0)$, and the superscript "*" denote the conjugate. Now

$$\boldsymbol{\Gamma}_A=\frac{\boldsymbol{\Gamma}_1}{\boldsymbol{\Gamma}_1^*}\,\frac{\boldsymbol{\Gamma}_1^*-\boldsymbol{\Gamma}_L}{1-\boldsymbol{\Gamma}_1\boldsymbol{\Gamma}_L}\,. \tag{1}$$

Eq. (1) also relates the voltage reflection coefficients for a lossless two-port junction.[1] This equation provides a basis for a graphical procedure for finding $\boldsymbol{Z}_A$ or $\boldsymbol{Z}_L$ when the other is known.

Symmetrical Networks

First, it is assumed that the network under consideration is both lossless and symmetrical. Some convenient value of R_0 is selected and the corresponding value of $\boldsymbol{Z}_1$ is computed or determined experimentally. (In the case of a two-port junction, R_0 would probably correspond to a matched load.) The impedance $\boldsymbol{Z}_{1N}=\boldsymbol{Z}_1/R_0$ is plotted on a Smith or Carter chart as shown in Fig. 1. The line $C\boldsymbol{Z}_{1N}$ is drawn from the center C of the chart through $\boldsymbol{Z}_{1N}$. The point M is located on this line so that $(\overline{C\boldsymbol{Z}_{1N}})(\overline{CM})=$ (radius of chart).[2] A graphical procedure for locating M is to draw the line DE through $\boldsymbol{Z}_{1N}$ perpendicular to the line $C\boldsymbol{Z}_{1N}$. The points D and E are the intersections of this line with the $R=0$ circle. The lines DM and EM are tangent to the $R=0$ circle.

If $\boldsymbol{Z}_L$ is known, the impedance $\boldsymbol{Z}_{LN}^*=\boldsymbol{Z}_L^*/R_0$ is plotted. The line GM is drawn from M through $\boldsymbol{Z}_{LN}^*$. The line $\boldsymbol{Z}_{1N}\boldsymbol{Z}_{LN}^*$ is drawn. The line CH is drawn from C so that $\angle \boldsymbol{Z}_{1N}\boldsymbol{Z}_{LN}^*M=\angle MCH=\theta$. The intersection of the lines MG and CH is $\boldsymbol{Z}_{AN}=\boldsymbol{Z}_A/R_0$.

If $\boldsymbol{Z}_A$ is known, $\boldsymbol{Z}_{AN}=\boldsymbol{Z}_A/R_0$ is plotted. The lines $C\boldsymbol{Z}_{AN}$ and $M\boldsymbol{Z}_{AN}$ are drawn. The line $\boldsymbol{Z}_{1N}K$ is drawn from $\boldsymbol{Z}_{1N}$ so that $\angle M\boldsymbol{Z}_{AN}C=\angle M\boldsymbol{Z}_{1N}K=\phi$. The intersection of the lines $M\boldsymbol{Z}_{AN}$ and $K\boldsymbol{Z}_{1N}$ is $\boldsymbol{Z}_{LN}^*$.

The symmetrical network used for the graphical construction shown in Fig. 1 is the section of lossless transmission line shown in Fig. 2. The characteristic impedance of the line is 100 ohms, its length is 0.15 wavelength, $R_0=50$, $\boldsymbol{Z}_1=98.21+j70.05$, $\boldsymbol{Z}_L=25$ $j75$, and $\boldsymbol{Z}_A=17.03+j27.94$.

Test for Losses

Often four-terminal networks and two-port junctions are assumed to be lossless. This can be checked experimentally by terminating the network in at least two lossless loads, such as a short circuit and an open circuit. If two different input impedances are measured which are pure reactances, then the network is lossless.

Test for Symmetry

The term *symmetrical network* is used here in the sense that the electrical characteristics of the network are symmetrical at the frequency being used. It is not necessarily symmetrical in appearance or at other frequencies.

A convenient procedure for checking experimentally the symmetry of a lossless network is to terminate the network in a short circuit. Let $\boldsymbol{Z}_{SC}$ denote the corresponding input impedance. The point $\boldsymbol{Z}_{SCN}=\boldsymbol{Z}_{SC}/R_0$ is plotted. The network is symmetrical if and only if the point $\boldsymbol{Z}_{SCN}$ lies on the line from $\boldsymbol{Z}=0$ to M. Another test is that

$$X_{SC}=\frac{R_1^2+X_1^2-R_0R_1}{X_1}, \tag{2}$$

where $\boldsymbol{Z}_{SC}=jX_{SC}$ and $\boldsymbol{Z}_1=R_1+jX_1$, if and only if the network is symmetrical.

For the network shown in Fig. 2, $\boldsymbol{Z}_{SC}=j137.64$ and $\boldsymbol{Z}_{SCN}$ lies on the line from $Z=0$ to M, as shown in Fig. 1. The network in Fig. 2 is made unsymmetrical by the addition of the shunt reactance $X_2=200$ as shown in Fig. 3 (next page). The value of $\boldsymbol{Z}_{SCN}$ remains unchanged and the new value of $\boldsymbol{Z}_1$ is $121.4+j84.44$. The point $\boldsymbol{Z}_{SCN}$ does not lie on the line from $\boldsymbol{Z}=0$ to M, as shown in Fig. 4. If $\boldsymbol{Z}_{SC}=0$, then $\boldsymbol{Z}_{1N}$ must lie on the circle shown in Fig. 5 when the network is symmetrical.

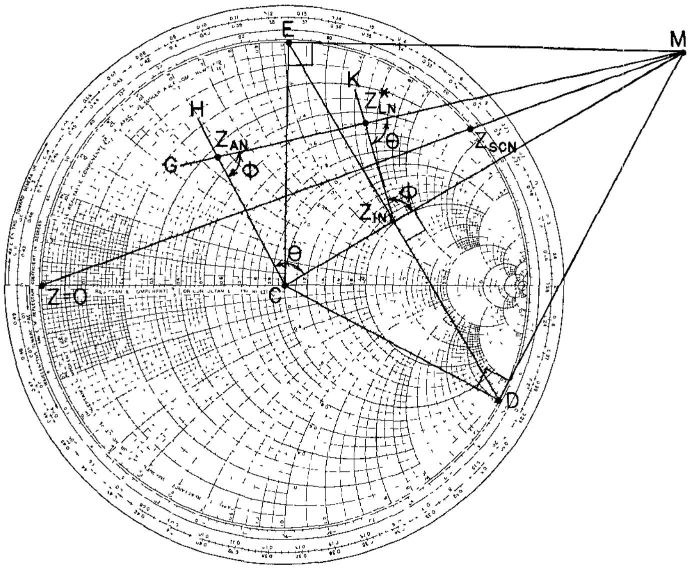

Fig. 1—Graphical construction for a symmetrical network.

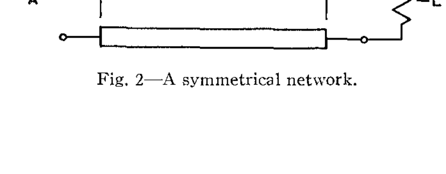

Fig. 2—A symmetrical network.

* Received January 14, 1963.

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