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FREQUENCY STABILIZATION SYSTEM FOR REFLEX KLYSTRONS

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ABSTRACT

A method of stabilizing a reflex klystron was developed which emphasizes ease of operation rather than maximum obtainable degree of stability and provides either amplitude-modulated or continuous-wave outputs which are instantly selectable by the operator. Stabilities of the order of 1 part in 10^6 are obtained for both CW and modulated outputs over the operating range of 8500 to 10000 megacycles. The system is based upon a microwave discriminator, operating on 1 percent of the generated power, which consists of an unmatched hybrid tee, a phase changer and a tunable reference cavity. The rectified output of the detectors affixed to the E- and H-arms of the hybrid, effect frequency control by adjusting the modulation amplitude supplied to the reflector of the klystron in the modulated case. For CW operation 1 percent of the power supplied to the discriminator is modulated at 1000 cycles by a crystal modulator. The rectified output of the E- and H-arm detectors control the amplitude of a 7-megacycle sine wave which is subsequently rectified and added to the fixed reflector voltage. The principle of operation should be valid for any frequency for which electronically-tunable reflex klystrons are available and for which the r-f plumbing of the discriminator is realizable in practice.

PROBLEM STATUS

This is a final report on this phase of the problem; work is continuing on the general problem.

AUTHORIZATION

NRL Problem R09-45R
NR 509-450

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FREQUENCY STABILIZATION SYSTEM FOR REFLEX KLYSTRONS

INTRODUCTION

The technique of frequency stabilizing a reflex klystron has been given much attention since the original work of Pound,[1] both by Pound and others.[2] Most of this effort has been devoted to an end product based upon CW output having a maximum obtainable degree of stability. There is, however, a large class of microwave instrumentation problems involving measurements of relatively low dispersion networks that does not require the maximum obtainable stability and in which amplitude modulation is desirable. Hence a stabilization method was sought which emphasized ease of operation rather than maximum stability and provided either amplitude modulated or continuous wave outputs which were instantly selectable by the operator. Such a system has been devised and has been in general laboratory use for several months.

GENERAL DESCRIPTION

The actual apparatus is pictured in Figure 1 and shown in simplified block schematic form in Figure 2.[3] This model operates in the frequency range of 8500 to 10000 megacycles and uses a 2K39 klystron. The basic principle of operation can be understood by referring to Figure 2 and assuming that all four elements of the emission selector switch are set to AM. Under these conditions the klystron output is square wave modulated. Approximately one percent of its power is diverted by a direction coupler to a frequency discriminator through an r-f attenuator. This discriminator is composed of an unmatched hybrid junction, a phase changer and a resonant cavity. The hybrid E- and H-arm bolometer detectors drive the two signal rectifiers through amplifiers of preset gain. The gains are fixed so that equal voltages are derived at the rectifiers for the mid-point of the frequency band when the reference cavity is replaced by a matched load. In operation, the phase changer is adjusted to obtain equal voltages from the rectifier when the cavity is detuned from resonance and the AFC switch is set to "off." The cavity is then tuned to

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[1] Pound, R. V. "An Electronic Frequency Stabilization System for CW Microwave Oscillators." Radiation Laboratory MIT Report 815, October 1945.

[2] Pound R. V. "Frequency Stabilization of Microwave Oscillators." Proc. I.R.E., 35: 1405-1415, December 1947.

Tuller, W. G. Galloway, W. C., and Zaffaranos, F. P. "Recent Developments in Frequency Stabilization of Microwave Oscillators." Proc. I.R.E., 36: 794-800, June 1948.

Grant, E. F. "An analysis of the Sensing Method of Automatic Frequency Control for Microwave Oscillators." Proc. I.R.E., 37: 943-951, August 1949.

[3] Standard I.R.E. symbols are used in Figure 2.

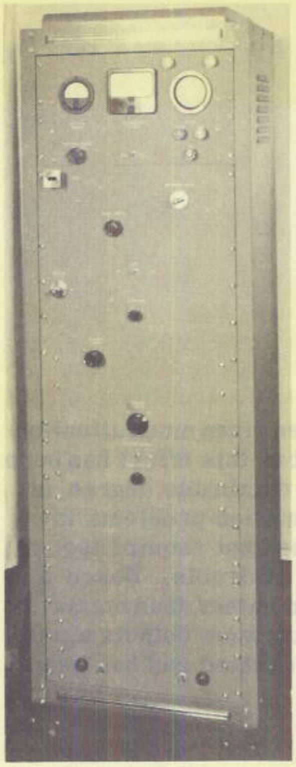

Fig. 1 - AFC-AM-CW-X-band generator, rack cabinet

resonance which again equalizes the voltages at the rectifiers and the AFC switch is set to "on." Subsequently, any tendency toward frequency change will cause an increase in power in one arm and a decrease in power in the other arm as a function of the cavity phase characteristic near resonance. Since there is a 180 degree phase reversal in the reflection from the cavity at resonance, the direction of frequency shift will determine whether the H-arm increases and the E-arm decreases or vice versa. Hence the amplified and rectified modulation components from the two arms may be used to control the G_m of the modulator tube and, consequently, the amplitude of the square wave output. When this square wave is added to the steady state klystron reflector voltage by derivative coupling and clipping, the total reflector voltage at the "on" oscillating condition is controlled by the discriminator and consequently the frequency of oscillation is stabilized. The "tightness" of this control loop is adjusted by the r-f attenuator.

The operation for the CW case is essentially similar to that just described. The sampled power diverted to the discriminator is sinusoidally modulated by a crystal, amplified, rectified, and used to control the G_m of the modulator tube as before. However, for this case a 7-Mc sine wave is the controlled output from the modulator tube which is derivatively coupled to a rectifier. The direct current output from the rectifier is added to the steady state reflector voltage thus closing the control loop as before.

It may be of interest to consider briefly the discriminator circuit. As previously indicated, this is composed of an

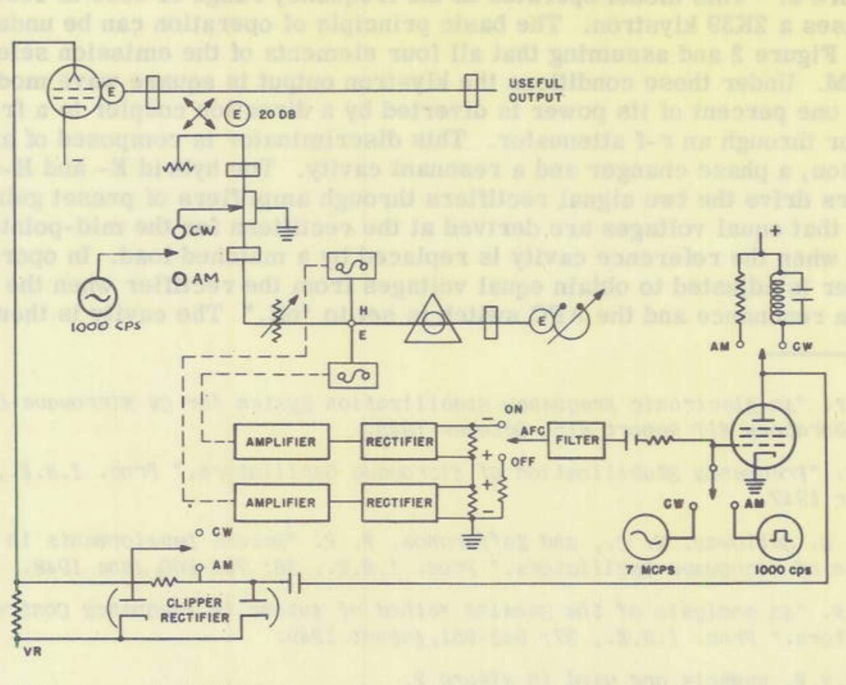

Fig. 2 - AFC-AM-CW-X-band generator, simplified block schematic

unmatched hybrid, phase changer and reference cavity and functions as follows. If in Figure 3 one supposes that the energy arriving at the hybrid from the generator is in phase with the energy arriving at the hybrid from the cavity then the energy in the E- or series arm will be a minimum and the energy in the H- or parallel arm will be a maximum. Further, if one supposes that the two incident energies are out of phase at the hybrid it is seen that the maximum-minimum roles of the E- and H-arms are interchanged. Thus the conditions for the extremes are established. All intermediate values result from the fact that the phase of the energy returned by the cavity will go from + 90 degrees to - 90 degrees around resonance thus resulting in an energy summation in the hybrid which may be used as a frequency discriminator. The discriminator slope will depend upon the Q of the reference cavity, particularly since no energy is returned at exact resonance, and upon the relative phase of the generator energy and reflected energy at the hybrid. The conditions for the extremes just mentioned are also the conditions for maximum slope for a cavity of given Q. This means that the vector sums and differences will be maximums and minimums, respectively, thus yielding the largest differences between the E- and H-arms for any given inputs. The phase changer is inserted in this circuit in order that a maximum reflection from the cavity may be adjusted to be in phase or out of phase with the generator energy at the hybrid. While it is true that the sense of the hybrid will depend on the choice of in-phase or out-of-phase operation in actual practice the discriminator sense may be made independent of this choice by a switch which interchanges the E- and H-arm detectors to the electrical sensing circuits.

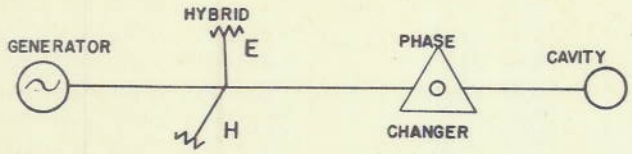

Fig. 3 - Discriminator circuit

Figure 4 is the complete schematic of the equipment. It is seen that the assembly is broken up into four separate decks and are numbered from bottom to top as they appear in the rack cabinet.

Deck 1 is a conventional, regulated power supply which provides a source of power for the klystron anode and reflector.

Deck 2 contains the channel amplifier operating from the two arms of the r-f discriminator and the square wave and sine wave modulators operating from a 1000-cycle, vacuum-tube fork, and associated power supply. The channel amplifiers are low-noise, tuned units which feed the power amplifiers through the previously mentioned phase selector switch. The 6L6 power amplifiers in turn feed a 6X5 discriminator diode which provides the control voltage for the 6SK7 modulation control tube in Deck 3. The square wave generator consists of several cascaded limiting triodes driven directly from the sine wave source of 1000 cycles.

Deck 3 contains the klystron, the 7-Mc modulator, the 6SK7 modulation control tube, the 6X5 reflector rectifier, the 6X4 reflector clamp and associated power supply. It also contains the r-f circuitry of the discriminator and output monitor and the emission selector switch.

Deck 4 contains the monitor scope and associated power supply and sweep systems. The reflector DC voltage control and the frequency deviation meter are also located on the front panel of this deck.

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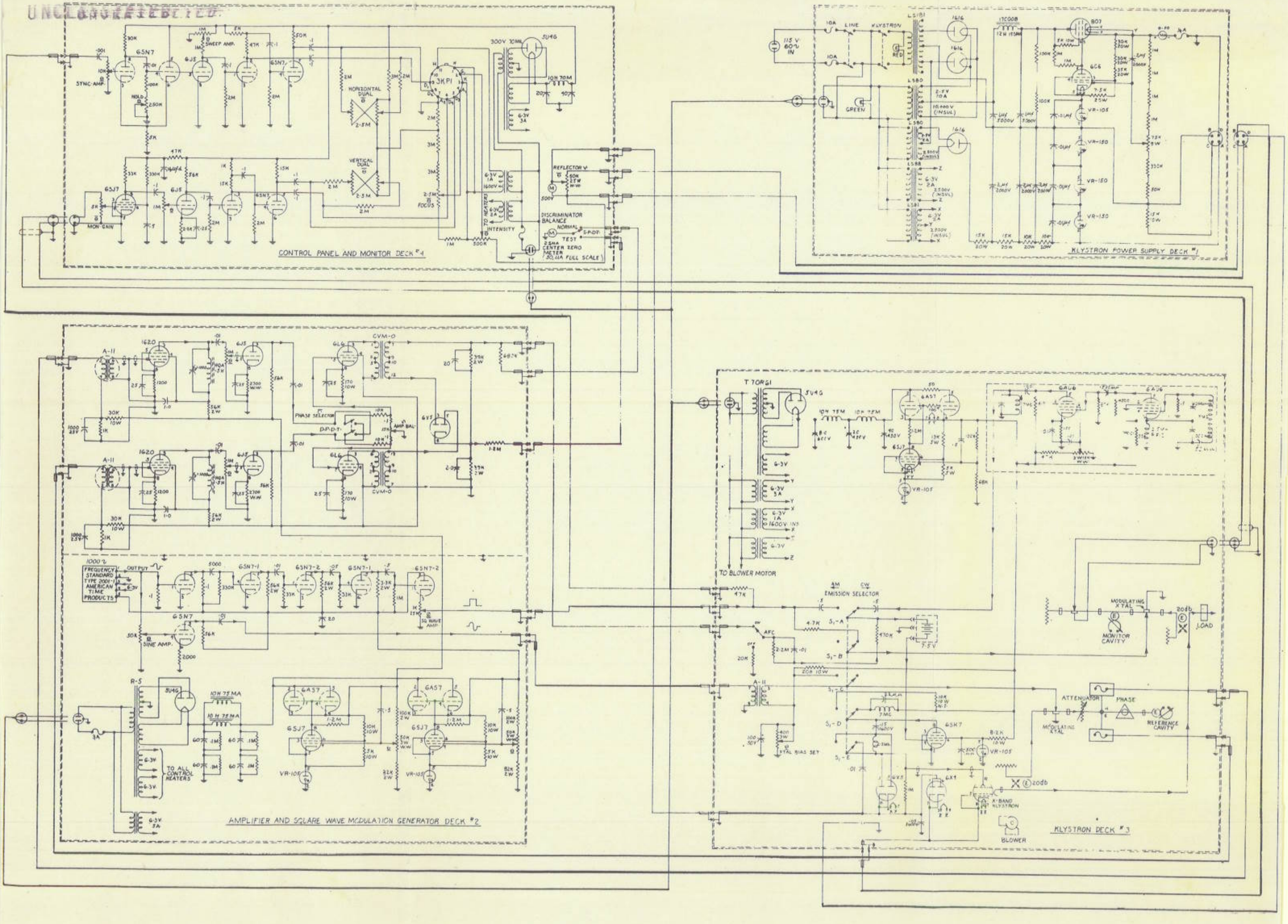
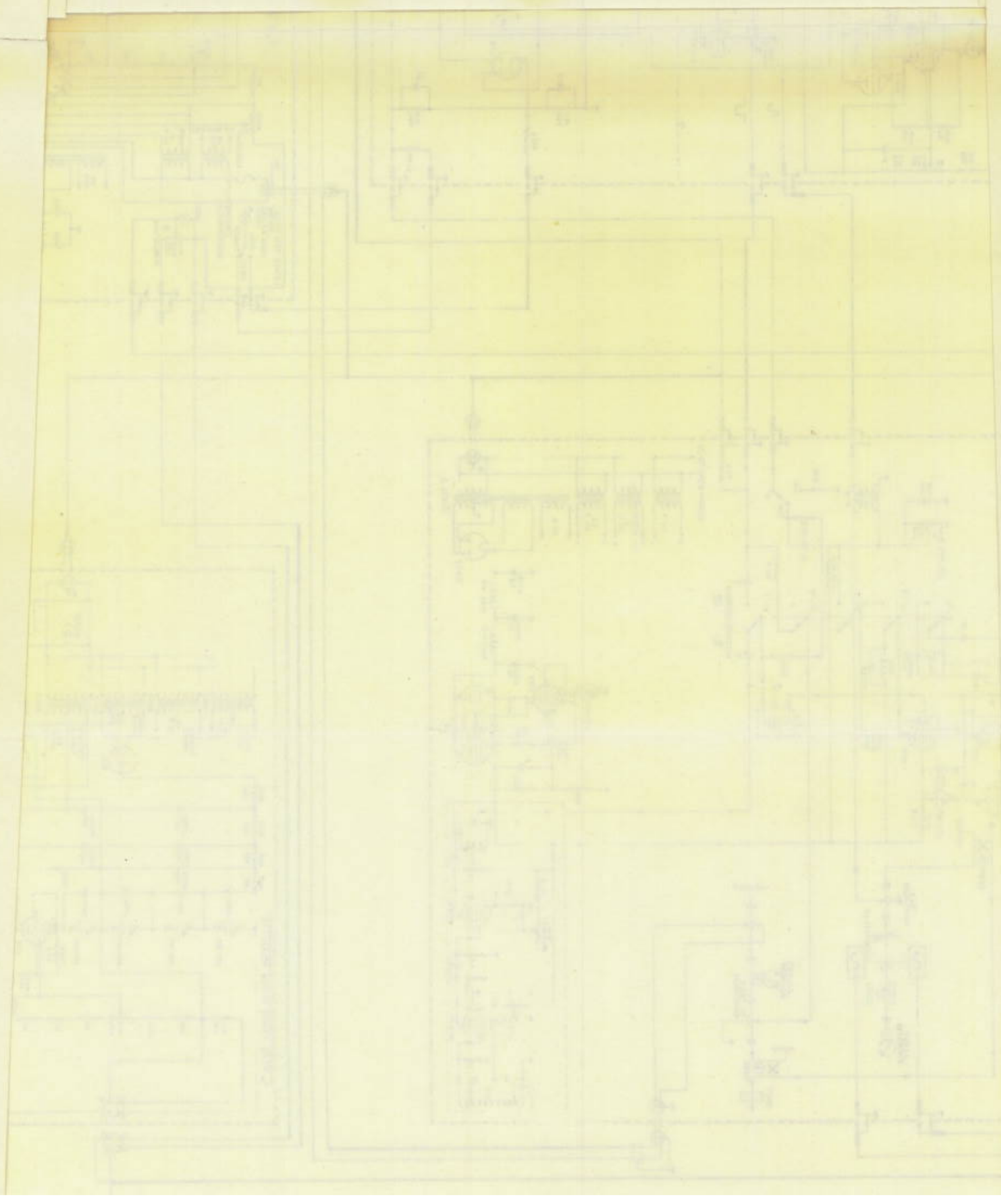


Fig. 4 - AFC-AM-CW-X-band generator, master schematic



PERFORMANCE

The performance of the stabilizer is somewhat better than was expected from preliminary calculations. This results from the fact that the control loop can be operated "tighter" than was expected without developing oscillations. It has been found that a 10,000 Mc carrier at CW or any one of the modulation spectral lines, when square wave modulated, will remain within ±5 kc of the center value about 90 percent of the time. The maximum momentary deviations observed are about ±20 kc. These momentary deviations account for the remaining 10 percent of the time and average about ±10-15 kc. Hence it would seem fair to rate the frequency stabilization value at 1 part in 10^6.

The amplitude stability of a klystron when operating frequency stabilized by the reflector is of course principally dependent upon the slope of the reflector mode at the point of operation and upon the inherent frequency stability of the tube. Thus, if the tube requires that large corrections in reflector voltage be made by the stabilizer in order to hold to frequency, relatively large variations in output amplitude will result. This can be seen by referring to Figure 5 which is a graph of a typical reflector mode.

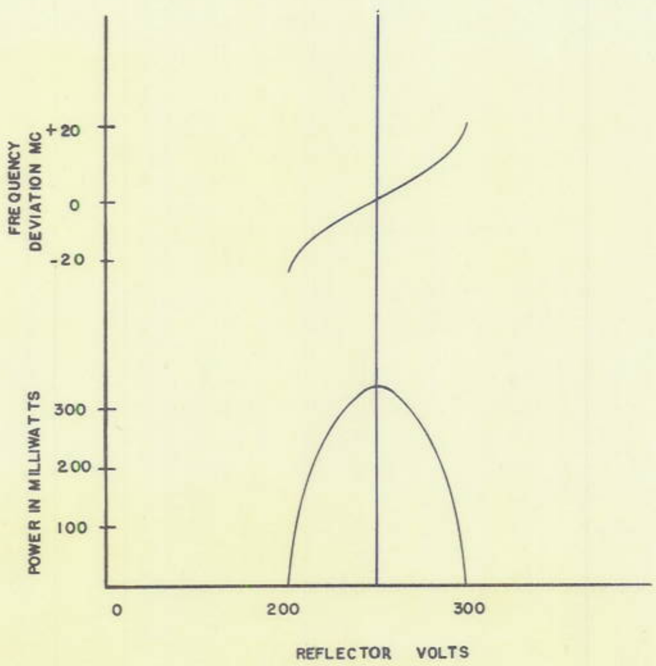


Fig. 5 - Graph of typical reflector mode

However, a normally functioning 2K39 which is supplied about 30 cubic feet per minute of fairly constant temperature cooling air will remain to within better than 1 percent of the nominal output power when frequency stabilized with the carrier adjusted to near the peak of the reflector mode. This adjustment is easily accomplished in practice and is indicated by the output monitor.

When the system is operating CW, the controlling energy supplied to the rectifier in the reflector circuit is at a frequency of 7 Mc. Hence the residual ripple from the rectifier will cause side bands to appear. However, since this control frequency is relatively high, an efficient, simple filter of very short time constant is realizable. Thus, the measured 7-Mc side bands are down more than 60 decibels from the carrier when the time constant of the filter is made consistent with the demands of the control loop.

CONCLUSIONS

Operation of this equipment both in controlled tests and in general laboratory service over a period of about six months indicates that the original objective has been achieved. There has evolved a system for frequency stabilization of a reflex klystron that is simple to operate and is capable of amplitude and frequency stabilities which are adequate for measurement needs for the majority of microwave networks. Further, this system is equally valid for either amplitude modulation or CW operation with the type of emission instantly selectable.

The principle of operation of the present X-band equipment should be equally valid at any frequency for which an electronically-tunable, reflex klystron is available and for which the r-f plumbing of the discriminator is realizable in practice.

ACKNOWLEDGMENT

Acknowledgment is made to Mr. F. W. Cleary for his able assistance in the working out of many of the details of the electronic and r-f circuitry.

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