NBS REPORT

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A PRECISION FREQUENCY STANDARD FOR X-BAND

by

M. C. Thompson, Jr., M. J. Vetter
and Donald M. Waters

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
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NATIONAL BUREAU OF STANDARDS REPORT

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ABSTRACT

A compact microwave generator (Fig. 1) is described in which an X-band reflex klystron is stabilized by a quartz-crystal secondary standard. Frequency stability of the order of several parts in 10^9 over periods of the order of a day has been obtained. A technique for obtaining continuous wide-range variation of output frequency with stability of the order of 1 part in 10^8 is described.

The generation of microwave signals of stable frequency has been accomplished during recent years by the stabilization of reflex klystrons with cavity resonators (such as the Pound oscillator) and by direct multiplication from lower frequency quartz oscillators. A third approach which appears to have numerous advantages over the two mentioned above uses a phase-locking technique (1) in which a small amount of microwave energy is used to establish the operating frequency of a relatively high-powered klystron. The general method of operation is shown in Fig. 2. A crystal oscillator at 10 Mc drives two vacuum tube multipliers to give about 1/2 watt output at 100 Mc. This is used to excite a silicon diode as a harmonic generator to produce small amounts of power at frequencies in the X-band, i.e., 9300, 9400, 9500 Mc etc. The power in these harmonics is mixed with a small amount of the output of the klystron. If the klystron is operating at its nominal frequency, for example, 9500.5 Mc, one of the beat frequencies present at the mixer will be 500 Kc. This signal is amplified and supplied to a phase discriminator where it is compared with a second 500 Kc signal from an auxiliary crystal oscillator. Any shift in phase of the klystron appears as a shift in phase of the 500 Kc beat and the discriminator responds with an error voltage to the klystron's repeller. Thus in normal operation, the klystron is held to an average output frequency determined completely by the 10 Mc and the 500 Kc crystals. Since the former is multiplied by about 1000, its stability practically determines the stability of the klystron. That is, a shift of 1 cps in the 10 Mc oscillator produces a shift of 950 cps in the klystron whereas a 1 cps shift in the 500 Kc oscillator will appear as a 1 cps shift in the klystron's frequency. The detail circuit used is given in Fig. 3. It consists of a conventional amplifier with AGC driving a discriminator. The reference oscillator is a Pierce circuit. In the various klystrons which have been tried to date (VA-203B, V-201, and V-58) the 60-cycle modulation, due presumably to AC heater operation, has been appreciable. To correct for this without going to a DC heater supply, a neutralizing signal is obtained from one of the heater transformers. The time constant of the error-signal circuit is adjustable. For most klystrons used, there is a definite, optimum setting for this time constant. A reset circuit is provided so that in the event of momentary interruption of operations which might cause the discriminator to lose control, the klystron is automatically swept slowly through the vicinity of the operating frequency until the discriminator regains control.

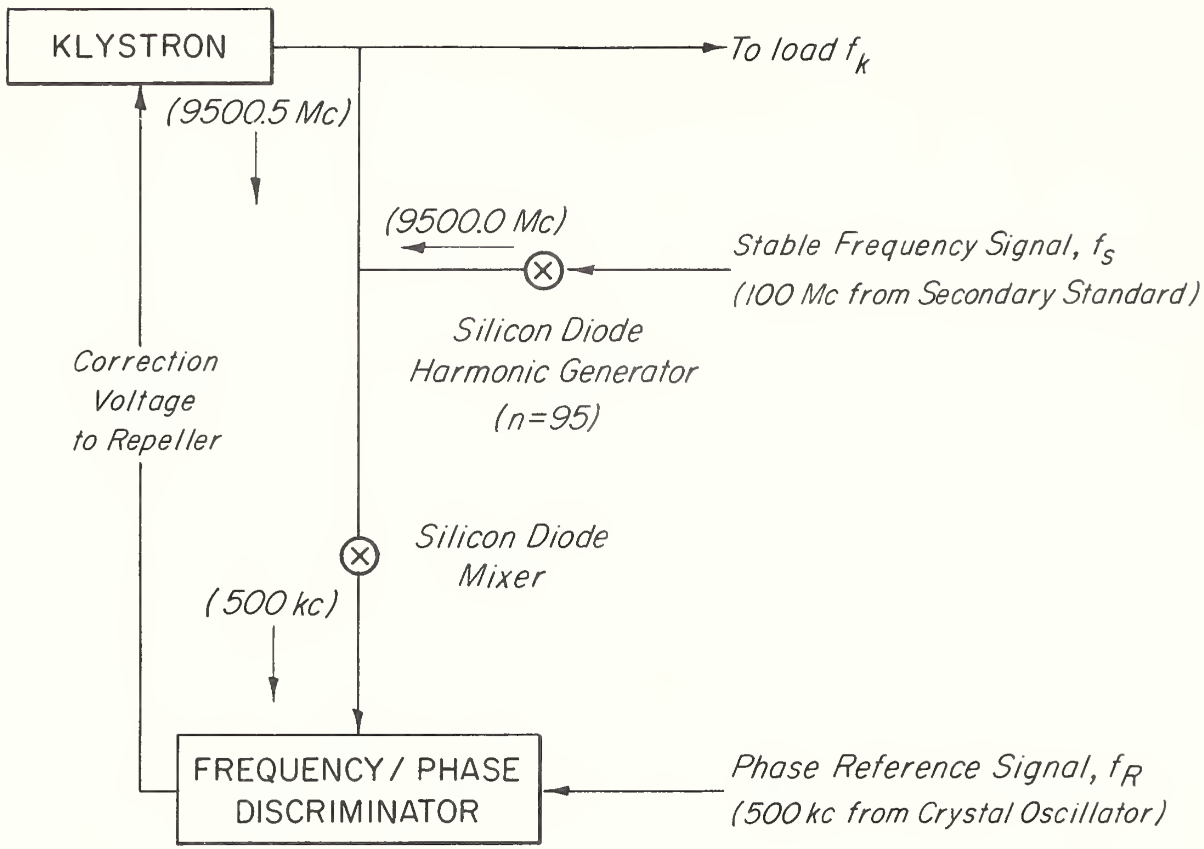
In normal operation, a 2" CRT is used for observing the Lissajou's figure formed between the reference oscillator and the 500 Kc IF frequency. The appearance of this figure is used as the criterion for adjustment of error-signal time constant, hum neutralization and general adjustment of repeller bias. The normal appearance is a rather clean ellipse or circle. Maladjustment of any of the above-mentioned controls is easily detected as a broadening of the pattern into a rectangle.

The two power supplies are sealed units using semiconductor rectifiers. One is rated at 350 volts at 20 ma (with built-in cold-cathode voltage regulation) for the repeller bias and the other, 350 volts at 100 ma supplies the klystron anode and all control circuits.

The klystron and its associated plumbing are shown in Figs. 4 and 5. About 1/2 watt of 100 Mc signal is used to drive a 1N23B silicon diode, mounted in a conventional waveguide holder, as a harmonic generator. A second 1N23 acts as a mixer to form the beat between the harmonic energy and the klystron. A double waveguide "T" is used for this purpose. The side arms of the "T" are about two wave lengths apart with a small screw halfway between. The location of the screw is such that essentially all of the power from the klystron passes out to the load. Adjusting the screw penetration provides control over the excitation of the mixer diode. A ferrite isolator follows the mixing system to reduce the effects of

FIG. I STABILIZED X-BAND OSCILLATOR WITH
10 Mc QUARTZ CRYSTAL SECONDARY STANDARD

MICROWAVE FREQUENCY STABILIZATION SYSTEM



$$f_K = n(f_S \pm \delta_S) \pm (f_R \pm \delta_R) = 9500.5 \pm 95\,\delta_S \pm \delta_R \text{ in Mc}$$

FIG. 2

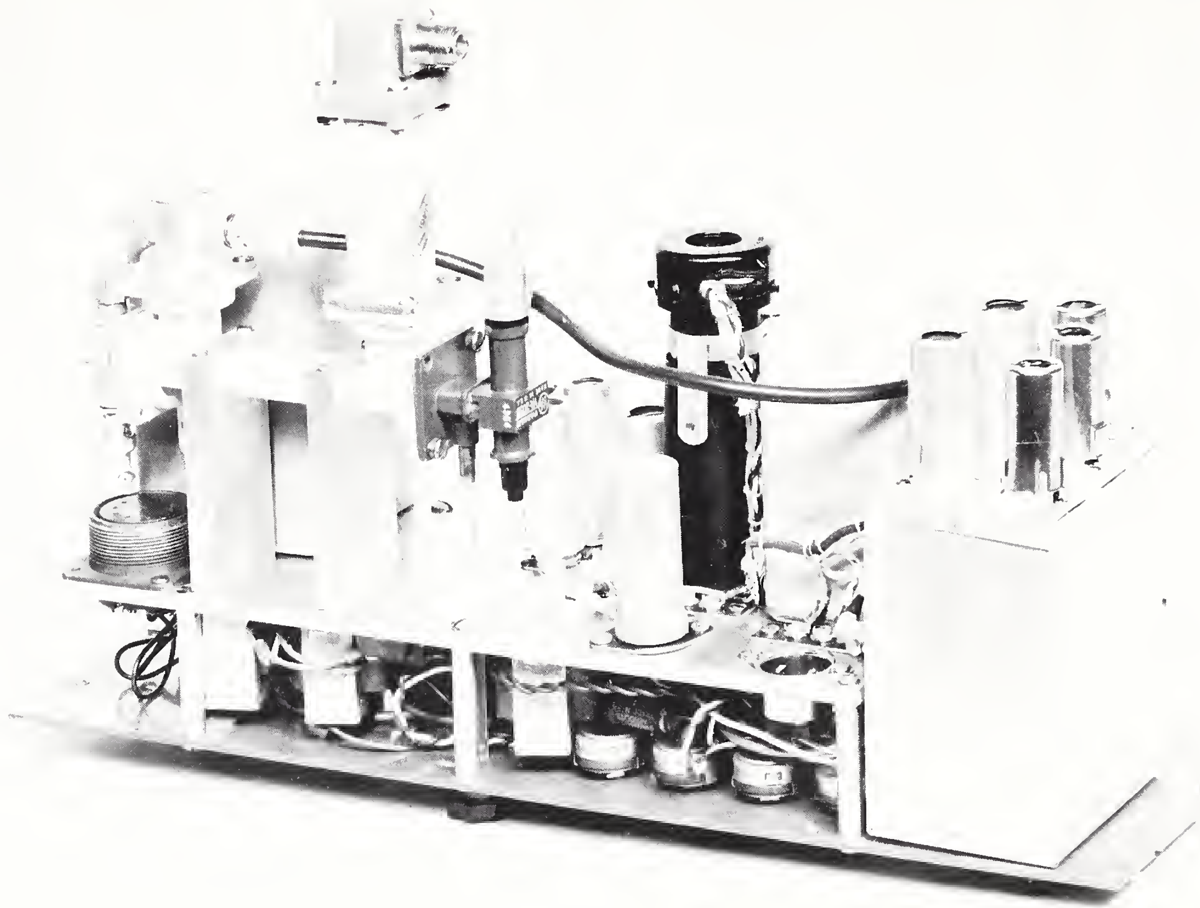


FIG. 4 SIDE VIEW, X-BAND OSCILLATOR

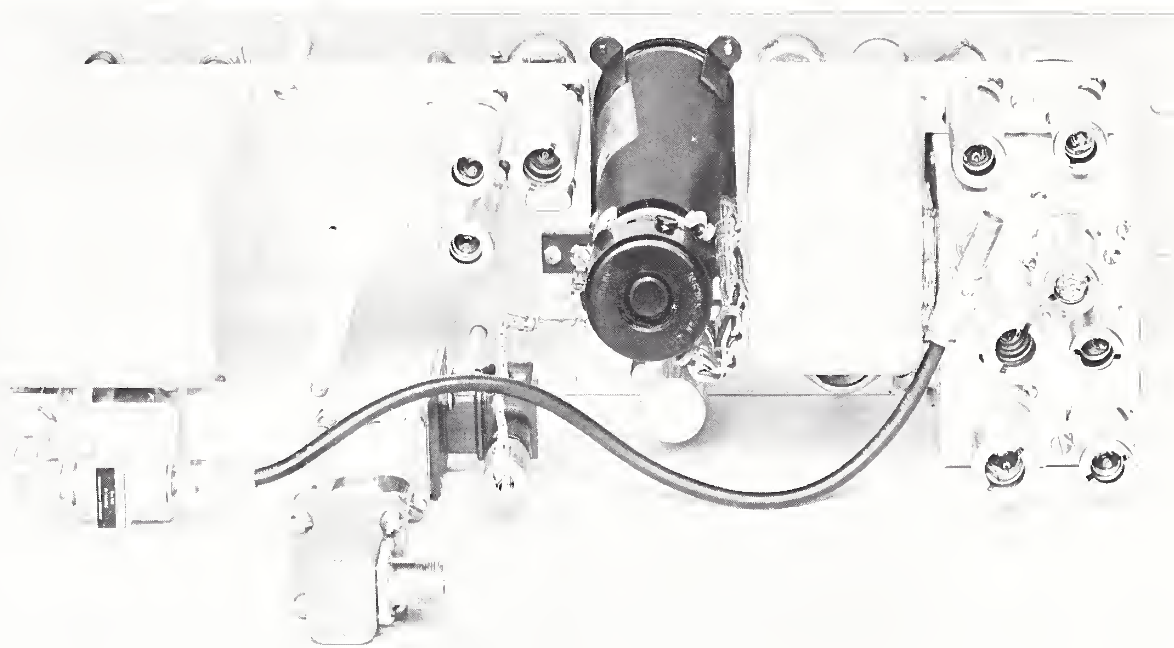


FIG. 5 REAR VIEW, X-BAND OSCILLATOR

load changes on the mixing levels. Output may be obtained by waveguide plumbing or a waveguide-to-coax adapter and cable may be used.

The entire plumbing assembly may be readily removed from its support brackets in cases where the unit is used to drive an antenna as a transmitter. Provision is made for a suitable power cable to plug into the rear of the chassis in such cases.

The operation as described above is limited to several discrete frequencies. In the detail description, an operating frequency of 9500.5 Mc was assumed, using the 95th harmonic of the 100 Mc signal and having the discriminator phased to operate the klystron above the incoming harmonic. By simply reversing the phase of the discriminator the stable operating point for the klystron becomes 9499.5 Mc, thus giving a shift of 1 Mc in the frequency of the klystron. A shift to a different harmonic, say the 93rd or 94th, is also relatively straightforward. If the klystron is simply retuned until its output is in the vicinity of 9600.5 Mc, the system will stabilize to this frequency. In fact, the limit is essentially the range of operation of the klystron since all harmonics from 85th to 96th are approximately the same amplitude.

In addition to frequency shifts of 1 Mc and 100 Mc as just discussed, it is also practical in this system to shift 10 Mc. This is the result of modulation which comes through the vacuum-tube multipliers from the 10 Mc oscillator to 100 Mc. By simply retuning the klystron by means of the repeller bias it is practical to lock the klystron to a frequency either 10 Mc below or 10 Mc above any of the above mentioned 100 Mc harmonics. In order to utilize this feature, an ordinary commercial wavemeter is added to the plumbing to permit easy identification of the harmonic or sideband which is controlling.

A further modification permitting continuous frequency variation is shown in Fig. 6. The beat frequency signal obtained from the mixer diode is fed into a conventional superheterodyne receiver and the phase-lock discriminator is designed to operate at the IF of the receiver. The control loop now requires that the klystron operate at such a frequency that, when its output is mixed with the harmonic of the secondary standard, the resulting beat equals the frequency to which the receiver is tuned. Thus, using the figures given above, if the receiver were tuned to 2.310 Mc, the klystron would be stabilized at a frequency either higher or lower than 9500 by

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