THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 53, No. 10, December 1974
Printed in U.S.A.

L5 SYSTEM:

39A Precision Oscillator

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(Manuscript received May 2, 1974)

The 39A precision oscillator is designed to operate at 40 watts from a 24-V ±10-percent power source. The reference frequency can be set digitally to 5.12 MHz $\pm 5 \times 10^{-11}$ *over a tuning range of* $\pm 4 \times 10^{-7}$*. The output signal is a 1-mW sinewave into a 100-ohm load. This performance is assured over a temperature range of 0 to 60 degrees Celsius. Oscillator outline dimensions for length, width, and height are 35.3, 22.1, and 21.8 cm respectively.*

I. INTRODUCTION

The 39A oscillator was developed to meet the precise frequency-control requirements of the L5 jumbogroup frequency supply. The need for frequency control as exemplified by the 39A oscillator is explained in the paper on the jumbogroup frequency supply in this issue. This 5.12-MHz precision oscillator is characterized by long-term stability of $<1 \times 10^{-10}$ per day, and by short-term stability of $<1 \times 10^{-8}$ for a 1-millisecond sampling time or $<2 \times 10^{-11}$ for a 10-second sampling time. External frequency control is accomplished utilizing a compatible digital word applied to the oscillator's 14-bit, TTL, precision, digital-to-analog converter. Setting range of the converter is $> \pm 4 \times 10^{-7}$, which gives a least-significant-bit resolution of $\approx 5 \times 10^{-11}$; the converter section incorporates a linearizing network to reduce the frequency-set deviation from a straight-line function to $< \pm 5 \times 10^{-11}$ over a $\pm 4 \times 10^{-8}$ tuning range, and to a maximum variation of tuning sensitivity of ±30 percent over the entire range of $\pm 4 \times 10^{-7}$, with less than $\pm 1 \times 10^{-10}$ departure from a smooth curve.

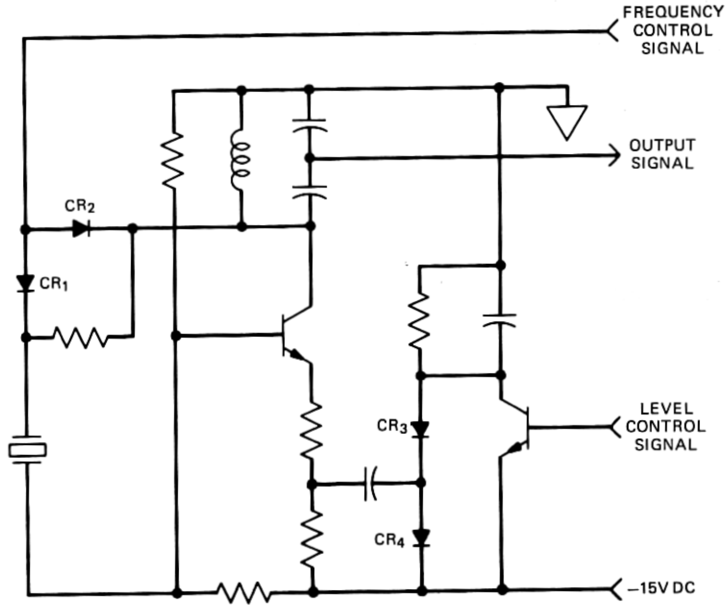

Fig. 1—Oscillator schematic.

II. GENERAL DESCRIPTION

The 39A oscillator can be separated into three major subassemblies:

(*i*) An oscillator RF subassembly consisting of a crystal oscillator circuit, a tuned feedback amplifier detector circuit (AGC) functioning to provide constant low-level crystal-current drive, and an output amplifier instituting sufficient load isolation for the output signal.

(*ii*) A thermal and electrical noise-isolation subassembly which is composed of temperature-control circuits, power-supply regulators, and redundant electrostatic shielding amply protecting all major circuitry.

(*iii*) The digital frequency-control subassembly with a precision digital-to-analog converter and a frequency-linearizing network for remote steering of output frequency.

III. OSCILLATOR SUBASSEMBLY

The crystal-oscillator circuit in the 39A oscillator is the modified Pierce commonly used in precision oscillators for many years.[1,2] Figure 1 is a functional schematic of the oscillator-circuit board. A varactor diode in the crystal network is used to control the operating frequency of the network. Earlier circuit designs have varied the oscillator-transistor dc operating point to control the loop gain, but here low-noise performance is achieved by fixing the dc operating point of the oscillator transistor and adjusting its positive loop gain. Oscillator loop gain is controlled by varying the forward bias of variolossers CR_3 and CR_4, which controls the degeneration of this transistor stage.

The AGC amplifier circuit is shown in Fig. 2. This is a three-stage direct-coupled feedback amplifier selected for low noise, simplified tuning, and having a minimum number of components. Passband tuning is accomplished by an LC network in the feedback path. This amplifier operates with 38-dB in-band gain and has a 3-dB bandwidth of about 200 kHz. The rectified output from diodes CR_1 and CR_2 is used to control the oscillator gain for a crystal-operating current of 100 to 200 μA.

The output signal of the AGC amplifier is coupled to the final amplifier circuit by a variable attenuator which is used to adjust the oscillator output level to 1 mW into a 100-ohm load. The design of the output amplifier is essentially the same as the AGC amplifier.

The crystal oscillator, AGC amplifier, and output amplifier combine to make up the oscillator subassembly shown in Fig. 3. The unit at

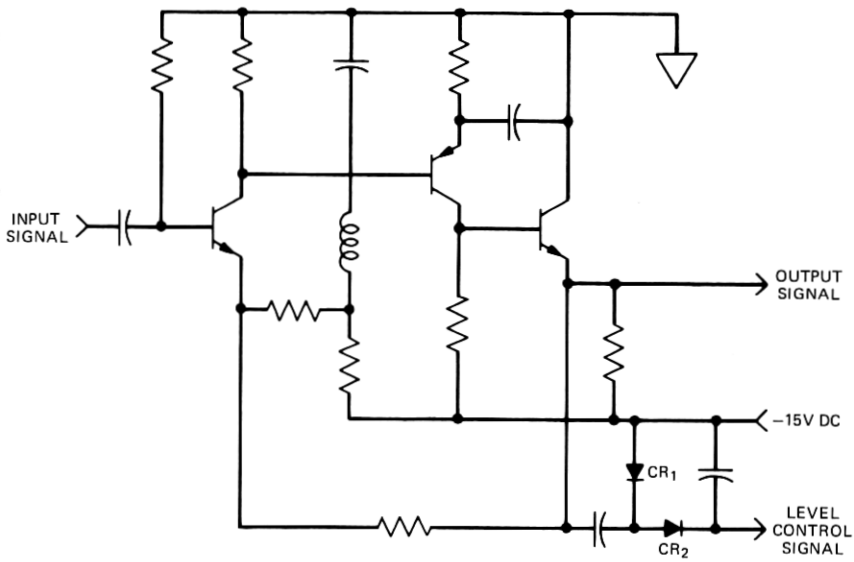

Fig. 2—AGC amplifier circuit.

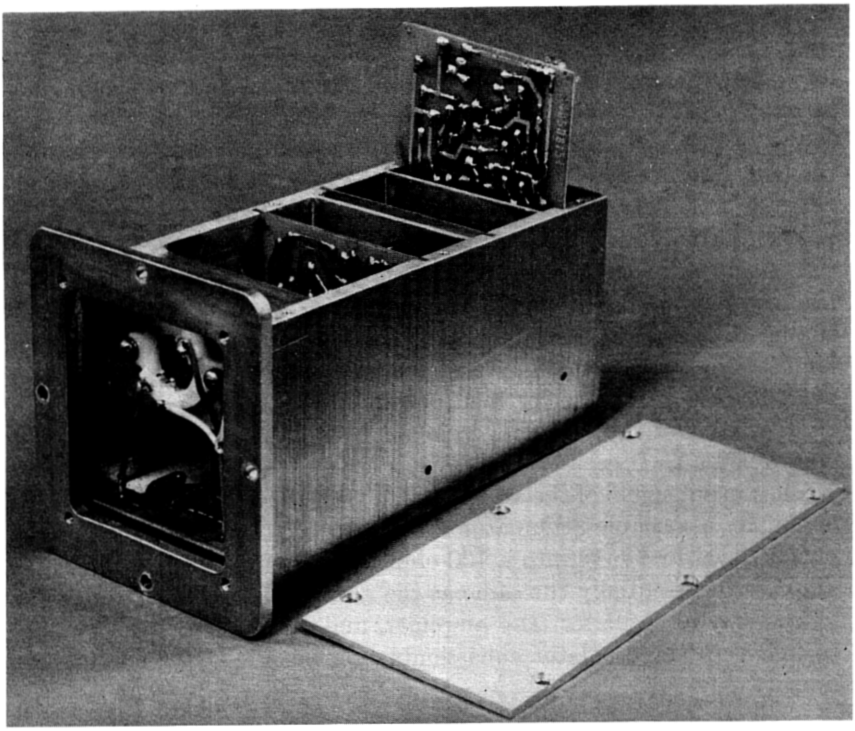

Fig. 3—Oscillator RF subassembly.

this stage in fabrication can be production tested as a functional subassembly. These tests include a thorough mechanical inspection, a test of AGC and output-level, and a check on harmonic distortion.

The long-term frequency of this precision oscillator is determined primarily by changes of the crystal unit and directly associated LC components. In this respect, these components have been selected for minimum long-term drift. Short-term frequency variations (times of less than 0.1 second) can be attributed to transistor noise and small fluctuations in crystal current. The effects of crystal-current variations have been reported[3] and are typically 1×10^{-11} per 0.02 dB for current levels in the range of 100 to 200 μA at a frequency of 5.12 MHz.

IV. THERMAL AND ELECTRICAL NOISE-ISOLATION SUBASSEMBLY

The 5.12-MHz crystal units[4,5] used in the 39A oscillator operate at 76°C minimum to 81°C. At this operating temperature, the frequency dependence on temperature is approximately $7 \times 10^{-9}/°C$ if the operating temperature of the crystal is $< \pm 0.25°C$ from the frequency turning point. In addition to the effects of long-term temperature variations, short-term changes in temperature cause perturbations in frequency due to thermal gradients within the crystal. A 1×10^{-11} frequency change results from a 4×10^{-3}°C/hour rate of change in crystal temperature.

To reduce frequency variation effects due to ambient temperature changes, the oscillator subassembly is housed in a two-stage temperature-stabilized oven. This two-stage oven has an ambient ratio of $>10^5:1$ resulting in short-term temperature variations being measured as $<1 \times 10^{-4}$°C per hour. The outer oven reduces ambient effects on the temperature-control and voltage-regulator circuits to $<5 \times 10^{-2}$°C. Two identical voltage regulators are used in the oscillator to reduce

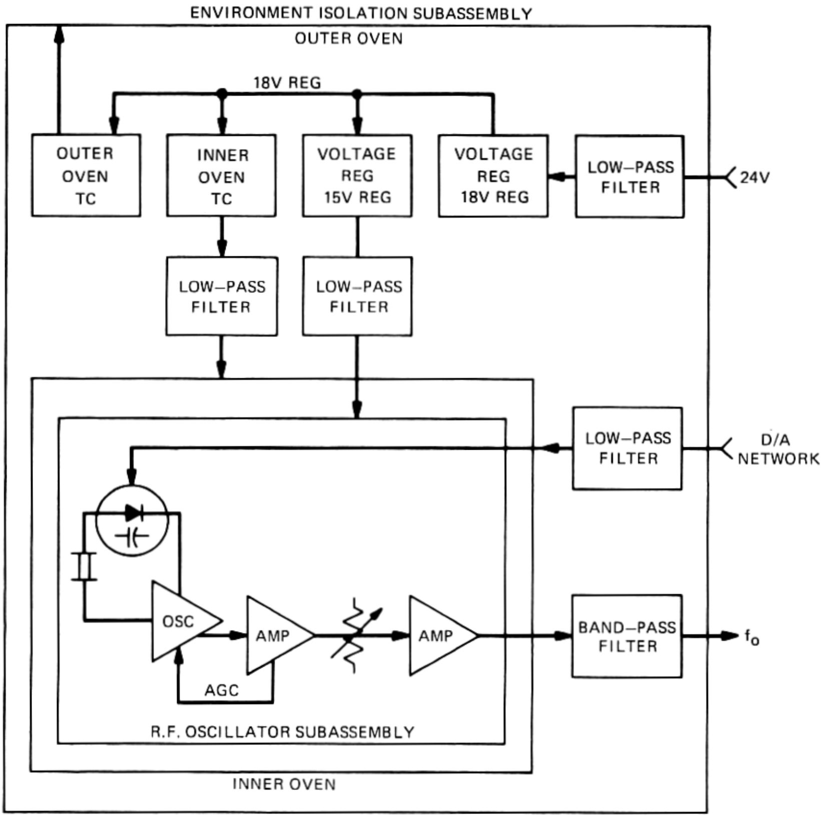

Fig. 4—Precision oscillator functional components.

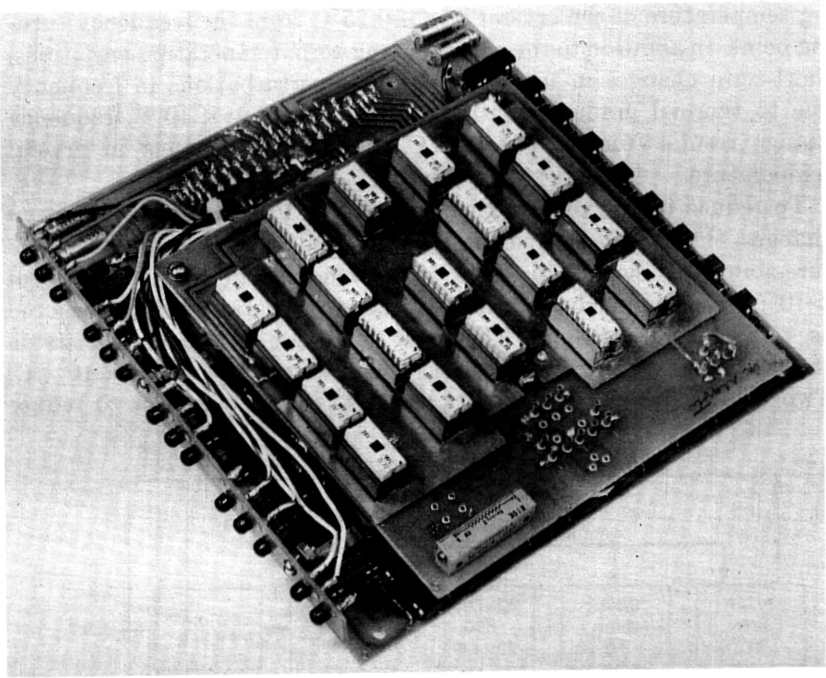

Fig. 5—Digital frequency-control subassembly.

the effects of power-supply variation on reference voltages, RF circuits, and control circuits. Figure 4 shows the environmental isolation subassembly.

V. DIGITAL FREQUENCY-CONTROL SUBASSEMBLY

Frequency control is accomplished by a varactor diode in the crystal circuit. The precision voltage supplying this diode is derived from the precision digital frequency-control subassembly shown in Fig. 5. This subassembly consists of a 14-bit digital gate network, with strobing option, fabricated from standard TTL logic. The network contains latching circuits, relay drivers, and relays (5 V dc) controlling a constant-impedance voltage divider. Figure 6 gives the basic circuit diagram for this digital-to-analog converter.

Figure 7 is a simplified schematic of the divider excluding the control logic. Resistors R_{V1}, R_{V2}, and R_{M1} (or R_{M2} if required) are selected by computer program at time of manufacture to precisely give the required nonlinear binary-voltage allowing a linear binary-frequency function of oscillator output. The loading resistor, R_{M1} or R_{M2}, de-

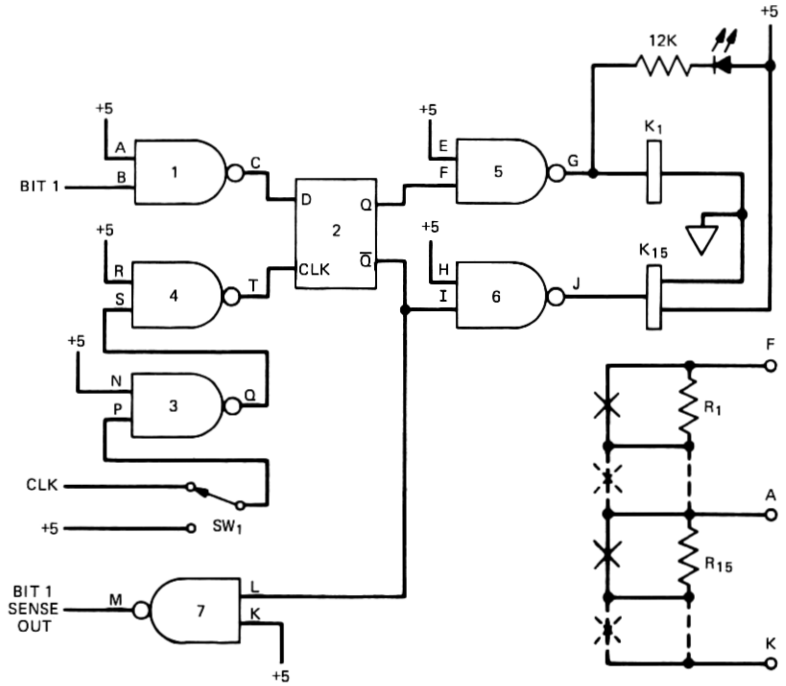

Fig. 6—39A oscillator simplified circuit.

termines the network output voltage function and is selected for each oscillator. A typical set of output-voltage characteristics for this network are shown in Fig. 8 for values of R_{M1} or R_{M2} from 20,000 ohms to ∞ plotted as output voltage versus ratio of the programmed binary divider.

Figure 9 shows the tuning characteristics of a typical 39A oscillator over the frequency range from $F_o\ (1 - 4 \times 10^{-8})$ to $F_o\ (1 + 4 \times 10^{-8})$ and plotted relative to the frequency setting. The mean slope achieved over this range is within a few percent of the objective, with slope uniformity within about ±10 percent over the range. Over the entire

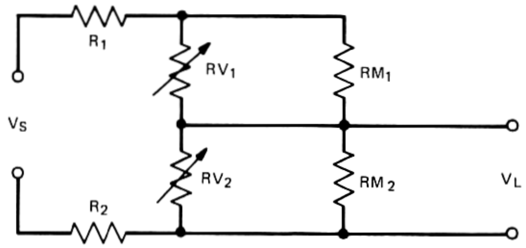

Fig. 7—Simplified divider schematic.

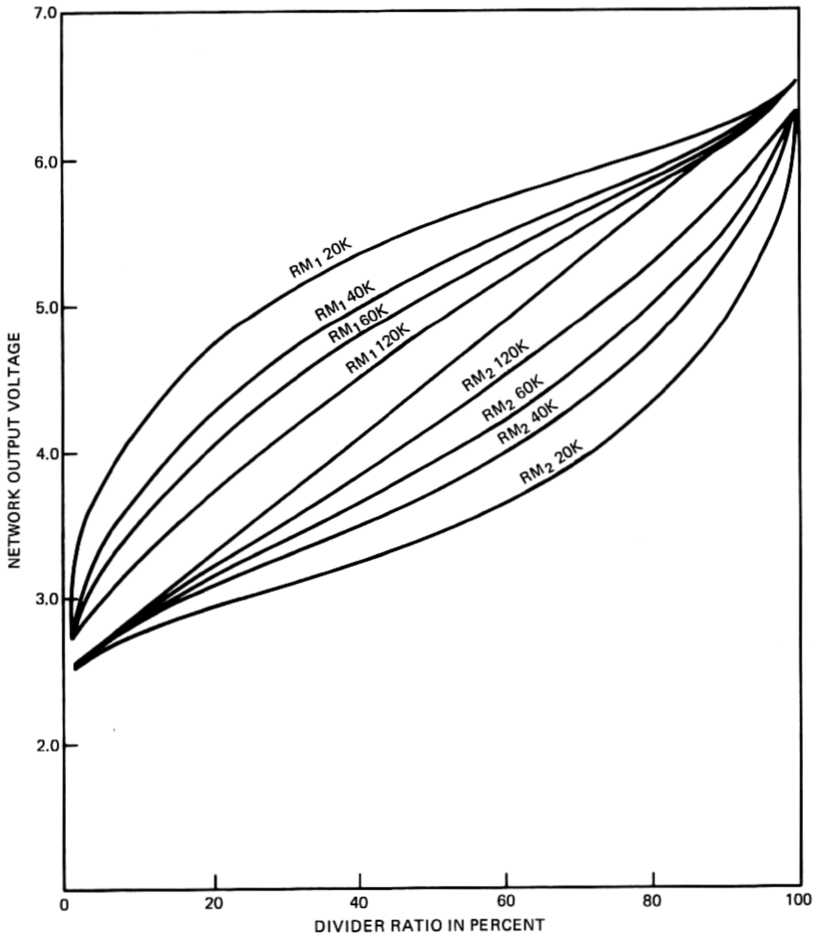

Fig. 8—Typical digital-to-analog converter output-voltage characteristic.

tuning range of $\pm 4 \times 10^{-7}$, slope variations are no more than ± 30 percent, and deviation from a smooth curve is no greater than $\pm 1 \times 10^{-10}$.

The circuit also provides an LED indicator for each input bit, which allows a visual check of the frequency-setting word. This, in addition to an electrical output provision for automatically sensing the tuning status, gives a convenient check on the complete functioning of the digital-to-analog converter.

VI. ELECTROMECHANICAL DESIGN

The overall electromechanical design makes maximum use of current instrument-fabrication methods. All printed-circuit boards are of a plug-in configuration simplifying assembly and testing by a large factor. Hand wiring has been held to a minimum throughout the entire assembly. Polyurethane foam both isolates and supports the inner and outer oven assemblies. RFI or constant K bandpass filtering has been incorporated between major subassemblies where deemed necessary.

Figure 10 illustrates the entire oscillator disassembled to show inner and outer ovens plus the inner and outer card frames. The front cover is mechanically attached to the digital-to-analog converter. The two connectors seen on the precision digital-to-analog converter circuit-board serve to provide a major part of the wiring interconnecting the rear input panel and the oscillator circuitry. The right front vertical edge of the external housing is designed to allow viewing of the LED

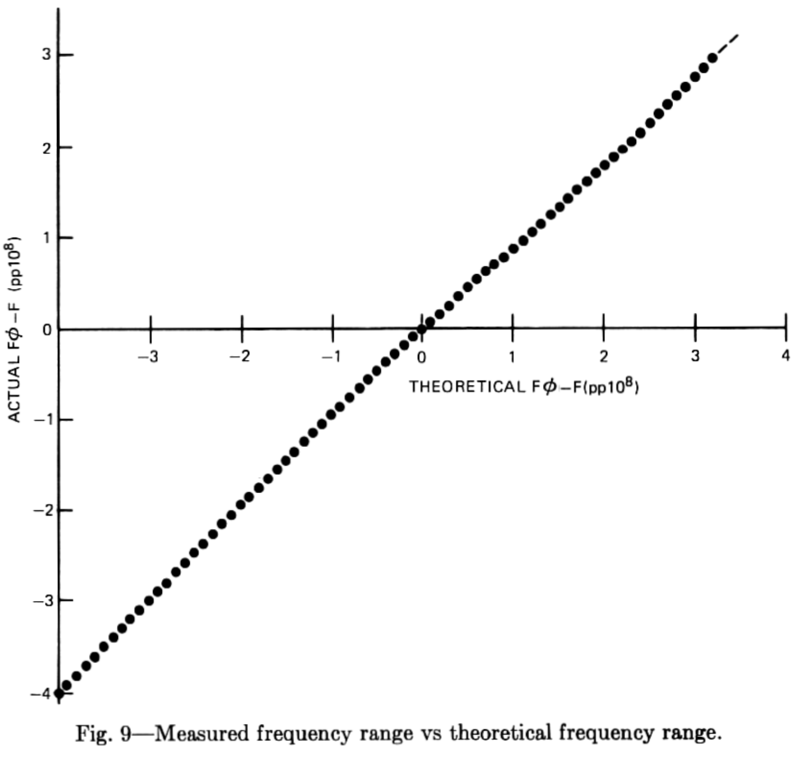

Fig. 9—Measured frequency range vs theoretical frequency range.

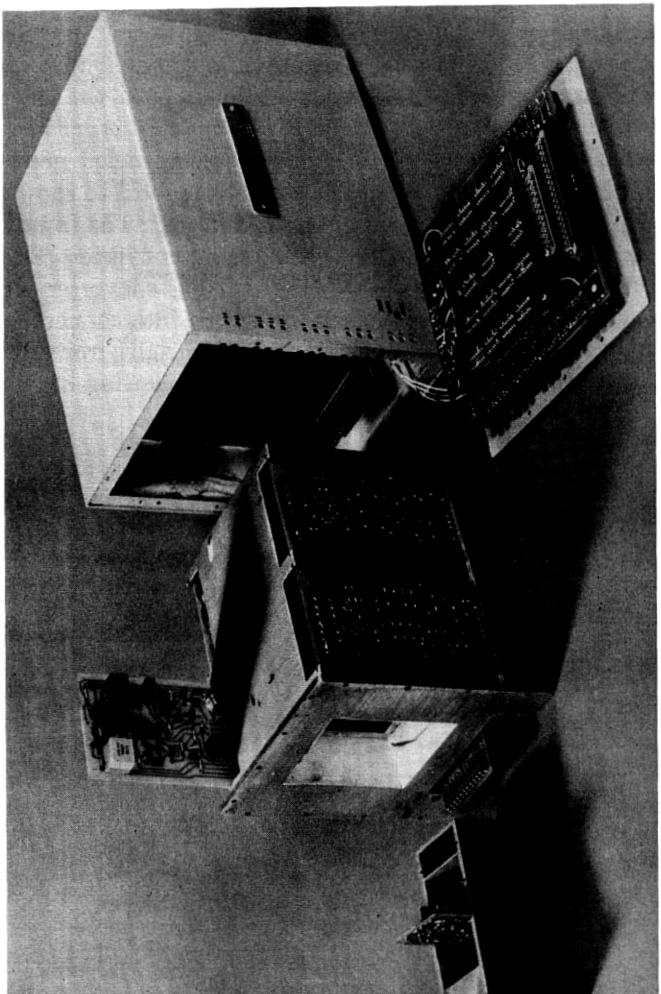

Fig. 10—Disassembled 39A oscillator.

indicator. All connections are made through the rear oscillator panel to the digital-word inputs, strobe pulses, 5- and 24-V dc power inputs and to the sense and RF outputs.

VII. SUMMARY

The 39A oscillator has been developed as a secondary frequency standard and is characterized by long-term stability of better than 1×10^{-10}/day, and short-term stability of better than 1×10^{-8} for a 1-millisecond sampling time and 2×10^{-11} for a 10-second sampling time. The total range of digital-to-analog frequency control is $\pm 4 \times 10^{-7}$ from a nominal 5.12 MHz having slope variations $< \pm 30$ percent with a maximum deviation of any point from a smooth curve of less than 1×10^{-10}. Midrange frequency control has a nominal straight-line tuning characteristic of 5×10^{-11}/bit, with an average slope tolerance of ± 10 percent and maximum deviation for a smooth curve of less than $\pm 5 \times 10^{-11}$. This oscillator has been designed to minimize the effects of thermal, mechanical, and electrical noise to a high degree and is fabricated using quality hardware and reliable components.

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