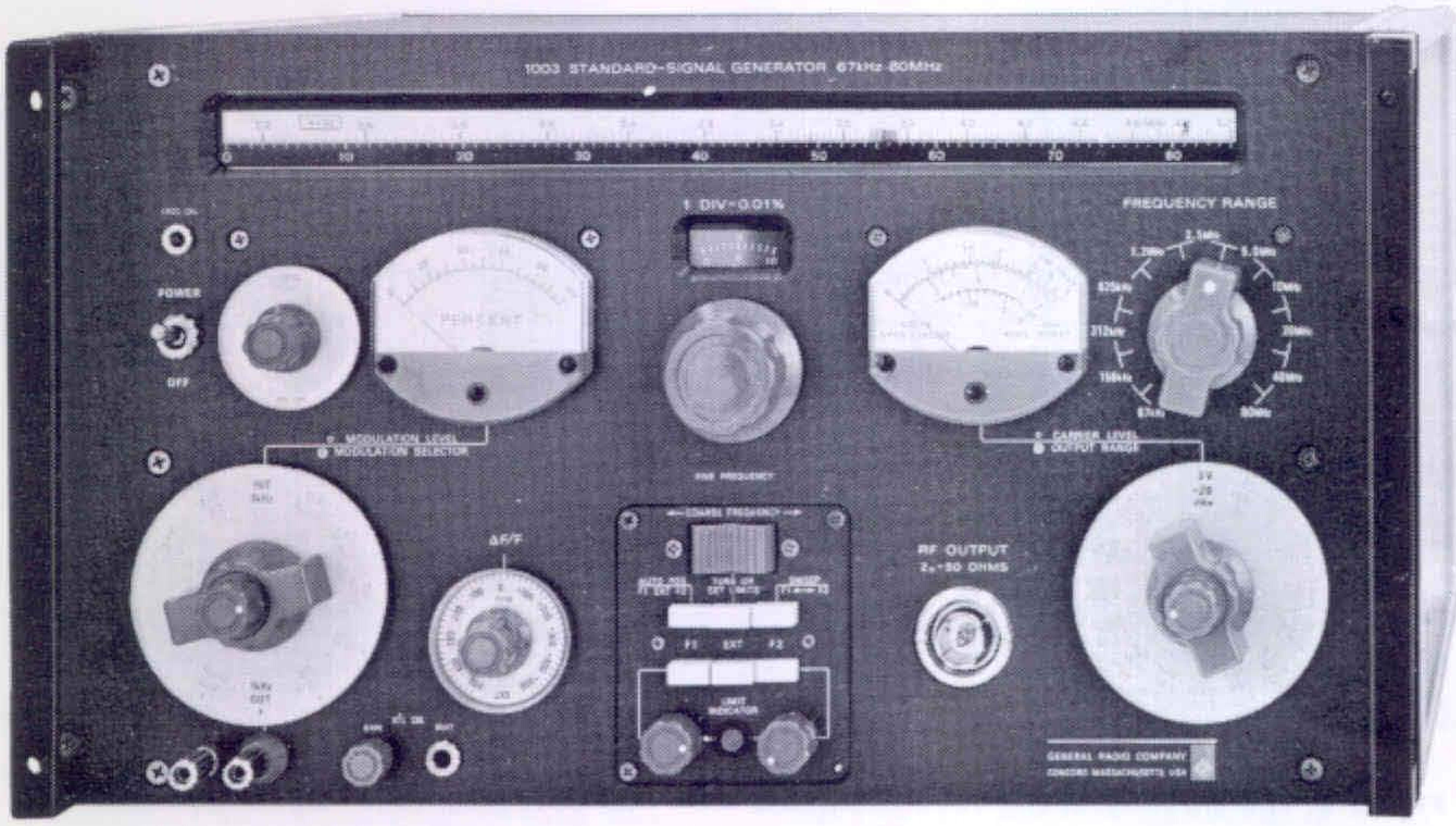

Figure 1. Type 1003 Standard-Signal Generator.

THE 1003 STANDARD-SIGNAL GENERATOR

It is infrequent that one sees major innovation in an art as mature as signal-generator design. Thus the subject of this month's feature is particularly noteworthy, for the 1003 is based on a truly innovative idea for achieving dramatic improvements in frequency stability, resolution, and accuracy. Freshness of approach marked the entire development, and the result is an interesting new chapter in the history of one of the most important of all electronic instruments.

A new generation of GR standard-signal generators began with the introduction, last March, of the 1026,[1] which upgraded many performance characteristics by an order of magnitude or more. Now the 1026 is joined by the lower-frequency (67 kHz–80 MHz) 1003, an all-solid-state signal generator that will probably be the ultimate in this class of instrument for some time to come.

The 1003 is distinctly different from the conventional signal generator. It is different in the way it generates frequencies (by a single-range oscillator, with dividers to produce the lower frequencies) and in the degree to which it maintains frequency, typically within a part per million per 10 minutes. Like the 1026, the 1003 was designed to be the highest-performance signal generator available in its frequency range, and test results indicate that it does in fact enjoy a wide margin over other signal generators now on the market.

[1] G. P. McCouch, "A New 500-MHz Standard-Signal Generator," *General Radio Experimenter*, March 1967.

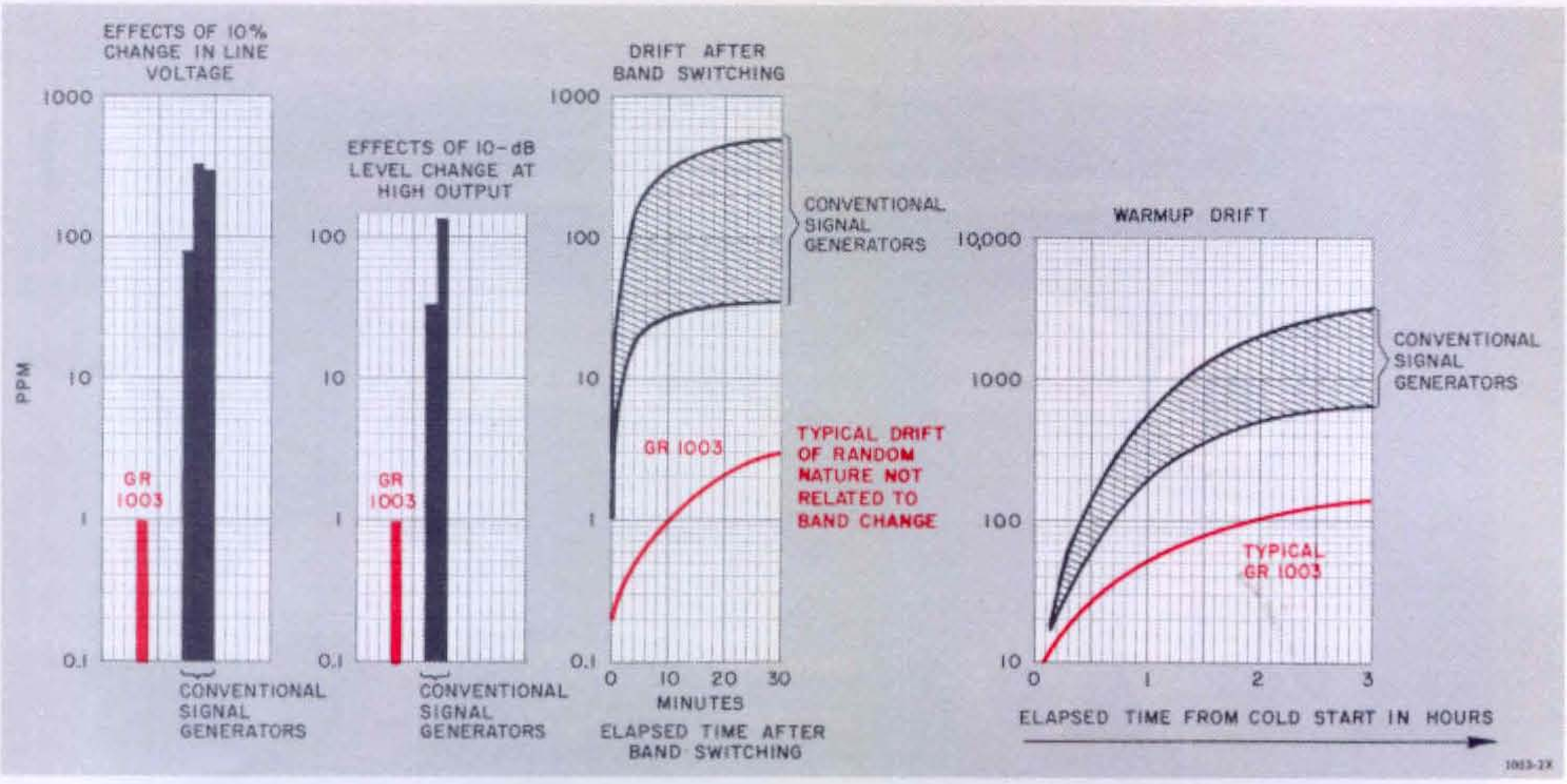

Figure 2. The stability of the 1003 compared with that of typical other signal generators.

For example, Figure 2 illustrates the stability of the 1003 compared with that of typical signal generators of conventional design. One of the chief reasons for the 1003's great advantage in stability is its new approach to frequency generation: Its oscillator is optimally designed for the highest range, and frequency dividers are switched in to produce the lower ranges, imparting the stability of the top range to all other ranges without deterioration. Another result of this approach is a calibration accuracy of ¼%, which is well beyond the reach of other signal generators.

The 1003 uses a motorized dial drive for tuning, sweeping, and programming. For fast, coarse tuning, pushing a rocker switch in the center of the front panel sends the indicator gliding along the slide-rule main frequency dial at about 7% frequency change per second. After using this motor drive to reach the right neighborhood, the user fine-tunes by means of a large rotary control, with each dial division corresponding to 0.01% of the main-dial setting. If this isn't precise enough, the $\Delta F/F$ front-panel control provides electronic, backlash-free settability to a few parts per million over a 1000-ppm range.

Both of the fine-tuning controls are fully calibrated in relative terms, so that the user can detune from a given point by a precisely known amount anywhere on the dial.

It is evident from the foregoing that the frequency stability, calibration accuracy, and resolution of the 1003 permit many more meaningful measurements in very narrow-band systems and devices (e.g., ssb receivers, crystal filters), where older signal generators are either marginal or useless because of resolution and drift problems. In such instances the user has had to use synchronizing schemes or synthesizers to provide a stable enough signal, and in the process he has encountered new problems, such as spurious signals, reduction in shielding efficiency, loss of calibration accuracy, to say nothing of the added tuning inconvenience.

The availability of a motor-driven frequency control presents obvious opportunities for both local and remote automatic tuning, and these are exploited by a programmable automatic-frequency-control device. With this unit, one can sweep between adjustable frequency limits and can automatically tune to preset frequencies. The 1003 can be purchased with or without the auto-control unit installed.

The 1003 has a full complement of auxiliary outputs, including a unique F/N monitor that is a byproduct of the frequency-divider method of rf generation. The F/N output frequency is an exact integral fraction 1/N of the actual output, always falling between 67 and 156 kHz. The value of N appears on the dial of the selected frequency range. The constant-level, unmodulated F/N output can be used in many ways, one of which almost suggests itself: measuring or monitoring output frequency indirectly by means of an inexpensive low-frequency counter, even with full modulation.

The main rf output frequency is available at the rear-panel F-monitor connector, which is fully isolated when not in use.

OPERATING CHARACTERISTICS

The 1003 covers its 67 kHz-to-80 MHz range in 10 bands, each somewhat over an octave wide. Over the entire range the instrument can deliver 180 milliwatts of leveled cw power into a 50-ohm load. This is equivalent to 6 volts behind 50 ohms. When the carrier is 95%-modulated, the maximum available carrier level is 3 volts. Envelope distortion and incidental fm are minimized.

The entire warmup frequency drift is typically about 0.01%, and frequency changes due to band switching and to variations in line voltage, load, and level are generally less than 1 part per million (see Figure 2).

The precision 10-dB-per-step attenuator maintains both accuracy and impedance match over the entire 140-dB stepping range. Attenuator error is less than 0.1 dB per step. with a maximum accumulation of 0.5 dB. The attenuator and the continuously adjustable carrier-level control provide an over-all range of 155 dB.

The all-solid-state 1003 draws only 20 watts from the power line. As a result, temperatures are low and components are not under stress. All active devices are operated very conservatively, and the power supplies are short-circuit-proof.

HOW IT WORKS

(See Elementary Diagram, Figure 3)

Oscillator and Power Amplifier

A single-range (34 to 80 MHz) master oscillator is the source of all output frequencies. The key to the instrument's excellent frequency stability is thus the success with which this oscillator was made insensitive to temperature variations and to the influence of the following stages.

A varactor diode permits incremental tuning (ΔF/F) over a limited range. A compensation scheme is used to obtain constant fractional resolution, permitting calibration of the ΔF/F control in ppm. The electronic tuning circuit is also the means by which the signal generator can be frequency-modulated or phase-locked to an external signal, when the ultimate in accuracy and stability is desired.

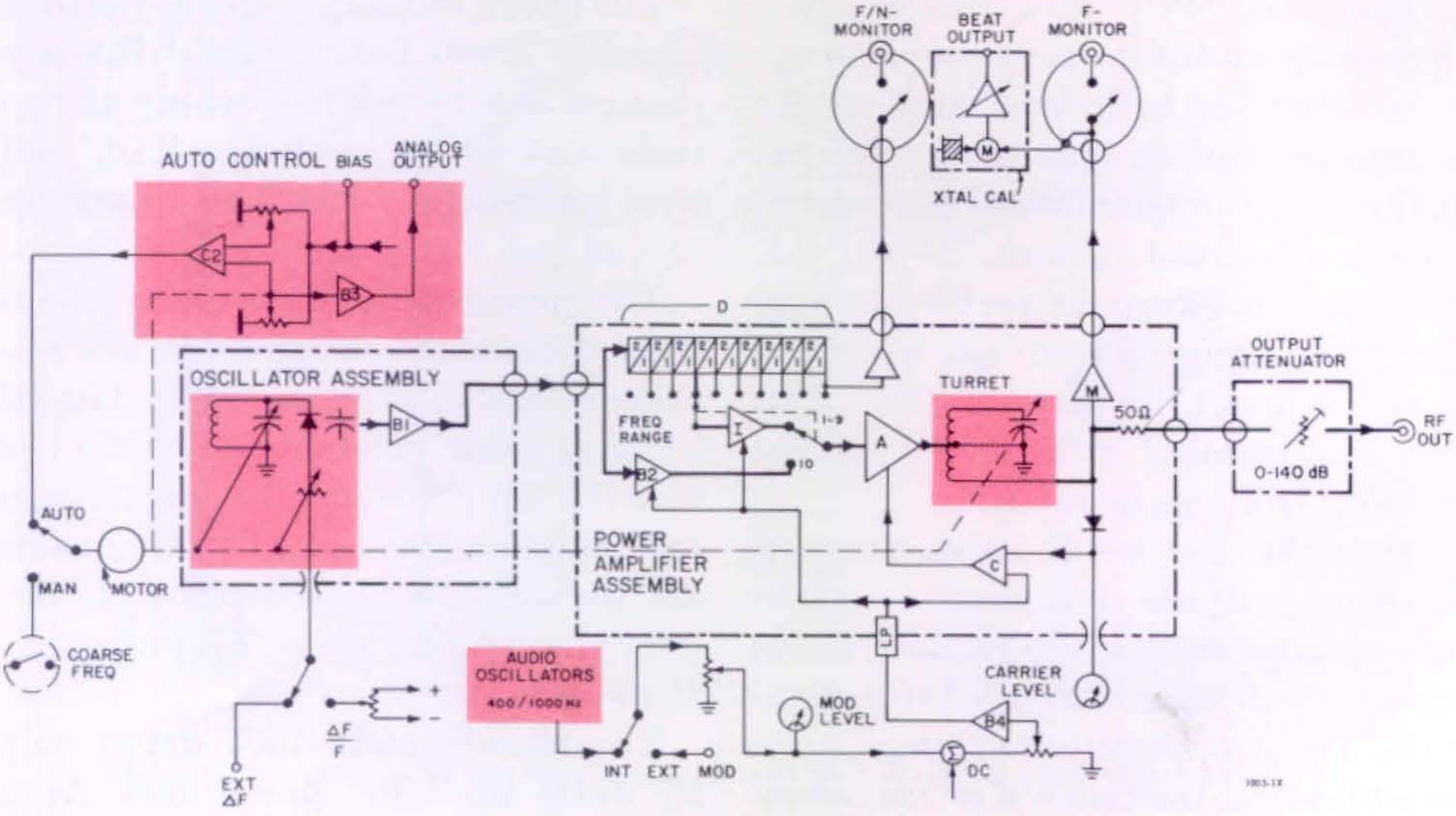

Figure 3. Elementary block diagram.

The oscillator output, after passing through untuned buffer *B1*, enters the power-amplifier unit. On the highest-frequency range (34 to 80 MHz), the rf signal passes through an additional untuned buffer *B2* to the main amplifier *A*. For all lower-frequency ranges, the signal is applied to a series of frequency dividers and thence through untuned buffer (*I*) to the power amplifier. The nine 2:1 dividers give a maximum divisor of 512. Accordingly, the lowest frequency range, produced by the entire cascaded divider chain, is the highest range divided by 512, or 67 kHz to 156 kHz. This low-range output is available as the F/N monitor output, mentioned earlier.

A high degree of isolation between the oscillator and the power amplifier under all conditions practically eliminates all frequency-pulling effects from changes in operating and loading conditions at the output stage. Furthermore, range-switching effects are virtually nil, as Figure 2 shows very clearly, since the same oscillator is used on all bands. Thus no time is wasted in waiting for the frequency to restabilize after band switching, as is typical with other signal generators.

When a particular range is selected, the appropriate number of dividers is activated, and a turret connects the appropriate tank circuit to the power transistor. The tank-circuit variable capacitor is ganged with the oscillator variable capacitor by a non-slip steel cord.

The power amplifier is a 2N3375, whose base voltage controls modulation and output level.

Output System and Leveling

The power-amplifier control voltage is supplied by comparator circuit *C*, which is part of a feedback control system. The other elements of the feedback loop are the tuned amplifier *A* and the detector circuit, whose dc output is compared against a composite reference signal. Any difference between these two signals generates an amplified correction voltage, which makes the rectified output follow the reference voltage. The regulating action is further enhanced by a secondary control path, which varies the drive level and thereby increases the dynamic range of modulation.

Because the stability of the reference voltage is essential to the maintenance of a constant carrier level, all circuits associated with the generation of this reference voltage are supplied with highly stabilized bias voltages. The results of such careful design are evident in Figure 4, which shows the carrier level varying well under 0.01 dB as the line voltage is swung ±10 percent.

The detected rf is measured and displayed by the carrier-level meter, which is calibrated in open-circuit volts (i.e., the voltage behind the 50-ohm source impedance) and in dBm of available power. Since the rf level at the sampling point is kept constant by the control circuit, this point can be considered to be a zero impedance source; a 50-ohm series resistor provides the true 50-ohm source impedance.

The carrier-level control varies the reference voltage of the feedback loop and thus provides continuous adjust-

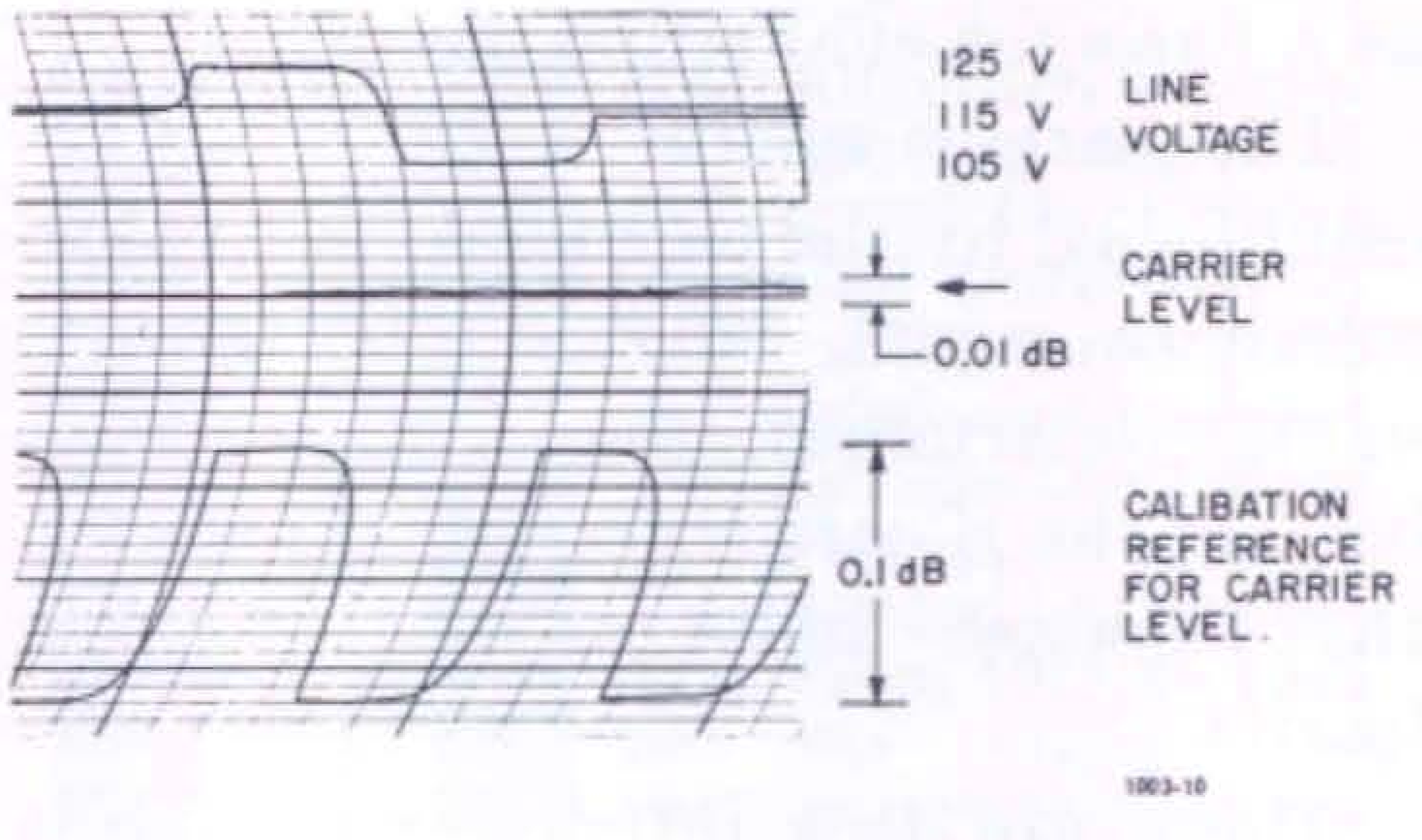

Figure 4. Effects of ± 10% line-voltage swing on carrier level.

ment of the leveled output, over a range of 15 dB. The precision step attenuator covers a range of 0 to 140 dB in 10-dB steps.

Modulation

The basic modulating function is performed in the power-amplifier stage by the base voltage on the 2N3375 transistor. This function is linearized through the feedback action, which makes the detected envelope essentially identical to the composite reference signal. In Figure 5 ,which is an X-Y display of a 90% modulated rf signal vs the modulating signal, one can judge the linearity by observing the straightness of the sloped sides of the trapezoid. Another, novel type of presentation (Figure 6) shows the sum of the modulated and modulating signals. Ideally this should produce a horizontal baseline. Departures from the ideal serve

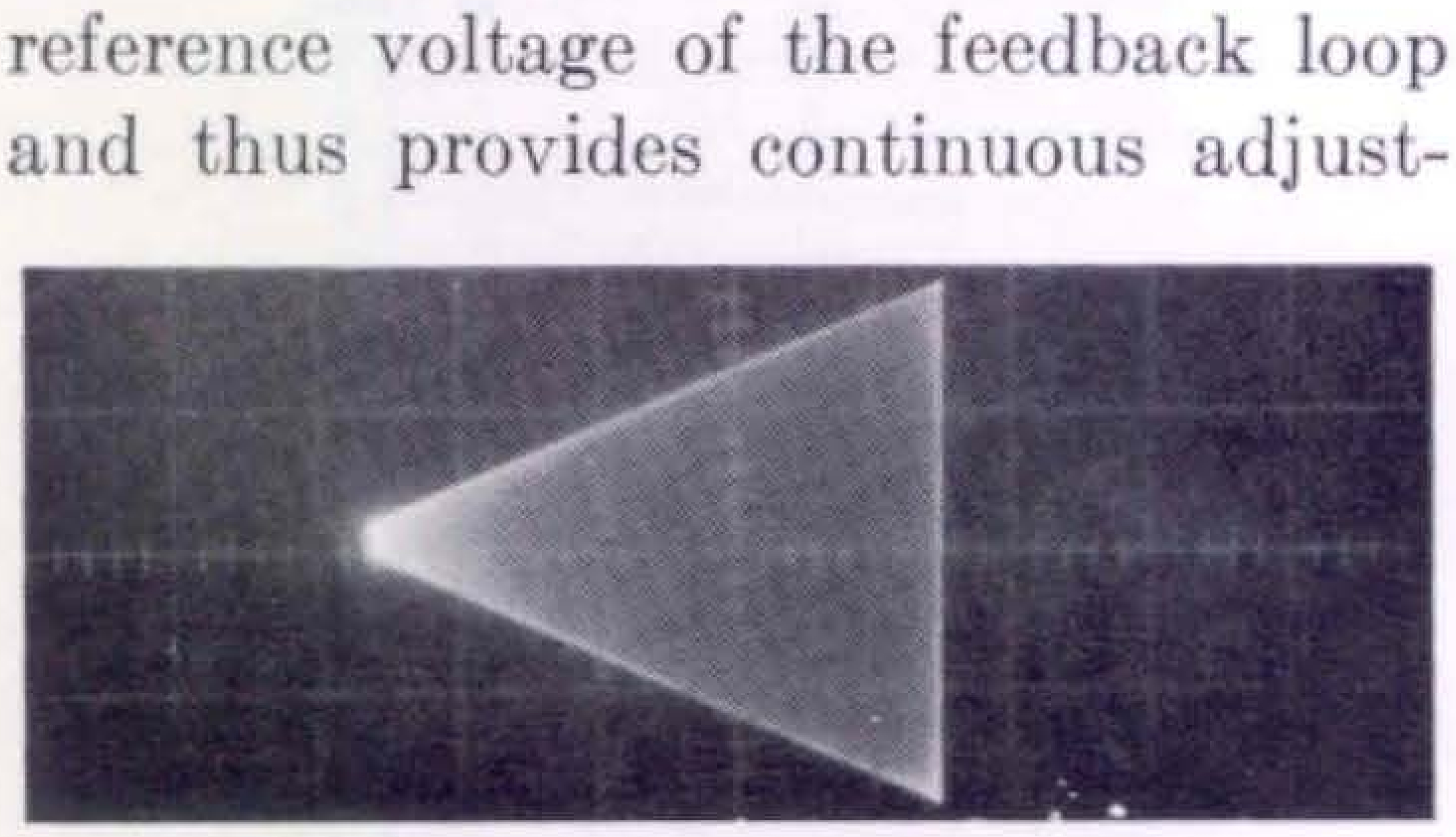

Figure 5. X-Y display of a 90% modulated rf signal (6.5 MHz) vs the modulating signal (400 Hz).

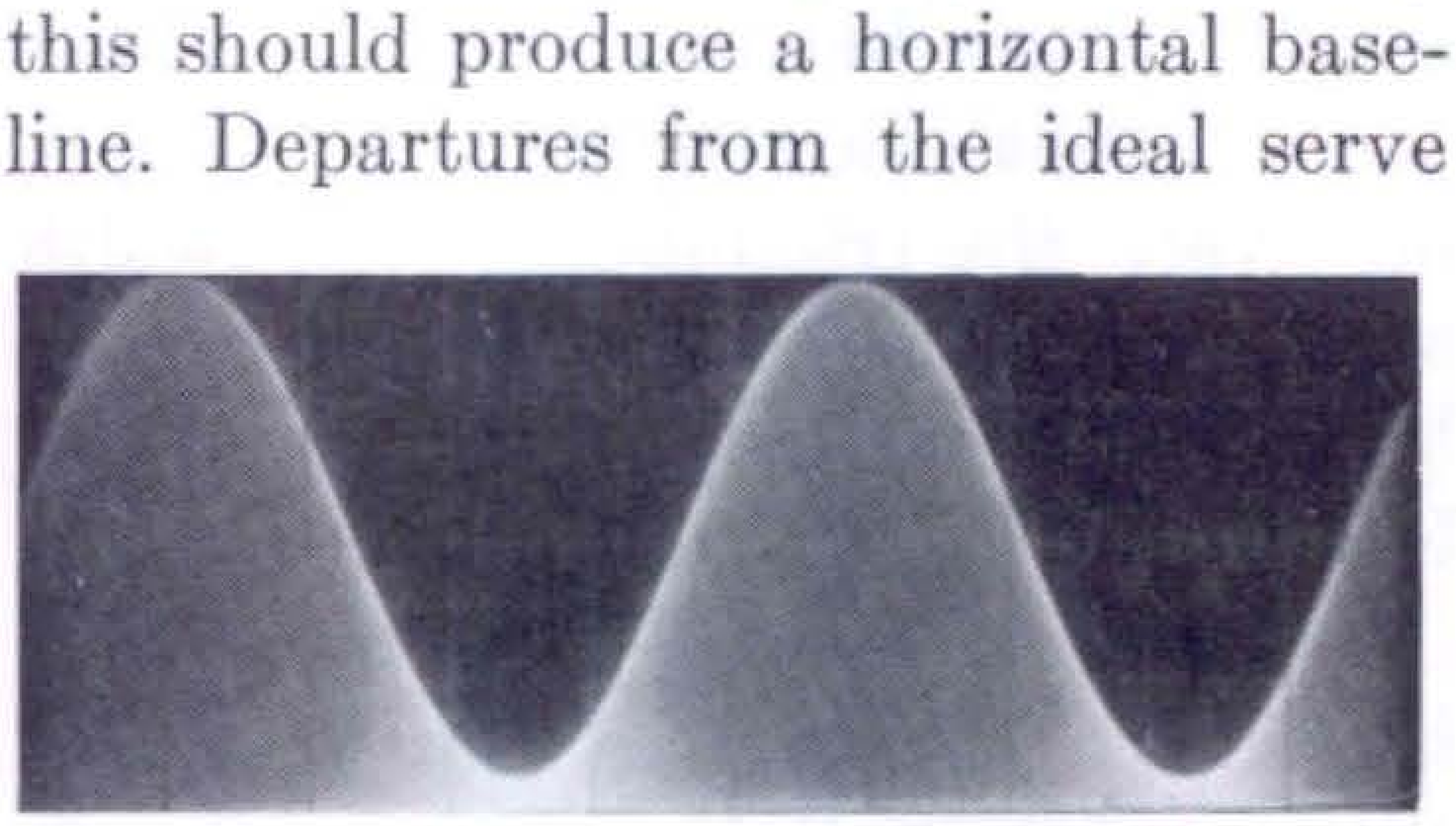

Figure 6. Oscillogram showing addition of modulated (6.5-MHz) and modulating (400-Hz) signals at 90% modulation. Horizontal baseline indicates lack of distortion.

as a basis for evaluating distortion.

The various modes of operation are established by the nature of the applied reference signal, whose instantaneous value determines the instantaneous level of the rf carrier (within, of course, the response limits of the feedback loop).

There are two internal modulating frequencies, 400 Hz and 1 kHz. At either frequency, the modulating signal is highly stable and has very low distortion. The amplitude of these modulating signals can be adjusted by the MOD LEVEL control for up to 95% modulation. The modulation level is monitored in terms of the audio modulating voltage but is calibrated directly in percent. A compensation circuit ensures that a given modulation setting is kept constant over the range of the carrier-level control.

External modulation can be applied with either ac or dc coupling. In the EXT AC mode, any audio-frequency signal can be accepted, controlled, and monitored in the same way as for internal modulation. With sinusoidal waveforms, the modulation passband is flat within 1 dB from 20 Hz to 10 kHz. The ultimate upper limit is the 20-kHz nominal cutoff frequency of the low-pass filter used to feed external signals into the power-amplifier enclosure. On the lower-frequency ranges, however, the rf-amplifier bandwidth also affects the highest usable modulation frequency and percentage modulation.

In the EXT DC mode, the input jack is coupled directly to the amplifier. With no input, the power amplifier is turned off, and a positive-going voltage is required to turn it on. In the off condition, the carrier is down by 50 to 60 dB. Internal limiters protect against excessive modulation input voltages. This mode of operation is particularly useful for remote-control applications and for low-frequency square-wave modulation.

Crystal Calibrator (See Figure 7)

A 1-MHz crystal oscillator is the basic reference source for the optional crystal calibrator. Two more frequencies, 200 kHz and 50 kHz, are derived by division and are thus coherent with the 1-MHz signal. Even the lowest marker frequency can be used up to the highest carrier frequencies.

Since the rf sample for the crystal calibrator is taken from the F-monitor channel (see Figure 3), a high degree of isolation is realized, providing a reverse attenuation well over 100 dB between crystal calibrator and main output. As a result, the crystal calibrator can be used without fear of contaminating the main output with spurious sidebands.

When the F-monitor output is switched on, it is possible to feed an external reference signal through the F-monitor jack and to use portions of the crystal calibrator circuitry as a

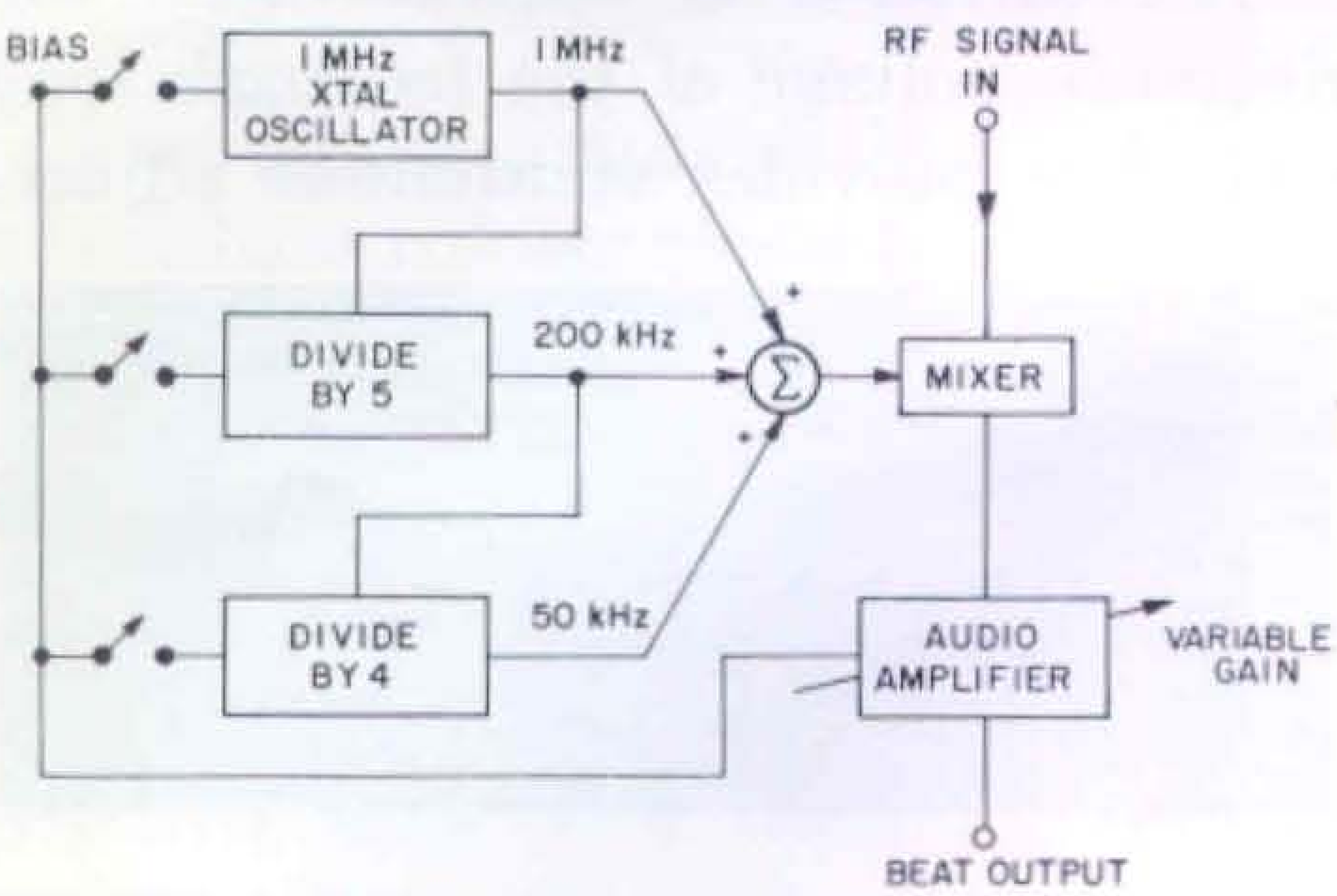

Figure 7. Elementary diagram of the crystal calibrator.

heterodyne frequency meter. In this case, only the mixer-amplifier part of the crystal calibrator is activated.

Auto-Control Unit

The auto-control unit permits a number of automatic tuning operations by either local or remote control. For automatic tuning, the standard frequency-control motor becomes part of a servo positioning system (see Figure 8). An analog dc voltage, proportional to tuning-shaft position, is compared against a reference voltage in a differential amplifier. The amplified error voltage actuates one of two relays, depending on the polarity of the error signal. The appropriate relay energizes the motor to bring the error to zero, and the relay then drops out and turns the motor off. Simultaneously, a dc pulse from a charged capacitor is applied across the motor windings to bring the motor to an abrupt stop. Resolution and accuracy are adequate to permit resettability to within 0.1%.

Rudi Altenbach received his Dipl. Ing. degree in EE from Karlsruhe Technical University in 1948. After three years as development engineer with Siemens and Halske in Germany, he came to Canada, and later to the U.S. From 1951 to 1963 he was engaged in various capacities in the design and development of radar, radio relay equipment and related devices at Canadian Marconi Company, Hermes-Itek Company, and Raytheon Company. In 1963 he joined the GR's Development Engineering staff and has since been working primarily on signal-generator development. He is a member of the IEEE.

The zero-error position is indicated by a neon lamp on the auto-control panel. This lamp is used in the setting of the reference potentiometers to a desired tuning position or limit and also serves as a frequency or position marker. Two internal multiturn high-resolution potentiometers (F1 and F2) permit continuous adjustment of the auto-tune positions or sweeping limits. Many more additional tuning points

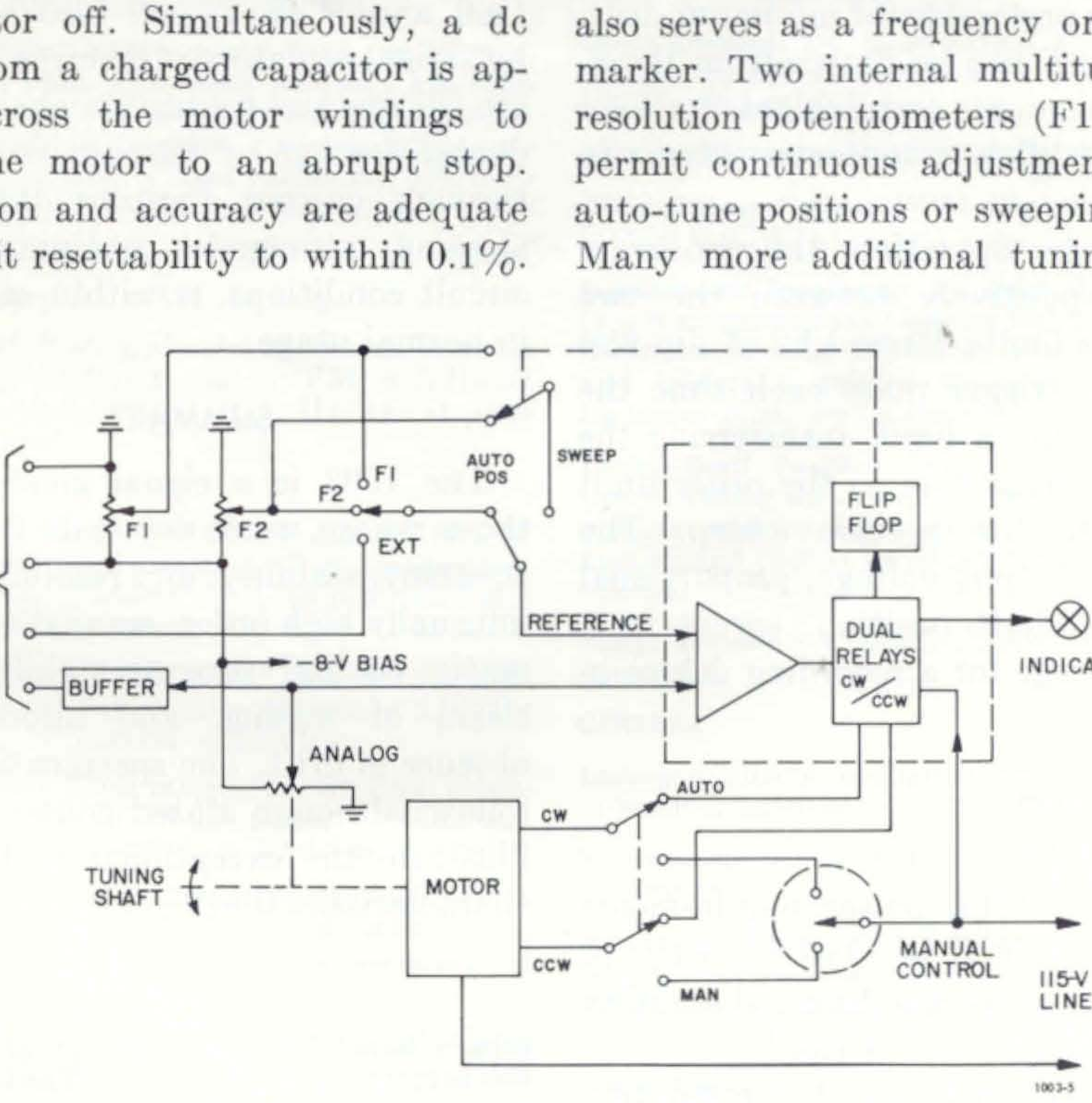

Figure 8. Elementary diagram of the auto-control unit.

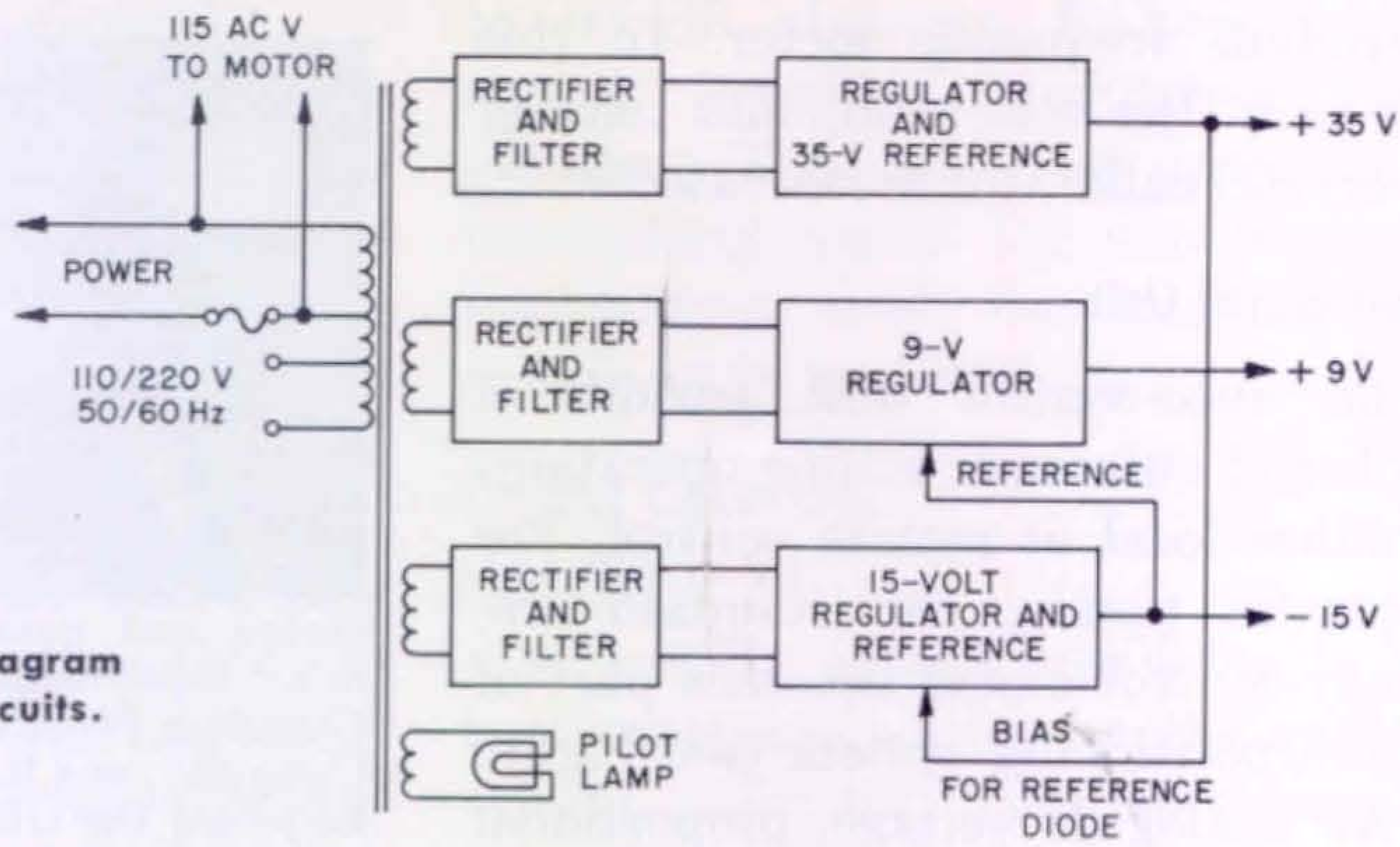

Figure 9. Elementary diagram of the power-supply circuits.

can be added by means of sequentially switched reference signals through an extension socket. An external reference may be either a voltage between 0 and −8 volts or a potentiometer connected to the extension socket. The latter method is preferable for minimum drift. Up to 5 mA can be drawn from the 8-volt bias source, equivalent to over thirty 50-kilohm potentiometers in parallel.

In sweep operation the motor is driven repetitively between the two adjustable limits, F1 and F2. A flip-flop receives a trigger pulse each time the motor reaches a limit, transferring the reference connection to the other limit to actuate the reverse sweep. The analog dc output voltage, proportional to tuning shaft position, serves as a sweep voltage for a recording device in this mode.

Power Supplies
(See Figure 9)

Since the total power requirements are very small, it is relatively easy to obtain excellent regulation and stability together with very low ripple.

Especially critical is the regulation of the −15-volt supply that feeds the oscillator section; variations in this supply are kept to a few millivolts under all adverse conditions by use of a temperature-compensated reference diode in a high-gain series regulator circuit. The other two bias voltages (+9 and +35 V) are also stabilized by series regulators. All active elements are silicon, and protection against accidental damage or burnout is achieved through current limiting. Total dissipation, even under continuous short-circuit conditions, is within safe limits in normal usage.

SUMMARY

The 1003 is a signal generator for those whose work demands frequency accuracy, stability, and resolution of an unusually high order, manual and automatic tuning, programmability, precision of setting, and almost total absence of drift. The specifications that follow, although stated conservatively, illustrate the exceptional performance characteristics that have been achieved.

— R. Altenbach

Editor's Note: The basic concept of the 1003 was suggested by A. Noyes, Jr. The instrument was developed by the author, with J. K. Skilling providing the divider circuitry.

SPECIFICATIONS

FREQUENCY

Range: 67 kHz to 80 MHz in 10 ranges: 67 to 156, 135 to 312, 270 to 625, 540 to 1250 kHz, 1.08 to 2.5, 2.16 to 5, 4.32 to 10, 8.64 to 20, 17.28 to 40, and 34.56 to 80 MHz.

Calibration Accuracy: ±0.25%, typically ±0.1%; scale logarithmic, 140 in. total length. Logging scale with vernier, 8500 div, 0.01%/div.

Crystal Calibrator (optional): Markers at 50-kHz, 200-kHz, and 1-MHz intervals, accurate to 20 ppm.

Mechanical Tuning: Fast motor drive, manually or externally controlled; manual fine tuning, 1% per revolution, calibrated, resettable to 0.01%.

Auto-Control Tuning (optional): 0.1% positioning accuracy. Motor drive sweeps between preset limits or tunes on command to preset frequencies (two internally, additional from external dc voltages or dividers). Sweep rate approx 7%/s.

Electronic Tuning: Internal, ±500 ppm, calibrated, settable to better than 2 ppm; external, approx 60 ppm /volt up to ± 1000 ppm typical, limited fm capability. Max input ±15 V into 15 kΩ (+ volts increase frequency).

Stability: After warm-up < 5 ppm per 10 min, typically 1 ppm. Frequency will vary less than 1 ppm as a result of ±10% line-voltage changes, range switching (instant restabilization), rf-level adjustments, or load variations. Warmup drift typically 150 ppm in 3 h at 20°C.

Temperature Coefficient: < 20 ppm/°C, typical.

Carrier Distortion: < 5%, typical.

Noise: A-M, hum and noise sidebands down at least 80 dB relative to carrier. FM, < 3 Hz pk at high-frequency end, < 1 Hz pk at low-frequency end.

RF OUTPUT

Range: CW, 0.1 μV to 6 V behind 50 Ω, 180 mW into 50 Ω (−133 to + 22.6 dBm); modulated, 0.1 μV to 3 V behind 50 Ω, 45 mW into 50 Ω (−133 to + 16.6 dBm).

Source Impedance: 50 Ω. SWR is < 1.02 with attenuator set for 0 dBm or less, < 1.05 for + 10 dBm, < 1.20 for + 20 dBm.

Level Control: Total range, 155 dB. Step attenuator, 140 dB in 10-dB steps; continuously adjustable level control, > 10 dB additional.

Accuracy of Leveled Output Power: ±1 dB at any frequency and termination. Attenuator, ±0.1 dB per 10-dB step, max accumulated error ±0.5 dB.

Level Stability: Warmup drift < 0.3 dB, temperature effects < 0.01 dB/°C, line-voltage variations < 0.02 dB.

Meter: Reads open-circuit volts and dBm.

MODULATION

Level: 0 to 95%, continuously adjustable. Stable within ±1 dB independent of carrier or modulation frequency (within modulation bandwidth) and output level.

ModulationBand width: At 100-kHz carrier, max modulation frequency is 500 Hz for 95% a-m and 2 kHz for 30% a-m. Above 1-MHz carrier, max is 5 kHz for 95% and 10 kHz for 30%.

Meter: Reads 0 to 100%. Accuracy ±5% of full scale, 0 to 95% to 10 kHz within stated modulation bandwidth.

Incidental Angle Modulation: < 0.1 radian pk at 30% a-m.

Internal

Frequency: 400 and 1000 Hz, ±0.5%. Output of 2 V behind 100 kΩ available at panel connector.

Envelope Distortion: < 1% at 50% a-m, < 2% at 70% a-m.

External

AC-Coupled: 20 Hz to 20 kHz, 2 V into 2.5 kΩ for 95% modulation.

Direct-Coupled: DC to 20 kHz. Carrier off with 0-V input; 3-V rf output with +5 V into 10 kΩ. Max input 10 V peak.

AUXILIARY MONITORING OUTPUTS

Main-Output Frequency: At least 0.5 V pk-pk into 50 Ω (CW) at output carrier frequency.

Subharmonic Frequency: At least 0.3 V pk-pk (approx square wave) behind 150 Ω. Frequency (between 67 and 156 kHz) is coherent with and integrally related to carrier frequency by factor N shown on main dial.

Tuning-Shaft Position (with auto-control option): Analog dc voltage proportional to shaft position and logging number. Approx −7.5 V max behind 7500 Ω, or 90 mV for 1% frequency change.

Range Indicator: Contact closure through rear connector.

GENERAL

Leakage: Effects negligible on measurements of receiver sensitivity down to 0.1 μV.

Environment: 10 to 50°C ambient for specified performance.

Accessories Supplied: 874-R22LA Patch Cord, power cord, 12-terminal connector for external controls, spare fuses, hardware for both bench and rack mounting.

Power Required: 105 to 125, 195 to 235, or 210 to 250 V, 50 to 60 Hz, 20 W (33 W with motor operating).