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FINAL REPORT

DEVELOPMENT OF A CALIBRATED HIGH SIGNAL SOURCE SG-( )/U

Daniel E. Farmer

AMERICAN ELECTRONIC LABORATORIES, INC.
Richardson Road, Colmar, Pennsylvania

AEL Report Number 60016

Contract No. AF30(602)-2219

Prepared for

Rome Air Development Center
Research and Technology Division
Air Force Systems Command
United States Air Force

Griffiss Air Force Base
New York

American
Electronic
Laboratories
COLMAR, PENNA.

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FOREWORD

This is a final report on the "Calibrated High Signal Source SG-( )/U", which covers the study and development of a High Power Signal Source which generates an RF test signal over the frequency range from 40 megacycles (mc) to 40 gigacycles (gc).

The work has been performed by American Electronic Laboratories, Inc. Colmar, Pennsylvania. The technical personnel engaged on this project were the following: D. E. Farmer, W. J. Messmer, and J. J. Pilman.

This work was sponsored by the Rome Air Development Center, Research and Technology Division, Air Force Systems Command, United States Air Force, Griffiss Air Force Base, New York. The management and technical supervision of this program was under the cognizance of Messrs. L. F. Moses, R. Powers, and G. A. Long of RADC.

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ABSTRACT

This report discusses the design and performance of a High-Power RF Signal Source developed by American Electronic Laboratories, Inc. for Rome Air Development Center. The Signal Source covers the frequency range of 40 Mc to 40 Kmc. The RF power output can exceed 100 watts at frequencies below 4 Kmc. Above 4 Kmc the power output falls off. Frequency stability of the order of one part in one hundred million is achieved by locking the system to an ultra-stable standard. Pulse, sine, and square-wave amplitude modulation, and sawtooth frequency modulation are provided.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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Task Engineer
Interference Research Section

Approved: SAMUEL D. ZACCARI, Chief
Vulnerability Reduction Br
Communications Division

FOR THE COMMANDER: IRVING J. GABELMAN
Director of Advanced Studies

I. INTRODUCTION

A. SCOPE

The purpose of this final report is to describe the development of a High Power Signal Source which generates an RF test signal over the frequency range: 40 Mc to 40 Kmc.

The report covers work performed on this project at American Electronic Laboratories, Inc.

B. BACKGROUND OF THE PROBLEM

The intensive efforts now in progress to study and reduce the effects of radio-frequency interference will require innumerable RF signal generators possessing a wide variety of properties. To the extent that versatility can be designed into a signal generator, the number of special-purpose instruments needed can be reduced. In that direction, the Electromagnetic Vulnerability Laboratory of the Rome Air Development Center has consolidated many of its instrumentation requirements in its specifications for a "High-Power, Wide-Range, Ultra-Stable, Microwave Signal Source". Although most of the desirable properties of a versatile RF source are obvious, reviewing them briefly will provide a background to the description of the instrument.

1. High Power Output

The maximum RF test power establishes, with other factors, the lower limit of sensitivity at which measurements can be made. Measurements of highly attenuated antenna lobes, skirt characteristics of filters, RF fields inside well-shielded enclosures and attenuator characteristics are among the applications where high relative power is useful. High absolute RF power is needed to reproduce the field strengths generated by transmitters in order to study their influence on nearby equipment.

2. Wide Frequency Range

Many RFI tests will require exploring large portions of the spectrum to ascertain the effects of interference on equipment. It is advantageous to have wide frequency coverage in a single instrument, not only to reduce set-up time, but also to minimize the problem of determining and controlling the relative performance of separate narrow-range generators.

3. Frequency Stability and Accuracy

Repeatability of tests on frequency-sensitive equipments and components, measurement of fine grain frequency-response structure, and RFI susceptibility measurements on narrow-band systems require test signals at stable and accurately known RF frequencies.

4. Signal Purity

Easy interpretation of susceptibility test data calls for RF test signals of high purity. Spurious and harmonic signal content must be at a minimum. Amplitude modulation should produce no frequency modulation and frequency modulation should not be accompanied by incidental amplitude modulation. Signal-to-noise ratio should be as high as possible.

C. GENERAL CHARACTERISTICS

The High-Power Signal Source is continuously tunable over the frequency range 40 Mc to 40 Kmc. The RF power output is 100 watts CW from 40 Mc to 4 Kmc. From 4 Kmc to 18 Kmc the power output exceeds one watt. Above 18 Kmc the output falls to the order of one milliwatt at 40 Kmc. The power output is adjustable over a 100 db range. The manually adjusted power is maintained constant automatically as the frequency is tuned through each band. Two modes of stable operation are provided. In one mode, a stability of one part in 10^8 is available. A second mode allows a simplified operating procedure at a stability of five parts in 10^5. Pulse, sine, and square-wave amplitude modulation over a frequency range of 10 cps to 20,000 cps is available in the system. The shortest pulse width attainable is 30 nanoseconds. Sawtooth frequency modulation is also included in the Signal Source. The FM rate is adjustable between 10 cps and 10,000 cps. The maximum attainable FM deviation is dependent on the RF frequency. At 40 Kmc a deviation of 65 Mc can be obtained. Both FM and AM can be applied simultaneously. Signal purity is maintained by applying amplitude modulation at a frequency-insensitive point and frequency modulation at an amplitude-insensitive point in the system. Spurious and harmonic signals are minimized by the use of fixed and tunable filters.

II. DISCUSSION

A. GENERAL

1. Performance Summary

Frequency Coverage:	40 Mc/s - 40 Kmc/s
Power Capability:	300 - 500 watts 250 Mc - 4 Kmc 5 - 10 watts in K-Band 100 db dynamic range
Frequency Stability:	1 part in 10^7
Pulse Modulation:	30 mμsec - 50 msec Incidental FM: negligible
Audio AM:	Sine and Square Wave, 10 cps - 20,000 cps
Frequency Modulation:	1 Mc - 20 Mc deviation 10 cps - 20,000 cps rate

2. Design Principles

The design of the Signal Source is an expansion of the Master Oscillator - Power Amplifier technique. An elementary form of the system is shown in Figure 1. A tunable oscillator provides an RF signal between 500 Mc and 1,000 Mc. This signal is amplified to produce a high-power output in the same band. Any signal between 1 Kmc and 40 Kmc is produced by successive steps of harmonic generation and amplification. Filters are used to select the desired harmonic and reject all unwanted signals. In order to produce a signal between 40 and 500 Mc, the output of the variable 500 to 1,000 Mc oscillator is heterodyned with the output of a second oscillator operating at a fixed frequency of 1,000 Mc. The desired signal is selected by filters. Both fixed and variable oscillators are stabilized by referencing their outputs to a crystal-controlled oscillator

The RF output of the system is maintained constant by amplifying a rectified sample of the output and applying the result to reduce the gain of an amplifier in the signal chain. The ratio of the leveling sample to the RF output is manually adjusted to control the power output of the Signal Source.

Both with respect to power output and RF frequency, only those portions of the amplifying chain are energized which are required to give the desired output. This extends component life, conserves power, and reduces output noise.

The frequency-modulating signal is applied to an electrically variable reactance in the frequency-determining element of the 500 to 1,000 Mc oscillator. Pulse amplitude modulation is applied to crystal switches in the 500 to 1,000 Mc line common to the entire RF Subsystem. Audio AM is introduced at a gain-controlling element in the 500 to 1,000 Mc amplifier common to all RF signal paths.

All components are designed for rack installation. The cabinets housing the components include forced-air cooling controls, indicators, and output connectors are mounted on the front panels of the units. Interconnections are made at the rear.

3. Design Features

a. Sectionalized Operation

The System may be energized in sections with respect to frequency and power. Input power is conserved and component life extended.

b. AM Without Incidental FM

Master Oscillator - Power Amplifier arrangement allows amplitude modulation of amplifiers without affecting frequency.

c. FM Without Incidental AM

Fast-acting feed-back power-leveling circuit maintains constant RF amplifier output regardless of input variations.

d. Harmonic Generation For Frequency Stability

The phased-locked stability of a UHF oscillator is retained to 40 Kmc by use of harmonics.

e. Spectrum Extension

The low-frequency amplifiers can deliver full output down to 200 Kc/s. A 20 to 40 Mc/s precise source is now incorporated in the system. Addition of a crystal heterodyne oscillator with appropriate filtering and switching can extend the output down to 200 Kc. Additional harmonic generators can extend the coverage above 40 Kmc/s.

f. Power Increase

Space, power supply capacity, and control circuitry will accept higher-power TWT's as they become available.

g. Effective Out-Of-Band Use Of TWT's

Power and gain reserves incorporated in the system allow use of the TWT amplifiers far beyond their nominal coverage. This has permitted extensive simplification and reduction in component cost.

h. Programming And Automatic Control

Internal programming is used in the system. External programming can be added.

4. Design Details

a. RF Subsystem

Figure 2 is a block diagram of the RF Subsystem. The signal originates in the 500 to 1,000 Mc tunable oscillator for all frequencies above 500 Mc. This signal is amplified in a medium-power travelling-wave tube amplifier which drives a high-power TWT amplifier to yield 100 watts CW in the 500 to 1,000 Mc band. Alternatively, the medium-power TWT can be adjusted to yield sufficient second harmonic to drive a high-power TWT in the 1 to 2 Kmc band. The change in operating mode is controlled by the manual band switch, which also actuates coaxial relays to change the signal path and introduce a 1 to 2 Kmc tunable filter into the line. In turn, the second harmonic of the 1 to 2 Kmc signal is generated in a TWT amplifier to drive a 2 to 4 Kmc high-power TWT amplifier. The medium-power amplifier is operated also under a different set of conditions to generate harmonics to produce signals for the 4 to 8 Kmc band. A third medium-power TWT serves as an output amplifier between 4 and 8 Kmc and a harmonic generator from 8 to 18 Kmc. Its harmonics, in turn, are used to drive a medium-power TWT in the 12 to 18 Kmc band. A crystal doubler, driven by signals in the two lower bands provides an output between 18 and 26 Kmc. A second crystal doubler yields a 26 to 40 Kmc signal, when energized from one or the other of the two lower bands.

In order to generate signals between 40 and 500 Mc, the output of a 1,000 Mc oscillator is added to the output of the 500 to 1,000 Mc tunable oscillator. The summed signals are fed to the 500 to 1,000 Mc TWT amplifier, which is readjusted to function as a mixer. The difference signal is fed through switches and low-pass filters which subdivide the 40 to 250 Mc range into less-than-octave bands for harmonic elimination. The signal is then amplified in five wide-band distributed amplifiers cascaded to provide 100 watts RF output between 40 and 250 Mc. Between 250 and 500 Mc sufficient beat signal is obtained to drive a high-power TWT amplifier directly.

Nineteen bands are required to cover the 40 Mc to 40 Kmc range. They are not all shown in Figure 2, in the interest of pictorial clarity. Octave bands were feasible where tunable filters could be used for signal sorting. Where fixed filters were used the bands were subdivided to insure rejection of all unwanted harmonic or beat signals. Many of the bands are switched to common output terminations so that the total number of outputs is reduced. This permits the use of power sampling, leveling, and measuring components common to many bands.

b. RF Power Control

The profile of RF power vs. frequency is shown in Figure 3. The upper line indicates the maximum power output of the system. This has been intentionally limited to 100 watts in order to provide a margin for leveling, a reserve for handling higher maximum load VSWR, and protection for connected components. The basic power capability reaches 350 watts in some bands. Space, power supply, control, metering, and cooling provisions have been made for high-power TWT's for operation between 4 and 12 Kmc. These tubes can be added, when they become available. The lower line on the power profile represents the maximum RF power obtained, when the signal is extracted ahead of the high-power amplifiers. Although not shown in Figure 3, three power ranges are extracted in some bands.

A typical RF power leveling loop is shown in Figure 4. The RF output is sampled with a directional coupler. The sample is fed to a crystal detector through a manually variable attenuator. The output of the detector is then amplified in a high-gain, stabilized amplifier and the output signal applied to the gain-control grid of a medium-power TWT. Adjustment of the variable attenuator sets the power which will be maintained by the leveling loop. A separate RF power meter is provided for monitoring the power output.

c. Frequency Stabilization

The 500 to 1,000 Mc oscillator is actually a triode oscillator and triode amplifier in coupled cavities which are tuned by ganged, adjustable coaxial lines connected to a manual control and frequency dial. The dial has a frequency scale for each of the 19 bands. Stability of this arrangement is five parts in 10^5. Alternatively, the tunable oscillator can be phase-locked to the harmonics of crystal-controlled 20 to 40 Mc oscillator to achieve an accuracy and stability of one part in 10^8. The 1,000 Mc beat oscillator is stabilized to one part in 10^8 by a similar technique.

d. Band Switching

A single manual band switch controls all relays, switches, meters and amplifier operating conditions required for proper operation in each band.

e. Frequency Modulation

A variable-frequency sawtooth signal is produced in a sawtooth generator. This signal is applied to a crystal diode and resistor connected across the adjustable coaxial line controlling the frequency of the 500 to 1,000 Mc oscillator, as shown in Figure 5. The variation in reactance of the diode-resistor combination introduces frequency modulation into the system. The diode and resistor are also used in the frequency stabilization network previously described.

f. Sine And Square-Wave AM

Variable-frequency sine or square-wave signals originate in the Waveform Generator. As shown in Figure 6, these are applied to a reference input point in the RF leveler amplifier; the resulting audio signals modulate a carrier oscillator which is transformer coupled to a rectifier in the control grid circuit of the 500 to 1,000 Mc TWT amplifier, common to all RF signal paths. The TWT gain variations thus produced, amplitude modulate the RF carrier.

g. Pulse AM

A Pulse Generator produces pulses variable in width and repetition rate. The pulses are applied to wide-band crystal switches inserted in the common 500 to 1,000 Mc RF line. The switches are of the type, as shown in Figure 7. For "pulsed-on" operation each switch is biased so that the series diodes are non-conducting and the shunt diode is conducting application of the pulse reverses this condition, thus turning the switch ON. By exchanging the roles of pulse and bias "pulsed-off" operation is obtained. Two switches are connected in series to achieve 110 db isolation and 3 db insertion loss. The switching time of these switches is one or two nanoseconds.

h. Input Power

The Signal Source requires about 15 kw of power from a three-phase, four-wire, 60-cycle service. The input voltage is regulated within 1 percent by a servo-controlled, motor-driven, ganged-variac arrangement.

i. 28 Volt DC Service

All remote-control circuits are energized from a 28-volt DC supply. A portion of the 28-volt output is made available for external use.

j. Medium-Power TWT Beam Supplies

A separate beam supply is provided for each medium-power TWT. These are alike in that three-phase bridge rectifiers are used to reduce ripple, and series vacuum-tube regulators are used in the high-voltage output circuit. The output voltage of each is programmed from the band switch so as to establish correct TWT operation for the band in use. These power supplies also furnish DC for the TWT heaters to prevent hum modulation of the RF signal.

k. High-Power TWT Beam Supply

Two six-phase half-wave rectifiers are connected in parallel or in series to provide the beam voltage for the high-power TWT amplifier in use.

Ripple before filtering is about 1-1/2 percent at 720 cps. The beam voltage is regulated and programmed from the band switch by means of servo-driven, ganged variacs in the primary circuit of the supplies. "Crow-bar" arc-over protection is included. This supply can energize high-power TWT's added to the "Signal Source".

l. TWT Solenoid Supply

A three-phase bridge rectifier supplies the current for the TWT solenoid in use. This is current regulated and programmed from the band switch by means of a current-sensing servo driving a ganged variac assembly in the AC input to the supply. This supply can furnish solenoid current for TWT's that may be added to the "Signal Source".

m. Controls And Indicators

Operating controls and indicators are grouped within the reach and vision of an operator standing at a fixed position in front of the Signal Source. Infrequently used controls and indicators are mounted on the units to which they relate circuit-wise.

n. Cooling

Each vertical stack of units is forced-air cooled. Air is inducted through a dust filter at rear, bottom and exhausted at rear, top. The air outlets are aligned for easy ducting outdoors. Individual components are spot cooled with small blowers, as required.

The solenoids and some of the high-power TWT's require water cooling. A pump-circulated closed water system is included for this purpose. A fan-cooled, water-air heat exchanger removes the heat.

o. Protective Circuits

The high-power TWT's are protected against loss of cooling, beam over-current, helix over-current, heater under-current, excessive RF power out, excessive reflected RF power, and arc-over. Controls and relays are inter-locked to prevent tube damage due to failure of programming circuit components. Medium-power TWT's are similarly protected. Fuses or circuit breakers are used to protect all other units of the "Signal Source". Doors and drawers are interlocked, and dangerous circuits covered and marked for personnel safety.

p. Packaging

Figure 8 is a photograph of the "High-Power Signal Source" taken during assembly. Six stacks of rack-width units are mounted in three dual cabinets. Almost all units are slide-mounted for withdrawal to the front. Rear access doors are also furnished. Units producing RF fields are fully shielded. A steel base is provided to distribute the weight and maintain alignment of the cabinets. The weight of the Signal Source is approximately 4,800 lbs.

B. WORK PERFORMED ON CONTRACT

1. State-of-the-Art Analysis

A thorough evaluation of the advances in the state-of-the-art between submittal of the Technical Proposal and letting of the Contract was carried out.

2. Preliminary Design Plan

On the basis of the Technical Proposal and the review of advances in the state-of-the-art, a detail Design Plan was prepared and submitted to RADC. With minor exceptions this plan was followed in the design and development of the Signal Source.

3. Component and Circuit Research

a. An experimental set-up was made to generate RF signals over the range 40 to 1,000 Mc by heterodyning a fixed 940 Mc oscillator with a variable 980 to 1,940 Mc oscillator. The desired difference-frequency signal exceeded unwanted signals by a factor of ten. Interest in this alternative for signal generation derives from the need to provide large FM deviations in the FM modulation mode at the lower end of the RF spectrum.

b. A microwave coaxial crystal switch was tested with the view to using it as an "in-line" pulse modulator to avoid the complications of introducing modulating signals into tube electrodes at high DC potentials. The crystal modulator had an Off-to-On rise time of less than six millimicroseconds with a modulation power depth of 90 percent to 99.9 percent over an octave bandwidth.

c. A VHF oscillator-amplifier combination, tunable over the 500 to 1,000 Mc band was tested for frequency stability. Half-hour stability after warm-up was 40 parts per million, or 0.004 percent. This unit is capable of being phase-locked to a low frequency crystal-controlled oscillator to give a stability of one part in 10^7 over a half-hour period. The amplifier section was tested for AM susceptibility. 99 percent modulation depth was possible with 0.001 percent incidental FM. AM modulation of the oscillator produced 100 percent modulation depth with 0.1 percent incidental FM. FM susceptibility tests showed a total FM deviation of 1.2 to 3.2 Mc over the 500 to 1,000 Mc band.

d. An investigation of tunable filters for harmonic selection was undertaken. Tests proved that it is possible to lock the Master Oscillator to a crystal-stabilized source and apply frequency modulation without destroying the lock. This technique is limited to narrow-deviation FM.

e. Tests were made on the basic low-power amplifier, TWT type

STL-235, rated at two watts between 500 and 1,000 Mc/s. Actual power over the band was seven watts, and gain exceeded the 30 db rated by 16 db. The tube exhibits useful gain down to 250 Mc/s. It also produces a usable 40 Mc beat signal, when driven by two signals near 1,000 Mc/s, spaced 40 Mc/s apart. Operating conditions for the tube may be adjusted for harmonic generation.

f. TWT Type STL-235 was energized with an input signal between 0.5 and 1.0 Kmc. Electrode voltages were adjusted to optimize harmonic generation. The second harmonic ranged between 1,000 Mw at 1.0 Kmc and 125 Mw at 2.0 Kmc. This will probably make additional amplification unnecessary ahead of the high-power TWT in the 1 to 2 Kmc/s band. The fourth harmonic ranged between 77 Mw at 2 Kmc and 1.3 Mw at 4 Kmc. The STX-175 TWT, nominally 4 to 8 Kmc, has sufficient gain from 2 to 4 Kmc, when used as a second harmonic generator to drive the 2 to 4 Kmc high-power TWT, when energized from the 1 to 2 Kmc second harmonic of the STL-235. Tunable bandpass filters are being used successfully for harmonic selection.

g. A signal adjustable between 500 and 1,000 Mc was injected into the TWT Type STL-235 (nominal band: 500 to 1,000 Mc/s), and tube voltages adjusted for second-harmonic generation. The second-harmonic, 1 to 2 Kmc/s was selected by filtering and injected into TWT Type STX-175 (nominal band: 5 to 11 Kmc/s) also adjusted for second-harmonic generation. Power output was +13.3 dbm at 2 Kmc/s and +21.3 dbm at 4 Kmc/s. When the STX-175 was optimized for 8th harmonic output, -6.1 dbm was produced at 8 kmc/s, and +9.1 dbm at 10 Kmc/s. Using the STL-235 as a mixer, with a variable input of 500 to 1,000 Mc/s and a fixed input of 1,063 Mc/s, a beat signal greater than +20 dbm was obtained between 250 Mc/s and 500 Mc/s. These data indicate that one STL-235, and two STX-175's will provide all the RF power required to drive the high-power TWT's or other output devices between 250 Mc/s and 40 Kmc/s. Between 40 and 250 Mc/s, distributed amplifiers are being used. Using the Ku-Band TWT amplifier, a 30 Kmc signal was generated and phase-locked to the secondary standard with a stability of one part in 10^7.

h. The 1 Kmc high-stability reference oscillator was heterodyned with the phase-locked 0.5 to 1 Kmc oscillator. The 0.5 to 1 Kmc low-power TWT was used as the mixer. Usable power can be obtained from 100 Kc to 0.5 Kmc.

i. Low-pass waffle-iron X-Band Filters were built and tested. An adjustable short on a K-Band Waveguide Tee was assembled and tested as a tunable filter. Its performance was not satisfactory for the application and the technique was abandoned. Transmission-type tunable cavity frequency meters were investigated and found to have reasonably low pass-band insertion loss.

4. Breadboard Development

Breadboards were constructed and tested for those units which were judged sufficiently novel in design concepts or components to require experimental verification of performance

5. Design and Construction

Design and construction of the High Power Signal Source was routine except insofar as it involved medium and high-power travelling-wave tubes. These tubes were developed for highly specific military applications and, in general, the tube manufacturers had accumulated neither experience nor data on tube performance outside the requirements of the initial development objectives. The very rapid advance in the TWT art during the design of the High Power Signal Source was characterized by sudden discontinuance of tube development after performance and availability had been publicized; abrupt replacement of a TWT by a new variant with different electrical and mechanical characteristics, and errors and omissions in published tube data. This situation had severe consequences in fixing the design of the Signal Source, because so many major component designs hinged on the TWT properties.

C. RELIABILITY

1. MIL Spec. Components

The bulk of the components were procured under the detailed component specifications listed under MIL-E-5148 (Electronic Equipment Ground, General Requirements For). These specifications, together with incoming inspection provide the basic assurance of reliability.

2. Non-MIL Spec. Components

Some components used in the System are not in categories covered by military specifications. Reliability has been assured by very conservative selection of components with respect to specified accuracy, age, and temperature stability and life from vendors known for the reliability of their products. These components were tested, then operated for extended periods in the System under normal conditions greatly derated from the maximums specified by the vendors.

3. Limited-Reliability Components

The travelling-wave tubes appear to be the weakest components on the basis of the manufacturer's warranties. However, these warranties are based on performance under the most severe environmental conditions specified for the military applications for which the TWT's were developed. Their reliability in the mild environment of the Signal Source cannot be evaluated because of the lack of a broad base of test data in the TWT field. If limited reliability is experienced in using the Signal Source, substitution of improved TWT types, as they become available, is the obvious solution.

4. Measures To Improve Reliability

The following measures were taken to improve reliability:

a. Heavy derating in application of components to circuits.

b. Wide use of forced-air cooling.

c. Extensive use of protection and interlock circuits, not only to clear faults before extensive damage could occur, but also to prevent misoperation due to human error.

d. All relay coils are shunted by reversed diodes for arc suppression to prevent damage to switch and relay contacts.

e. Design to allow sectionalized operation, so that only those units used in a specific operating mode need be turned on.

5. Effectiveness of Reliability Measures

During 60 hours of operation during test, among the thousands of parts only two failed - a relay, and a gas tube.

D. MAINTAINABILITY

1. Preventive Maintenance

a. All blower and control motors are equipped with sealed ball bearings and require no lubrication.

b. The Water Cooling System, used to cool the high-power TWT's, requires reasonable attention and care. Water level must be maintained. After prolonged shut-downs, or after repairs or replacement of elements of the cooling system, it should be run and closely observed for evidence of leaks. Because of uncertainty about the hardness of local water sources, distilled water is the preferred coolant. When it is anticipated that the cooling system will be exposed to below-freezing temperatures, ethylene glycol should be added, circulated, then the coolant can be drained. Draining alone is not sufficient protection against freeze-up.

2. Trouble-Shooting and Repair

Most of the major components of the Signal Source are mounted on drawer slides and withdrawn to the front. The interconnecting cables in the rear are long enough to permit operation in the extended position for trouble-shooting purposes. The design of major units involving RF components and plumbing was dominated by electrical rather than mechanical considerations. For this reason replacement of some components is tedious, because of location and mounting requirements.

III. CONCLUSIONS

The "High-Power Signal Source" is a versatile instrument producing relatively ideal RF test signals over a large portion of the spectrum. The extended power range and the high power output make the instrument useful in RFI tests requiring either large or small RF signals.

The High-Power Signal Source is expandable with respect to frequency coverage. Only switches and filters need be added to make 100 watts output available down to 100 Kc. The frequency may be extended above 40 Kmc by the addition of passive doublers or amplifiers, for which the energizing power and control circuits are already incorporated in the equipment.

Power output may be raised in the C, X and K-Bands by the addition of TWT amplifiers, when they become available. Power supply and control provisions had been included for this expansion.

IV. RECOMMENDATIONS

Recommended herein are areas of further research and development relating to the High Power Signal Source, developed by AEL under the subject contract. The proposed research areas fall into two major categories: those leading to refinements in the High Power Signal Source as a general-purpose, wide-range RF signal generator for use in measurement and simulation of Radio Frequency Interference, and those directed at adapting the instrument to digitally programmed inputs for use in the DOD Radio-Frequency Compatibility Program. The proposed researches would not be limited in application to the High Power Signal Source, but would lead to state-of-the-art advances of wide utility.

A. RESEARCH ON HIGH-POWER RF GENERATORS

1. High-Power RF Amplifiers

Above 500 Mc the choice of high-power wide-band RF amplifiers for general use has been limited to components previously developed for specialized military applications. The existing designs should be reviewed to determine if the original requirements could be relaxed to achieve performance better suited to general-purpose ground equipment use. For example, the high-power CW travelling-wave tubes used in the "High Power Signal Source" were designed for high-altitude airborne CM use. Reduction in the severe environmental specifications may permit meeting some or all of the following characteristics:

a. 100 watts CW output, 4 to 8 Kmc
   70 watts CW output, 8 to 12.4 Kmc

b. 1,000-hour tube life

c. Open-circuit RF output without tube damage

d. Standby heater operation without tube damage, to eliminate time delay in switching bands

e. Substitution of air cooling for liquid cooling

f. Two-octave bandwidths in coaxial TWT's

2. Passive RF Output Components

A complete line of fixed, adjustable, and variable attenuators; fixed and tunable filters; and isolators are needed - both as internal components and external auxiliaries. These must match the output amplifiers in bandwidth and power-handling capability.

3. RF Power-Leveling Units

Line-insertion units, capable of reducing input RF power variations of 10 db to 1 db at the output are needed. Such units should be capable of accepting one watt CW for insertion ahead of RF power amplifiers. These devices should have octave bandwidths in coaxial configurations and full waveguide bandwidths in waveguide configurations. Fast response is essential. One feasible scheme is to use crystal switches as electrically-variable attenuators controlled by a transistor amplifier in a feedback loop.

4. Frequency Multipliers

Efficient doublers, triplers, and quadruplers should be developed for use up to 120 Kmc. Flat response should be sought for full output waveguide bands.

5. High Power TWT Supplies

Non-dissipative, fast-acting power-supply regulator circuits are needed for TWT beam supplies. The application of silicon control rectifiers to AC primary regulation appears most promising. However, control circuits and components for heavy-duty, multiphase supplies must be developed further.

B. PROGRAMMABLE SIGNAL GENERATORS

The DOD Compatibility Program may require both high and low power RF sources that can be programmed from stored digital data with respect to RF frequency, power and harmonic content, and also modulation waveform and amplitude. Two general classes of solutions are anticipated: systems in which digital techniques are applied throughout, and systems in which the input digital control information is converted to analog equivalents for application to continuously variable control elements. The required data rates will probably dictate the choice between these alternatives in specific applications. Areas for research and development suggested by AEL's work on the "High Power Signal Source" and on other programs relevant to signal programming are outlined as follows.

1. Crystal Switches

A complete line of HF, UHF and microwave crystal switches should be developed for RF signal selection applications.

2. Electrically-Variable Attenuators

Crystal switches should be studied with respect to their use as high-speed electrically-variable RF attenuators. Control circuitry should be evaluated at the same time.

3. Electrically-Tunable Filters

Band-pass filters, electrically tunable over octave or waveguide bands should be researched. The problem of tracking arrays of filters to harmonically related variable-frequency RF signals should be explored.

4. Electrically-Tunable RF Oscillators

The various types of electrically-tunable RF oscillators should be refined to minimize spurious signal emission, improve their repeatability, smooth their frequency vs. control characteristics, and level their power output. Development of appropriate control circuitry should accompany refinement of the basic oscillators.

5. Electromechanically-Tuned Filters

A series of mechanically tunable band-pass filters are essential to reducing spurious and harmonic signal output. These should tune over octave bandwidths below 12.4 Kmc, and over waveguide bandwidths above 12.4 Kmc. High-power filters are desirable but low-power filters are essential. These should have a smooth frequency vs. position characteristic. The problem of tracking filters with a tunable master oscillator, producing harmonically related RF signals, should be solved. The feasibility of producing self-tracking filters should be investigated.

C. INTEGRATED SYSTEMS

Breadboard development of programmable RF signal generators incorporating improved techniques and components is recommended. High frequency stability and signal purity should be prime objectives. Digital programming of RF frequency, RF power, and type of modulation should be undertaken.

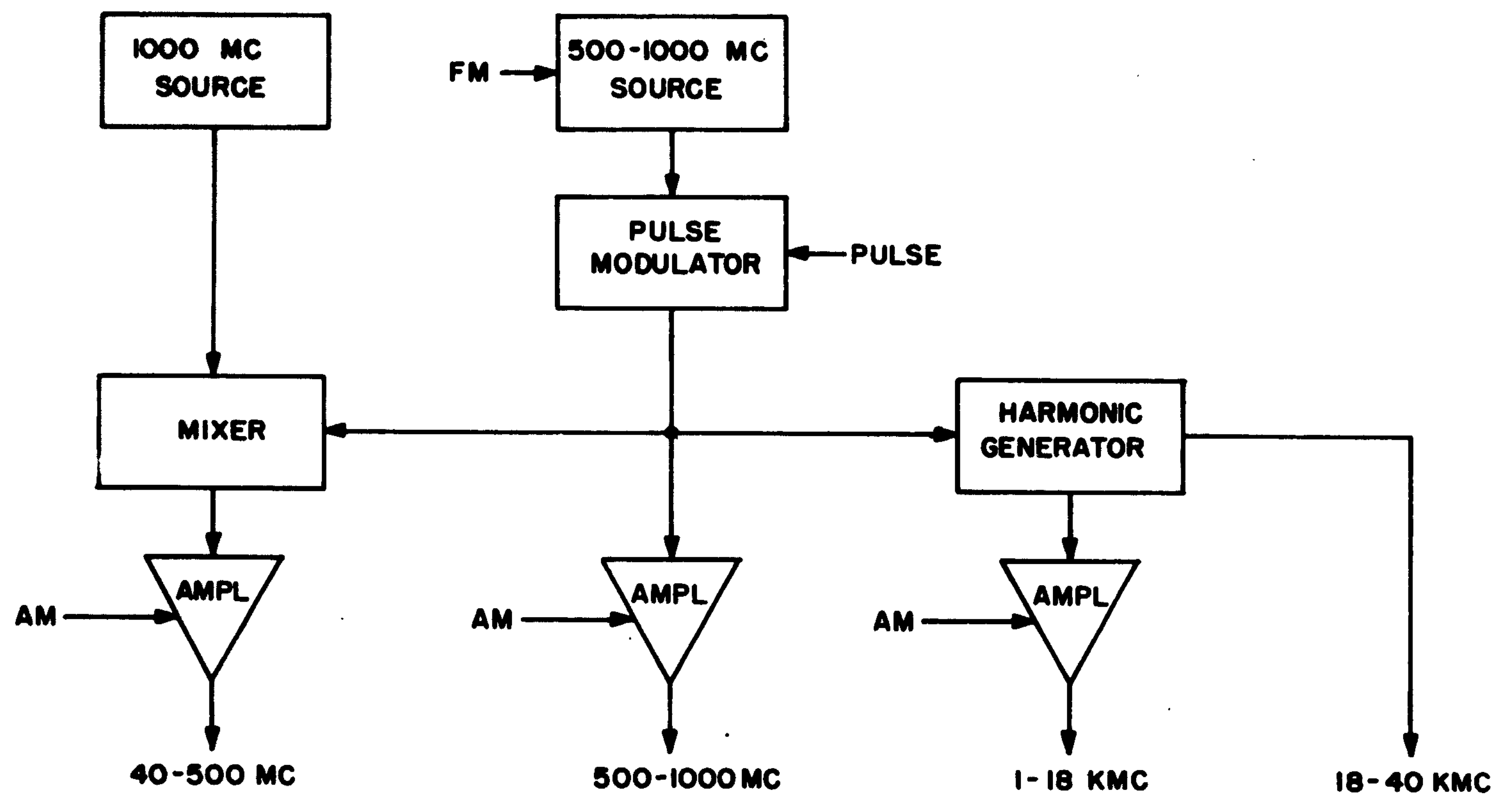


FIGURE 1
SIMPLIFIED BLOCK DIAGRAM
CALIBRATED HIGH POWER RF SIGNAL SOURCE
RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016

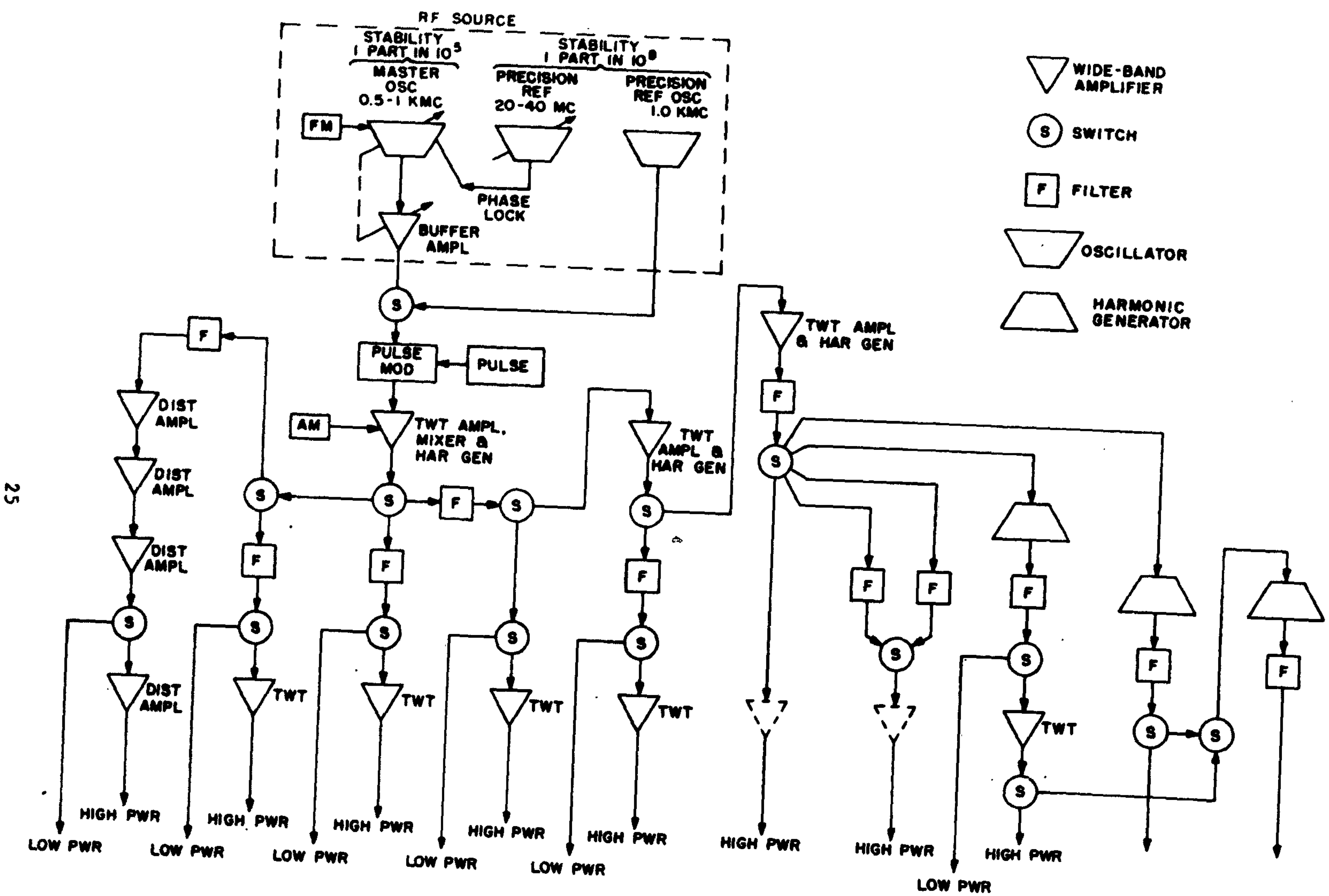


FIGURE 2
DETAILED BLOCK DIAGRAM
CALIBRATED HIGH POWER RF SIGNAL SOURCE
RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016

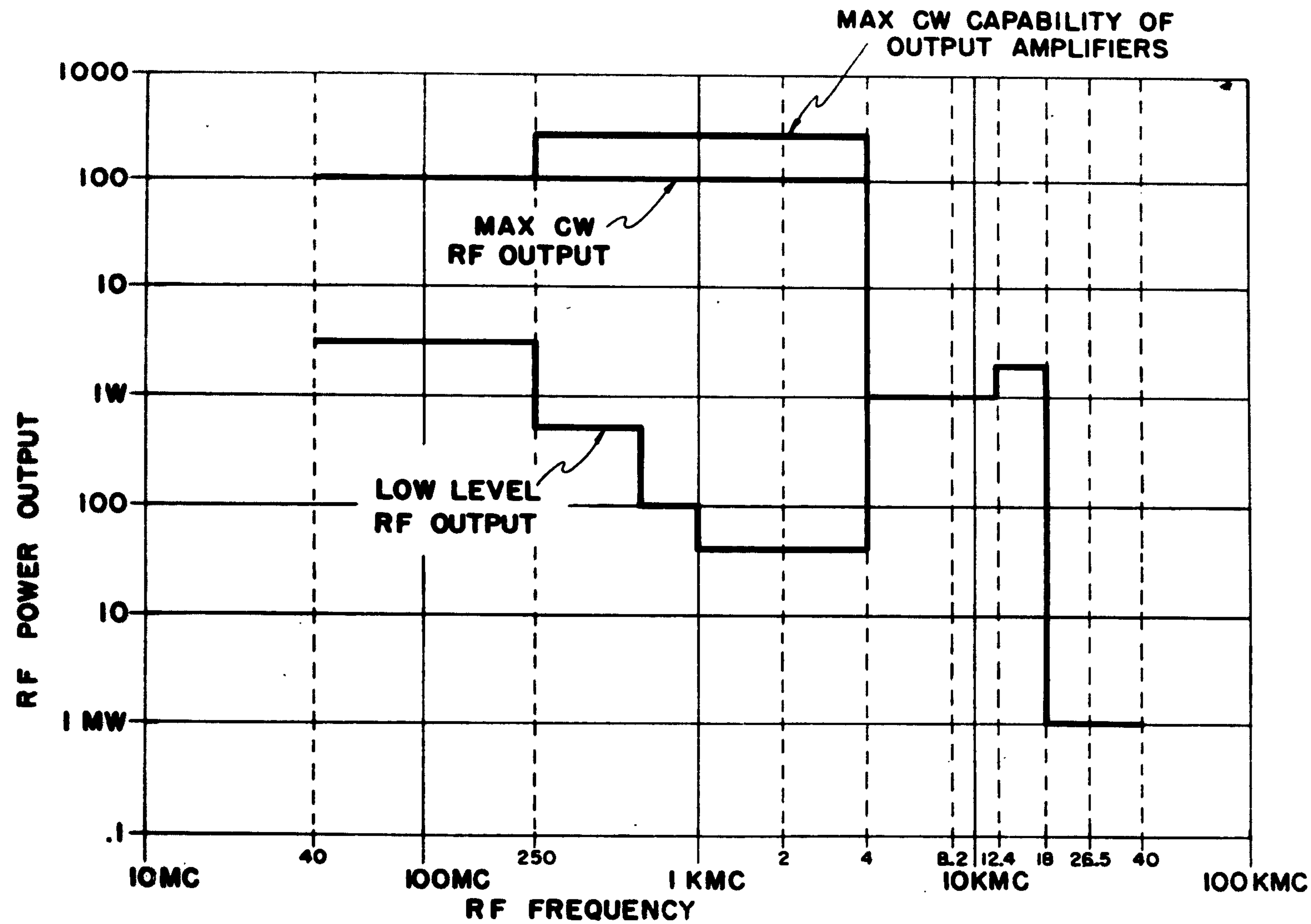


FIGURE 3 RF POWER OUTPUT PROFILE

RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016

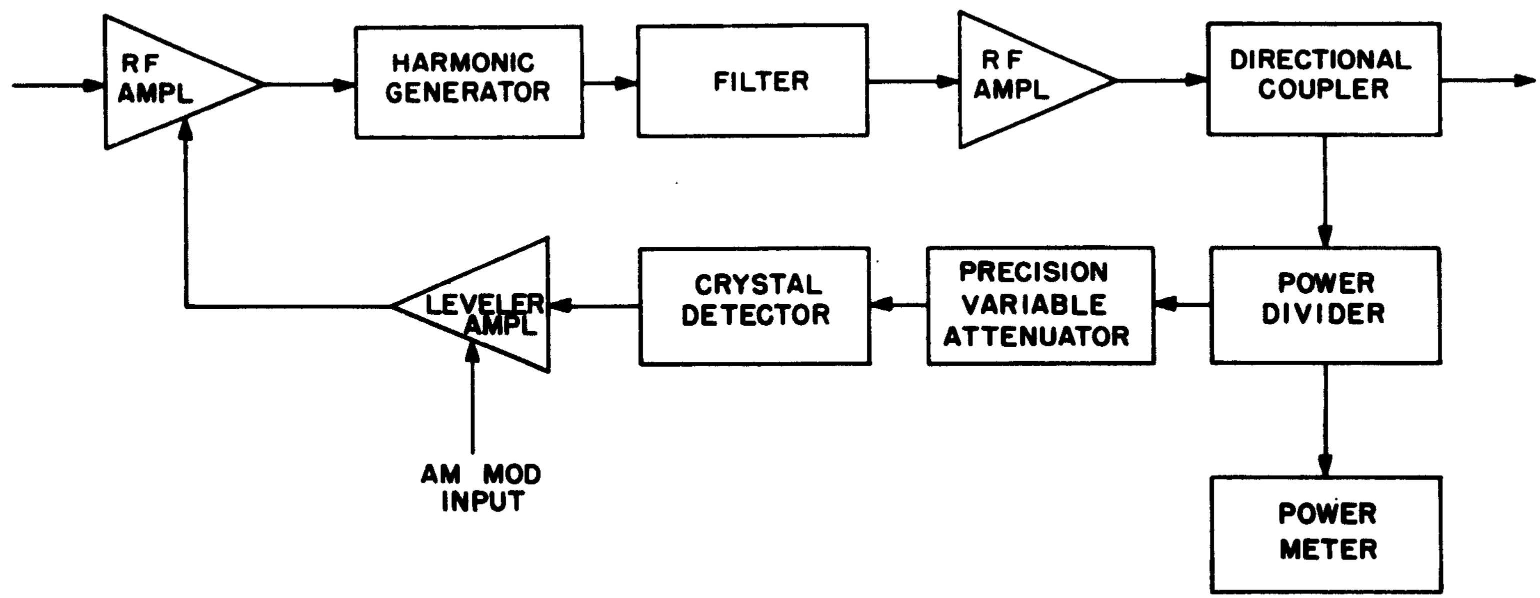


FIGURE 4
SIMPLIFIED BLOCK DIAGRAM
TYPICAL RF POWER LEVELING LOOP

RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016

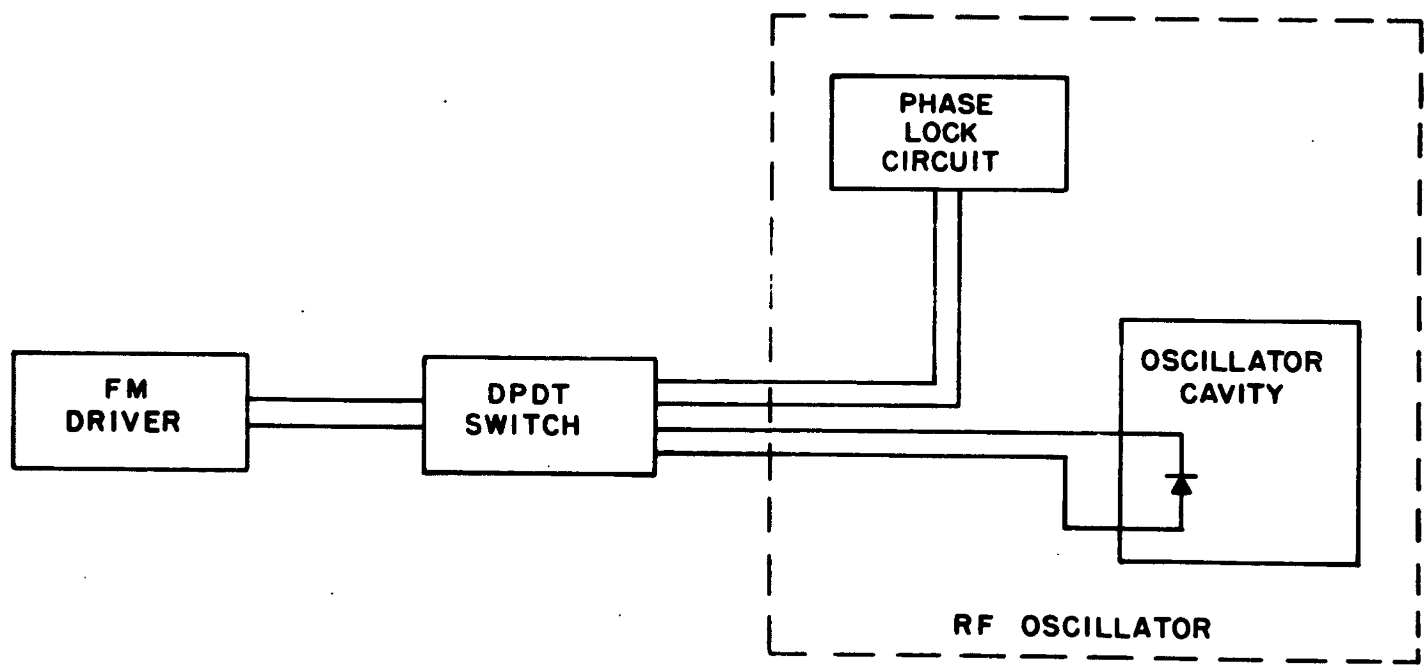


FIGURE 5
SIMPLIFIED BLOCK DIAGRAM
FM SUBSYSTEM

RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016

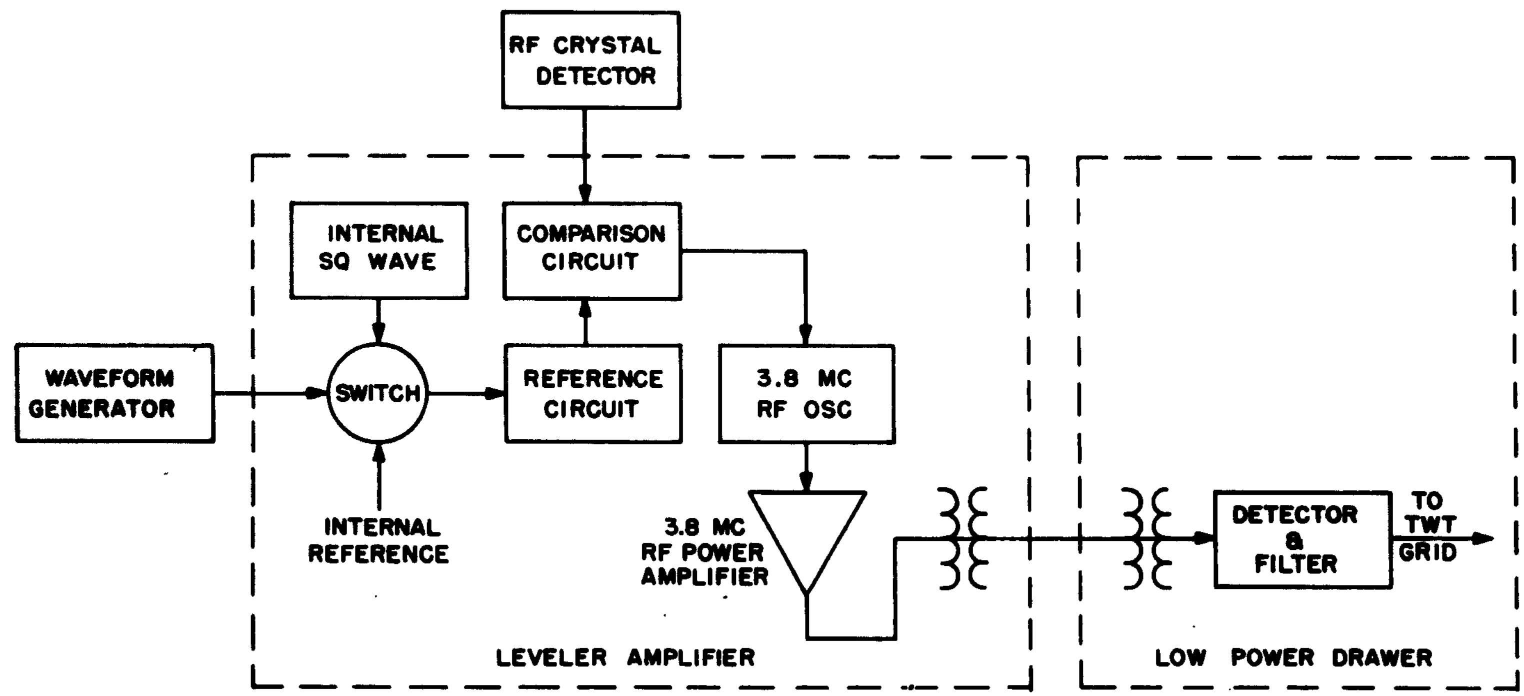
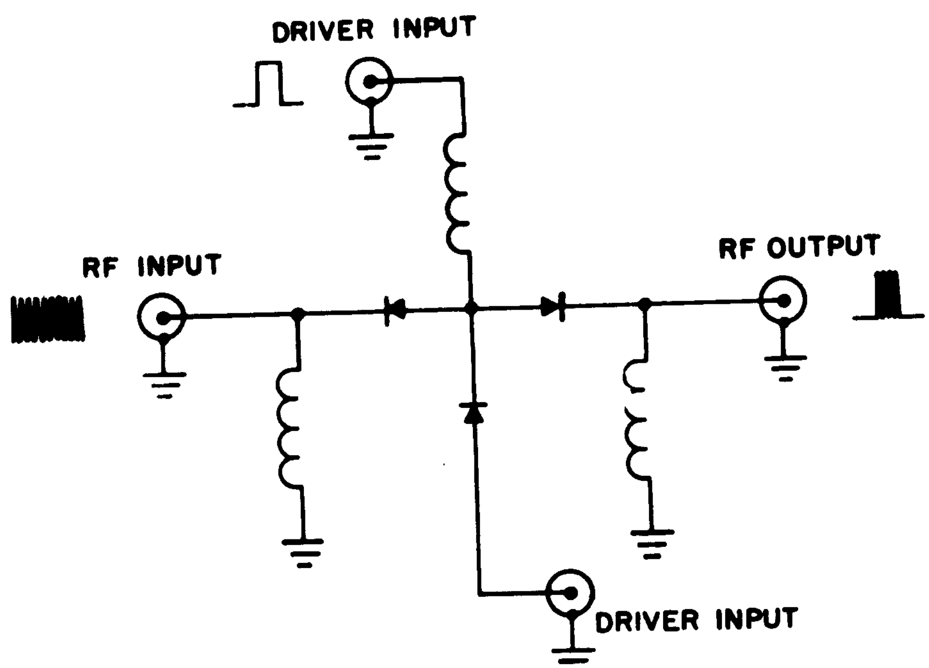


FIGURE 6
SIMPLIFIED BLOCK DIAGRAM
AMPLITUDE MODULATION & LEVELING CIRCUIT
RADC CONTRACT NO. AF30(602)-2219 AEL, INC PROJECT NO. 60016



SIMPLIFIED SCHEMATIC

FIGURE 7
PULSE MODULATOR SWITCH

RADC CONTRACT NO. AF 30(602)-2219 AEL, INC PROJECT NO. 60016

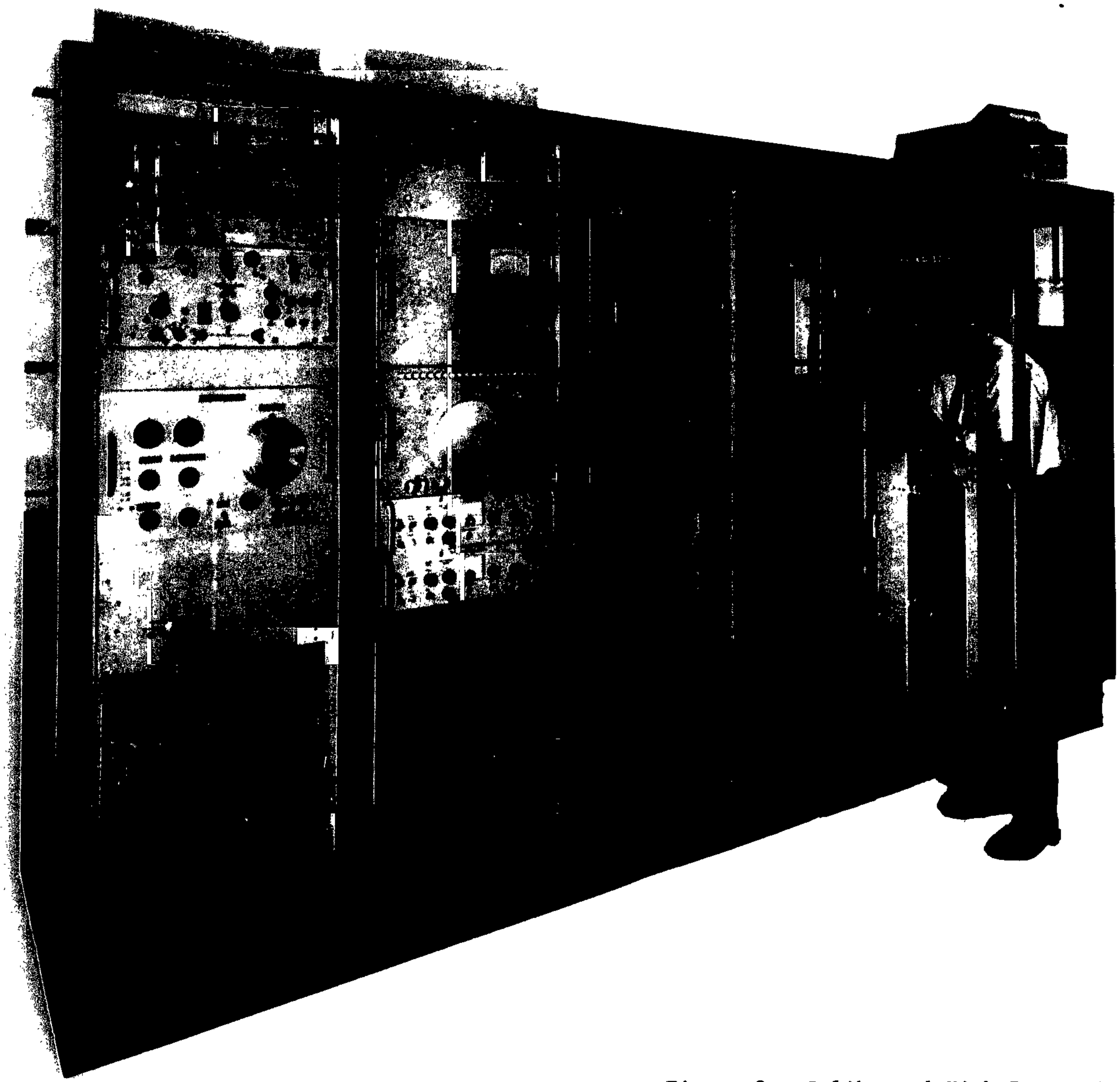
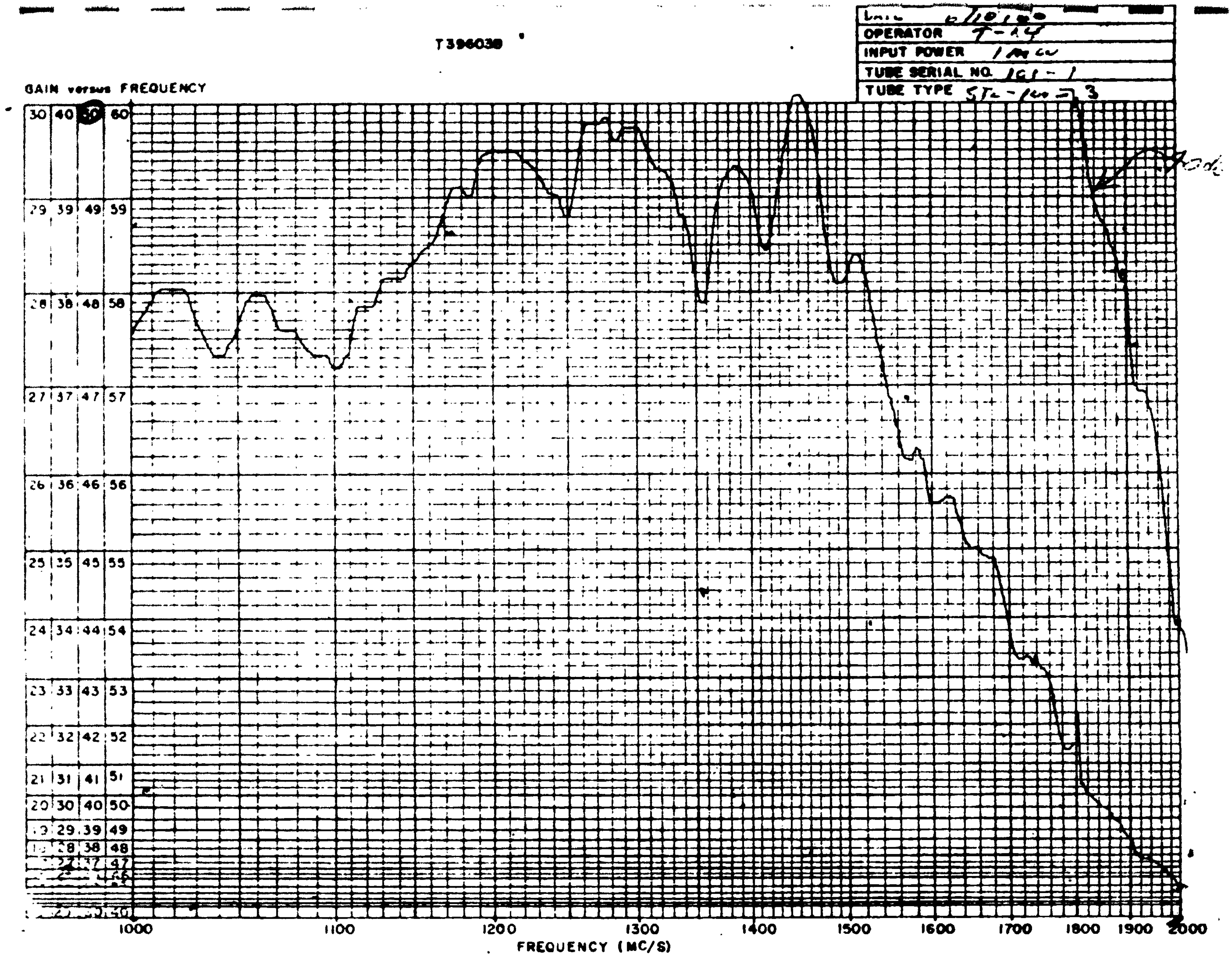


Figure 8. Calibrated High Power RF Signal Source During Construction

APPENDIX I

TRAVELLING-WAVE TUBE CHARACTERISTICS

T396038


GAIN versus FREQUENCY
OPERATOR
INPUT POWER
TUBE SERIAL NO.
TUBE TYPE
30 40 50 60
29 39 49 59
28 38 48 58
27 37 47 57
26 36 46 56
25 35 45 55
24 34 44 54
23 33 43 53
22 32 42 52
21 31 41 51
20 30 40 50
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
FREQUENCY (MC/S)

TEST DATA SHEET

TUBE STL-100
S/N 101
DATE 6/?/60

TEST PARAMETERS

E_f(V)	12.6	I_w(ma)	8
I_f(A)	5.4	E_m(V)	109
E_b(V)	5600	I_m(A)	3.0
I_k(ma)	420	H (G)	460
μ_k	1.19		

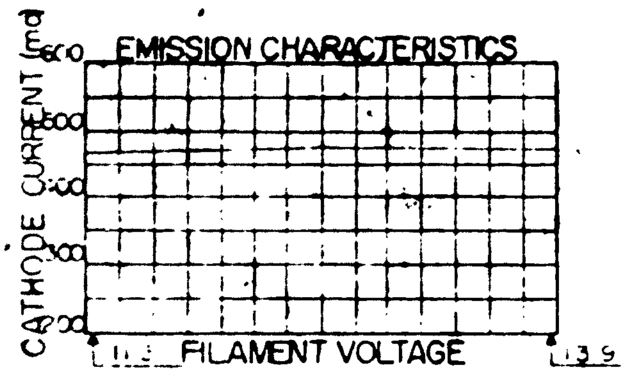
COLD TEST RESISTANCE (Ω)

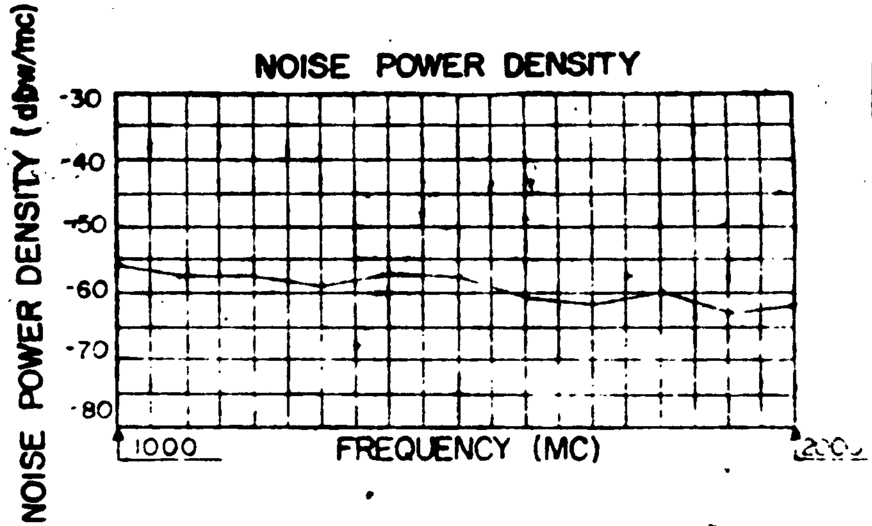
Rw-b	∞
Rw-w	0.1
Rk-b	∞
Rk-h	0.2

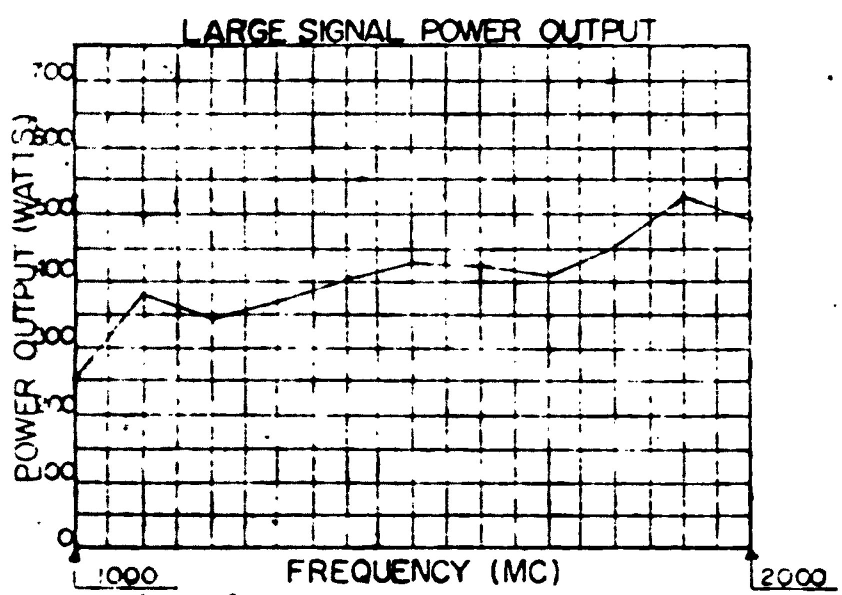
STABILITY (P_o WATTS)

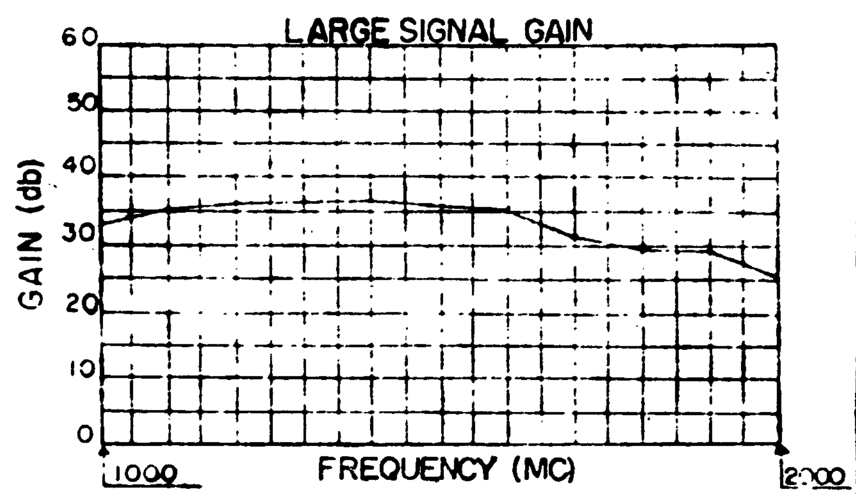
INPUT SHORT 0.01
OUTPUT SHORT 0.02

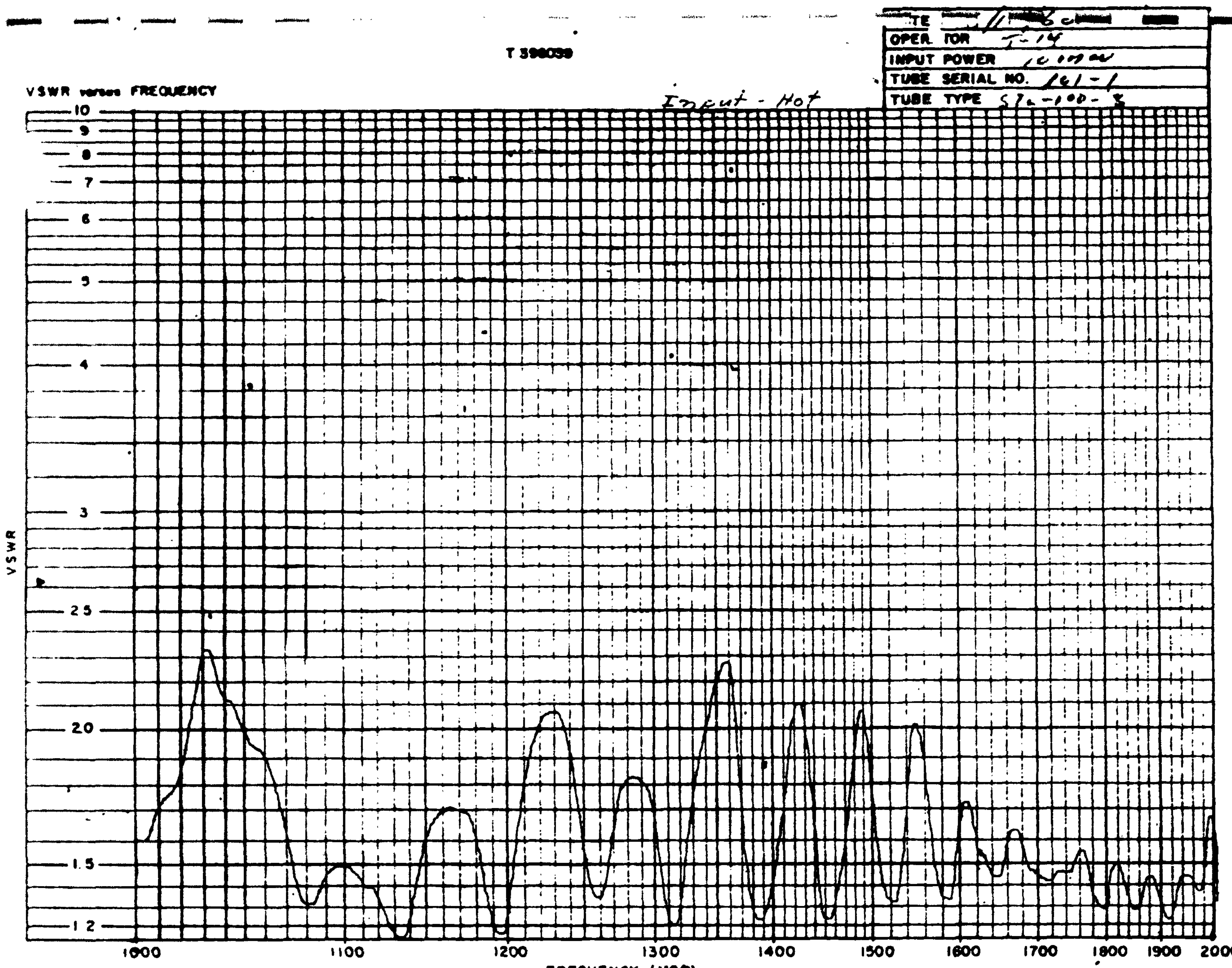
DRIVE RANGE
1000 18.8 db
1500 22.0 db
2000 13.0 db







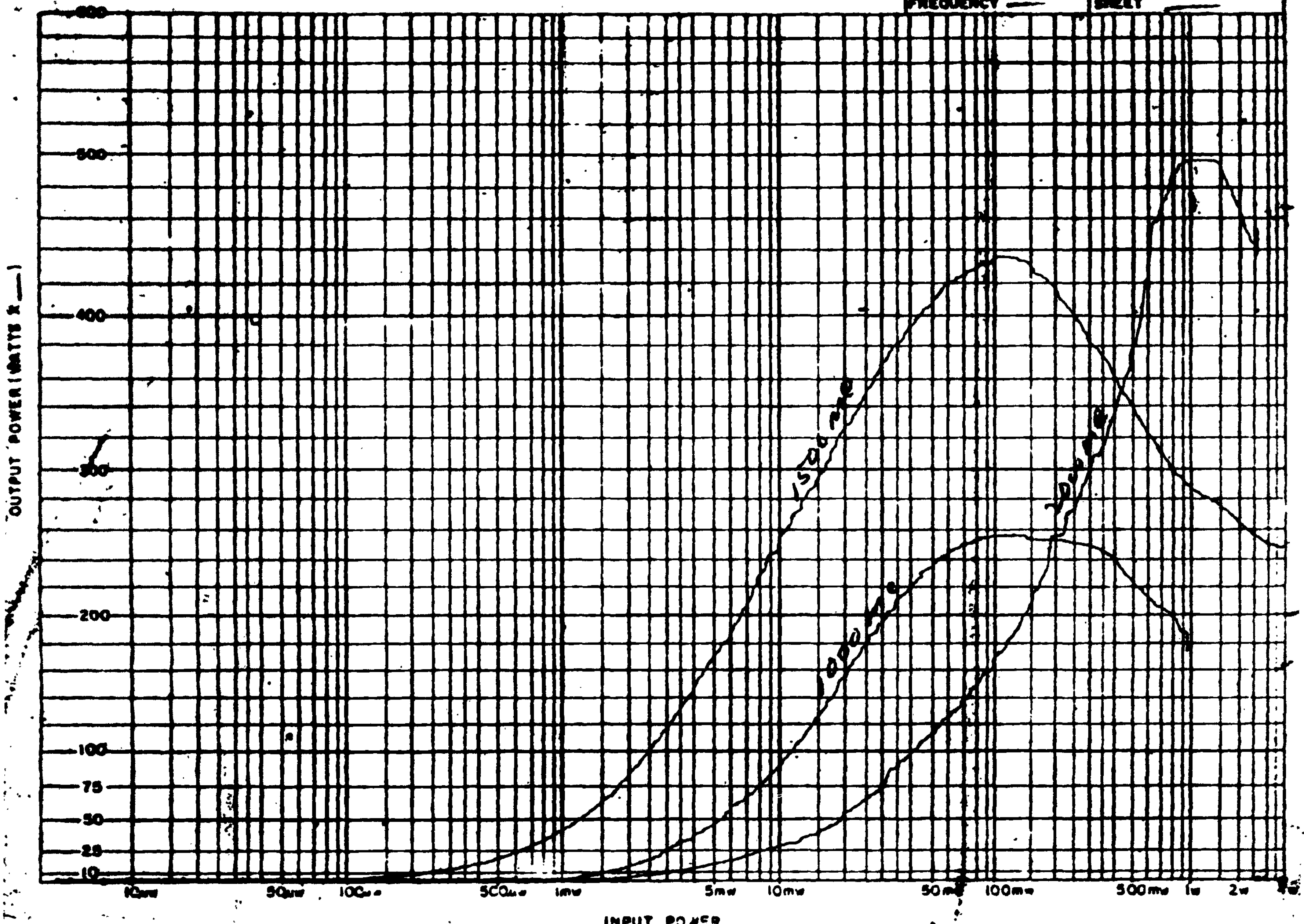



TE [redacted]
OPER TOR T-14
INPUT POWER 10 mw
TUBE SERIAL NO. 161-1
TUBE TYPE S7c-100-3
T 398039
VSWR versus FREQUENCY
Input - Hot
VSWR
10
9
8
7
6
5
4
3
2.5
2.0
1.5
1.2
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
FREQUENCY (MC/S)

T 390039

INPUT POWER versus OUTPUT POWER

DATE 6/14/60	TUBE TYPE
OPERATOR	SERIAL NO.
FREQUENCY —	SHEET



APPENDIX II

RECOMMENDED DEMONSTRATION AND TEST PLAN FOR

CALIBRATED HIGH SIGNAL SOURCE SG-( )/U

September 3, 1963

Prepared By:

W. J. Messmer
Section Head
Microwave Test Equipment

Approved By:

R. S. Markowitz
Manager
Equipment Division

American Electronic Laboratories, Inc.
Richardson Road, Colmar, Pennsylvania

RECOMMENDED DEMONSTRATION AND TEST PLAN FOR

CALIBRATED HIGH SIGNAL SOURCE SG-( )/U( )/U

1.0 Introduction

In order to demonstrate the capabilities of the Signal Source in producing stable, modulated, high power RF signals, the following demonstration and test plan is provided. These tests exercise each function of the equipment together with the associated circuitry. While it is not necessary to perform the test steps in order, the overall demonstration can be performed more simply if they are carried out in order.

2.0 Turn-On

Turn on the Signal Source following the procedure on pp 3-3 and 3-4 of the "Handbook of Operating and Maintenance Instructions for Signal Generator SG-( )/U". Allow, at least, one (1) hour warm-up.

3.0 Tests and Demonstrations

3.1 VHF Region

Set the Signal Generator controls for Band 2.(76-125 Mc). The RF signal paths for this band are shown on Table 1-3, page 1-22.

3.1.1 Set the Signal Generator to generate "Low-Power" at 80 Mc and 100 Mc (0.1 watt nominal) and measure this output at the LOW LEVEL OUTPUT 40-1,000 Mc connector on the RF Control Assembly (3A).

3.1.2 Set the Signal Generator to generate "Medium-Power" at 80 Mc and 100 Mc (1 watt nominal) and measure this output at the MEDIUM & HIGH LEVEL OUTPUT connector on the High Power TWT Unit A (4A).

3.1.3 Set the Signal Generator to generate "High-Power" at 80 Mc and 100 Mc (100 watts nominal) and measure this output at the MEDIUM & HIGH LEVEL OUTPUT connector on the High Power TWT Unit A (4A).

3.2 UHF Region

3.2.1 Band 5

3.2.1.1 Set the Signal Generator controls for Band 5 (250-500 Mc). The RF signal paths for this band are shown on Table 1-6, page 1-25.

3.2.1.2 Set the Signal Generator to generate "Low Power" at 250 Mc and 375 Mc (0.1 watt nominal). Measure the output at the LOW LEVEL OUTPUT 40-1,000 Mc connector on the RF Control Assembly (3A).

3.2.1.3 Set the Signal Generator to generate "Low-Power" at 500 Mc and connect a heterodyne frequency counter, through an appropriate attenuator, to the LOW LEVEL OUTPUT 40-1,000 Mc connector on the RF Control Assembly. Measure the output frequency (nominal stability 1 part in 10^6 per day) for a period of five (5) minutes.

3.2.1.4 Set the Signal Generator to generate "High-Power" at 350 Mc and 500 Mc. Be careful to follow the High Power TWT Operating Instructions, as applicable, on pp 3-4 to 3-7. Measure the power output (100 watts nominal) at the HIGH LEVEL OUTPUT 250-1,000 Mc connector on the High Power TWT Unit (4A).

3.2.2 Band 6

3.2.2.1 Set the Signal Generator controls for Band 6 (500-1,000 Mc). The RF signal paths for this band are shown on Table 1-7, page 1-26. Operate the Signal Generator for "Low-Power" operation at 750 Mc.

3.2.2.2 Amplitude modulate the signal at a rate of 10 Kc. Observe the RF output on a Spectrum Analyzer. Use a crystal detector to demodulate the signal and observe the resultant audio frequency signal on an oscilloscope.

3.2.2.3 Pulse modulate the signal with a 1.0 microsecond wide pulse at a rate of 1,000 pulses per second. Observe the RF output on a Spectrum Analyzer. Use a crystal detector to demodulate the signal and observe the resultant video signal on an oscilloscope.

3.3 SHF Region

3.3.1 Set the Signal Generator controls for Band 9 (4-8 Gc). The RF signal paths for this band are shown on Table 1-10, page 1-29.

3.3.1.1 Set the Signal Generator to generate "Low-Power" at 4.0 Gc and 6.0 Gc (0.1 watt nominal). Measure the power output at the LOW LEVEL OUTPUT 4,000-8,000 Mc connector on the RF Control Assembly (3A).

3.3.1.2 Set the Signal Generator to generate "Low-Power" at 8.0 Gc. Frequency modulate the signal at a rate of 20 Kc. Observe the output signal on a Spectrum Analyzer.

3.4 EHF Region

3.4.1 Set the Signal Generator controls for Band 18 (32-36 Gc). The RF signal paths for this band are shown on Table 1-17, page 1-36. Set the Signal Generator to generate "Low-Power" at 34 Gc (0.1 mw nominal). Measure the power output at the OUTPUT 26.5-40 Kmc flange on the RF Control Unit (3A).

4.0 List of Typical Test Equipment

3.1.1, 3.1.2, 3.1.3, and 3.2.1.2 Power Meter HP-431B or equivalent
Thermistor Mount HP-478A or equivalent
Appropriate Attenuators

3.2.1.3 Heterodyne Counter HP-5245L and HP-5253A or equivalent

3.2.1.4 Power Meter, Thermistor Mount and Attenuators, as above, or
Colorimetric Power Meter HP-434A or equivalent
Appropriate Attenuators

3.2.2.2 and 3.2.2.3 Spectrum Analyzer Polarad SA-84WA or equivalent
Detector Mount AEL or equivalent
Appropriate Attenuators

3.3.1.1 Power Meter as in 3.2.1.4

3.3.1.2 Spectrum Analyzer Polarad SA-84WA or equivalent
Appropriate Attenuators

3.4.1 Power Meter HP-431B or equivalent
Thermistor Mount HPR-486A or equivalent

5.0 Data Sheet for Demonstration and Test of Calibrated High Signal Source SG-( )/U

3.1.1	.46 w at 80 Mc	.7 w at 100 Mc
3.1.2	1.8 w at 80 Mc	2.7 w at 100 Mc
3.1.3	60 w at 80 Mc	50 w at 100 Mc
3.2.1.2	.225 w at 250 Mc	.095 w at 375 Mc
3.2.1.3	* Mc to	Mc
3.2.1.4	200 w at 350 Mc	180 w at 500 Mc
3.3.1.1	0.1 w at 7.2 Gc	
3.4.1	** +15 db at 34 Gc	

*Note 1 - Strong lock to the FM-6 was obtained and the frequency drift or instability was less than that measurable with the SPA Analyzer.

**Note 2 - Output at 34 Gc was 15 db above full scale on an SPA Spectrum Analyzer with vertical gain set at maximum and controls set for Log presentation.