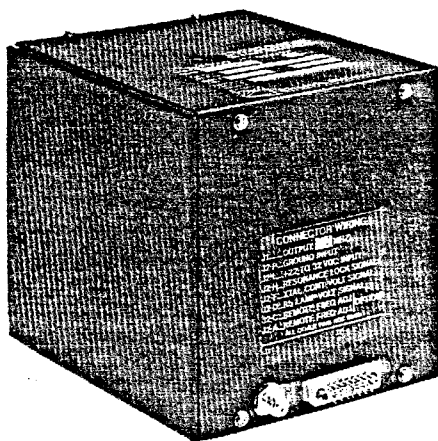




OPERATION AND MAINTENANCE MANUAL



MODEL FRK (H OR L)

RUBIDIUM FREQUENCY STANDARD

LIMITED WARRANTY

"The seller warrants that each article of goods sold by it will at the time of shipment be free from defects in materials furnished and workmanship performed by the seller. This warranty and seller's liability are limited either to granting credit or repairing or replacing, at seller's option, with reasonable promptness after return to seller of any article which is disclosed to seller's satisfaction to be defective, and only if said article is returned to the seller promptly after discovery of such defect and in no event later than *12 months* (or such other time period as may be specified in writing as a warranty period for a particular article) from the date of delivery thereof. Normal transportation charges in connection with an article returned shall be at the seller's expense, but only if the seller is responsible under the terms of this warranty. This warranty does not extend to any article which has been subject to misuse, neglect or accident, nor does it extend to any article which has been repaired or altered by other than the seller. **THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES EXPRESSED OR IMPLIED, INCLUDING ANY WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE. THE RIGHTS AND REMEDIES PROVIDED HEREIN ARE EXCLUSIVE AND IN LIEU OF ANY OTHER RIGHTS OR REMEDIES. IN NO EVENT SHALL SELLER BE LIABLE FOR CONSEQUENTIAL DAMAGES**".

Ball Corporation, Efratom Division, will be happy to answer any application or usage questions which will enhance your use of this unit. Please address your requests or correspondence to: Ball Corporation, Efratom Division, 3 Parker, Irvine, California 92718-1605, Attention: Sales Department, or call (714) 770-5000, Fax: (714) 770-2463.

European customers may contact: Ball Efratom Elektronik GmbH, Fichtenstr 25, 8011 Hofolding, West Germany, Telephone: 8104/90 40; Telex 529701; Fax: 08104/99 18.

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SECTION I

INTRODUCTION AND SPECIFICATION

1.1 INTRODUCTION.

The Efratom Model FRK Rubidium Frequency Standard (RFS) is a compact, atomic resonance-controlled oscillator which provides an extremely pure and stable sinusoidal signal of 10 MHz, at 0.5 Vrms into a 50 ohm load (refer to 1.5, Available Options, for other standard outputs). The unit is designed for use in high-performance communication systems, frequency standard equipment, advanced navigation equipment, and all other equipment and systems which require extremely precise frequencies/time intervals. With the proper input power provided and suitable cooling provisions, the FRK can be operated as a free-standing frequency standard for laboratory and testing purposes.

1.2 MANUAL CONTENT.

This manual contains information regarding the operation and field maintenance of the Model FRK RFS. Sections I and II contain general information concerning the unit. It is recommended that these sections be read completely prior to attempting operation. Section III provides the general theory of operation for the technician or engineer who requires a more thorough understanding of the unit's operation. Section IV provides the required information for performing field maintenance on the unit. An Outline Drawing, Schematic Diagrams, Assembly Drawings and Parts Lists are provided in the Appendix.

1.3 CONNECTORS.

All necessary connectors for inputs, output and monitor signals are easily accessible from the outer cover of the unit. The unit is manufactured using either a Winchester connector, P/N SRE-20PJ, which mates with SRE-20SJ and a SMA-type coaxial connector; or an optional eight-pin push-on connector with SMA-type coaxial connector may be ordered. For other connector configurations, refer to unit label for pin out information. (Other optional connectors are available; contact Efratom sales department).

1.4 ELECTRICAL PROTECTION.

The unit is protected against reverse polarity input power by both an internal fuse and diode. The output and monitor signals are short-circuit protected.

1.5 SPECIFICATIONS.

The pertinent performance specifications for the Models FRK-L and FRK-H are listed in Table 1.1.

Table 1.1. Specifications

CHARACTERISTICS	MODEL FRK-L	MODEL FRK-H
Output	10 MHz sine wave 0.5 rms into 50 ohms, floating ground (not floating with filter connector).	
Accuracy	Factory set to 10.0 MHz \pm 5E-11 at shipment.	
Signal to Noise (SSB 1 Hz BW)	120 dB at 100 Hz and 145 dB at 1000 Hz from carrier.	
Input Power	13W at 24Vdc, 25°C ambient; 22 to 32 Vdc; peak during warm-up, 1.8A.	
Warm-up Characteristics	<10 minutes to reach 2E-10 at 25°C ambient.	
Retrace	\pm 2E-11	
Long Term Stability	<4E-11/month	<1E-11/month
Short Term Stability	3E-11 t = 1 sec 1E-11 t = 10 sec 3E-12 t = 100 sec	1E-11 t = 1 sec 4E-12 t = 10 sec 1E-12 t = 100 sec
Trim Range	\geq 2E-9	
Voltage Variation	<1E-11/10% change (within input power limits stated above).	
Operating Temperature*	<3E-10 from -25°C to +65°C	<1E-10 from -25°C to +65°C
Storage Temperature	-55°C to +75°C	
Magnetic Field	<4E-13/AM ⁻¹ (3E-11/0.1 millitesla)	
Altitude	<1E-13/mbar (sea level to 21,000m).	
Humidity	95% MIL-T-5422F	
Shock	MIL-STD-810C, Method 516.2, Procedure 1	
Vibration	MIL-STD-810C, Method 514.2, Procedure 1	
Size	9.9 cm x 9.9 cm x 11.2 cm (3.9 in. x 3.9 in. x 4.4 in.)	
Weight	1.3 Kg (2.9 lbs); 1.55Kg (3.5 lbs.), with optional heat sink.	

* Highest operating temperature as measured at the baseplate. the highest ambient temperature the unit may be operated in is dependent on the heat transfer between the unit's baseplate and the ambient.

1.6 AVAILABLE OPTIONS.**Optional Standard Output Frequencies:**

- (1) 5 MHz Low Noise, @ 1.0 Vrms into 50 ohm load (See FRK-LN manual)
- (2) 10 MHz TTL

External (Remote) Frequency Adjustment Option

Additional Magnetic Shield

Low Operating Temperature Option: FRK-H $\leq 4E-10$ from -55°C to +65°C
FRK-L $\leq 6E-10$ from -55°C to +65°C

FRK

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SECTION II

INSTALLATION AND OPERATION

2.1 INTRODUCTION.

This section of the manual contains information regarding the installation and operation of the Efratom FRK. It is recommended that this section be read carefully prior to attempting operation of the unit.

2.2 SHIPPING AND RECEIVING INFORMATION.

The Model FRK is packaged and shipped in a foam-packed container. The unit was inspected mechanically and electrically prior to shipment. Upon receipt of the unit, a thorough inspection should be made to ensure that no damage has occurred during shipping. If any damage is discovered, contact Ball Corporation, Efratom Division, 3 Parker, Irvine, CA. 92718-1605. Telephone (714) 770-5000; Telex 685-635. European customers should contact Ball Efratom Elektronik GmbH, Fichtenstrasse 25, 8011 Hofolding, West Germany, Telephone 08104/90 40. If reshipment of the unit is necessary, the original container and packing should be used. If the original container is not available, a suitable container with foam-packing is recommended.

2.3 MOUNTING.

The unit's baseplate has been drilled and tapped to accommodate installation. The unit should be mounted with the aluminum thermal baseplate in contact with a flat metal surface. Mounting screws must not be allowed to penetrate the baseplate more than 0.2 inches (5mm). It is recommended that the mounting surface be designed to permit free access to the unit's frequency adjust potentiometer. Refer to outline drawing 703-203-1 in the appendix for mounting dimensions.

The heat transfer characteristics of the mounting surface must be adequate to limit the rise of the unit's baseplate to $< +65^{\circ}\text{C}$. The maximum allowable environmental temperature (T_a), for this mounting is:

$$T_a = 65^{\circ}\text{C} - (V_s \times I_s \times R_k)$$

Where: V_s = Supply Voltage in volts

I_s = Supply Current in amperes

R_k = Thermal Resistance between unit and ambient, ($^{\circ}\text{C}/\text{watt}$).

NOTE

A standard heat sink is an available option from Efratom; order Model 70223, Air Cooled Heat Sink.

2.4 POWER REQUIREMENTS.

The Model FRK requires an external power source capable of providing between +22 and +32 Vdc, with a minimum of 1.8 ampere output. The positive input voltage for the unit is to pin L with the negative return voltage on pin P of the panel connector.

In order to obtain the cleanest output signal close to the carrier, the maximum ac ripple on the supply voltage must be less than 1 mV peak-to-peak. If it is acceptable for the output frequency to contain spurious multiples of the powerline frequency (50, 60, or 400 Hz), the ripple can be higher, but in no case should the supply voltage AC \pm peak exceed the upper or lower input power limit of the unit.

2.5 INSTALLATION CONSIDERATIONS.

Some consideration must be given to the operating location of the unit regardless of its application. To minimize frequency offsets and/or non-harmonic distortion, the unit should not be installed near equipment generating strong magnetic fields such as generators, transformers, etc.

CAUTION

CARE MUST BE TAKEN TO ENSURE THAT THE MAXIMUM OPERATING TEMPERATURE IS NOT EXCEEDED, (+65°C AS MEASURED AT THE UNIT'S BASEPLATE). IN ADDITION, THE UNIT'S OUTER COVER IS A SPECIALLY DESIGNED MAGNETIC SHIELD; DAMAGE TO THE OUTER COVER COULD CHANGE IT'S SHIELDING CHARACTERISTICS.

2.6 FREQUENCY AND MONITORING SIGNAL OUTPUTS.

Figure 2.1 illustrates the standard Model FRK coaxial connector J1 with Winchester connector J2, and presents a brief functional description of the pin connections. Figure 2.2 presents the same information for the optional 8-pin, wirewrap or press-fit connector with coaxial connector.

- J1 10 MHz OUTPUT
 J2 A. Optional remote frequency adjust
 C. Optional remote frequency adjust
 D. Rb LAMP VOLTAGE SIGNAL
 F. XTAL CONT VOLTAGE SIGNAL
 H. RESONANCE LOCK SIGNAL
 L. +22 TO +32 VDC INPUT
 P. GROUND (connected to enclosure)

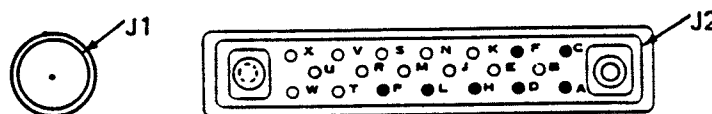


FIGURE 2.1. Winchester Connector and Pin Arrangement

1. 10 MHz OUTPUT
2. 10 MHz GROUND (isolated from enclosure)
3. GROUND (connected to enclosure)
4. +22 TO +32 VDC INPUT
5. RESONANCE LOCK SIGNAL
6. XTAL CONT VOLTAGE SIGNAL
7. Rb LAMP VOLTAGE SIGNAL
8. Optional remote frequency adjust
9. Optional remote frequency adjust

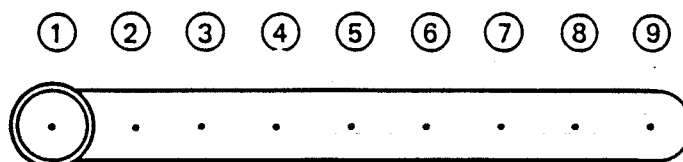


FIGURE 2.2. Optional Coaxial 8-Pin Wirewrap or Press-fit Connector and Connector Pin Arrangement

NOTE

Although Figure 2.1 illustrates the output signal (10 MHz) from the coaxial connector J1, the unit can be wired to provide the output signal to the Winchester connector, thus eliminating the need for the coaxial connector. For that configuration the output signal is to pin W, and the shield to pin T.

2.7 NORMAL OPERATION.

When the unit's output is terminated with a 50 ohm resistive load, and 28 Vdc is applied to J2 pins L (+) and P (-), the unit will immediately begin producing a 10 MHz signal from the crystal oscillator. Within approximately 10 minutes after application of input power, the unit will "lock". At that time the crystal is stabilized by the atomic resonant frequency.

2.8 FUNCTIONAL OPERATION TEST EQUIPMENT.

The test equipment required to functionally test the unit is listed in Table 2.1. Test equipment other than those items listed may be used provided that the performance equals or exceeds the MINIMUM USE CHARACTERISTICS as stated in Table 2.1.

TABLE 2.1. Functional Operation Test Equipment

ITEM	MINIMUM USE CHARACTERISTICS	TEST EQUIPMENT
DC Power Supply	Output Voltage: 22 to 30Vdc Output Current: 2.0 Amps Min.	Hewlett-Packard 6433B or 6296A
DMM (Digital Multimeter)	Voltage Range : 0 to 30 Vdc Accuracy: $\pm 1.25\%$ Resistance Range: 0 to 150	Fluke 8020A or 8000A
Freq. & Time Interval Analyzer	Internal Ref. Freq: 10 MHz Accuracy: $\pm 1E-12$ Stability: parts in 10^{12}	Hewlett-Packard 5371A Frequency & Time Interval Analyzer

NOTE

Throughout the test procedures in this manual the Model FRK will be referred to as the Unit Under Test, (UUT). All connections described or illustrated pertain to the standard Winchester connector; if the UUT has a different connector arrangement, make the described connections to the appropriate pins as described in 2.6 or the pin diagram accompanying the UUT.

2.9 OPERATIONAL FREQUENCY ACCURACY TEST.

2.9.1 Connect the equipment as shown in Figure 2.3.

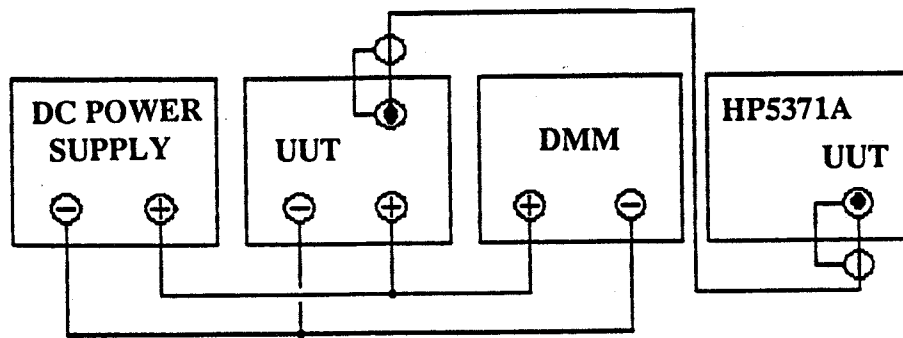


Figure 2.3. Operational Frequency Accuracy Test Setup.

2.9.2 Adjust the DC power supply controls to obtain a 28 ± 1.4 Vdc indication on the DMM.

2.9.3 Allow sufficient time for equipment to stabilize.

NOTE

The UUT requires 10 minutes stabilization to obtain the following frequency accuracy: $\pm 2E-10$ of the final frequency (calibrated frequency), or the frequency before turn off, (if turn off was within 24 hours and at the same environmental temperature). If the UUT was in storage, the worse case error = $\pm 2E-10$ warm-up + \pm last calibration accuracy or $\pm 5E-10$ factory setting at shipment, whichever is applicable + *aging specification.

The UUT requires 1 hour stabilization time to obtain the following accuracy: $\pm 2E-11$ of final frequency or frequency at turn off (if turn off was within 24 hours and at the same environmental temperature). If UUT was in storage, the worse case error = $\pm 2E-11$ warm-up +/- last calibration accuracy or $\pm 5E-11$ factory setting at shipment, whichever is applicable + *aging specification.

* Aging Specification: FRK-H $\leq 1X10^{-11}$ /month
FRK-L $\leq 4X10^{-11}$ /month

2.9.4 Follow the instructions in the HP5371A Frequency and Time Interval Analyzer Operation Manual to begin the test.

2.9.5 Allow sufficient time for the HP5371A to indicate the UUT OFFSET for the data you require. Verify that the UUT frequency offset is within the tolerance stated in the NOTE following Step 2.9.3.

NOTE

If the UUT is not within the stated tolerance limits, perform the Frequency Adjustment procedure, paragraph 4.4.1.2.

2.10 SHORT-TERM STABILITY TEST (ALLAN VARIANCE)

NOTE

If you have just completed 2.9 through 2.9.5, and the Allan Variance indications (as displayed by the HP5371A) are of the required averaging times, the test results as indicated are valid. If 2.9 was not performed continue with 2.10.1

2.10.1 With the equipment connected as shown in Figure 2.3, and the required stabilization time allowed, (refer to NOTE following 2.9.3), begin the test.

2.10.2 Allow sufficient time for the HP5371A to display the required data for the averaging times, and verify that UUT Allan Variance is within tolerances listed in Table 1.1 SPECIFICATIONS.

FRK

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SECTION III

THEORY OF OPERATION

3.1 INTRODUCTION

This section of the manual contains a general theory of operation, block diagram analysis, and detailed description of the FRK circuits. A simplified block diagram (Figure 3-1) is included to help clarify the text.

3.2 SIMPLIFIED BLOCK DIAGRAM

As shown in Figure 3-1, the Model FRK contains a Servo Assembly (A1), Lamp Board Assembly (A2), Power Supply Assembly (A3), Oscillator Assembly (A4), Synthesizer Assembly (A5), and a Resonator Assembly.

3.3 RUBIDIUM (Rb) OSCILLATOR

The Rb oscillator provides the 10 MHz signal. Section 4 of this manual contains complete troubleshooting and repair information, as well as detailed circuit descriptions. Refer to Appendix A for assembly photos, schematic drawings, and parts lists of assemblies specific to the FRK.

3.3.1 General Theory of Operation Rb. Freq. Standard

The FRK's highly frequency-stable output signals are obtained from a 10 MHz Voltage Controlled Crystal Oscillator (VCXO), whose frequency is referenced and locked to the atomic "resonance frequency" of rubidium (f_{Rb}).

The atomic reference frequency is provided by the 6.834 GHz ground-state hyperfine transition of the Rb87 (rubidium). The VCXO is locked to the f_{Rb} at approximately 6.834 GHz, by synthesizing a microwave signal, from the 10 MHz VCXO output, having a frequency in the vicinity of f_{Rb} . The microwave signal is used to excite the rubidium atoms that are contained within a microwave cavity (resonance cell). The frequency synthesis scheme is designed so that the VCXO frequency is exactly 10 MHz when the microwave frequency is equal to f_{Rb} . The frequency of the signal applied to the microwave cavity can be maintained equal to f by generating an error signal to servo the VCXO through its control voltage.

Light from a rubidium lamp is generated by an rf excited plasma discharge. The light passes through the resonance cell, where it interacts with the enclosed rubidium atoms. Some of the light is incident upon a silicon photo detector photocell within the resonance cell. When the applied microwave frequency is equal to the f_{Rb} , the rubidium atoms resonate within the microwave field in the cavity; this causes the light reaching the photo detector to decrease. This behavior is illustrated by the left, uppermost curve in Figure 3-2.

FRK

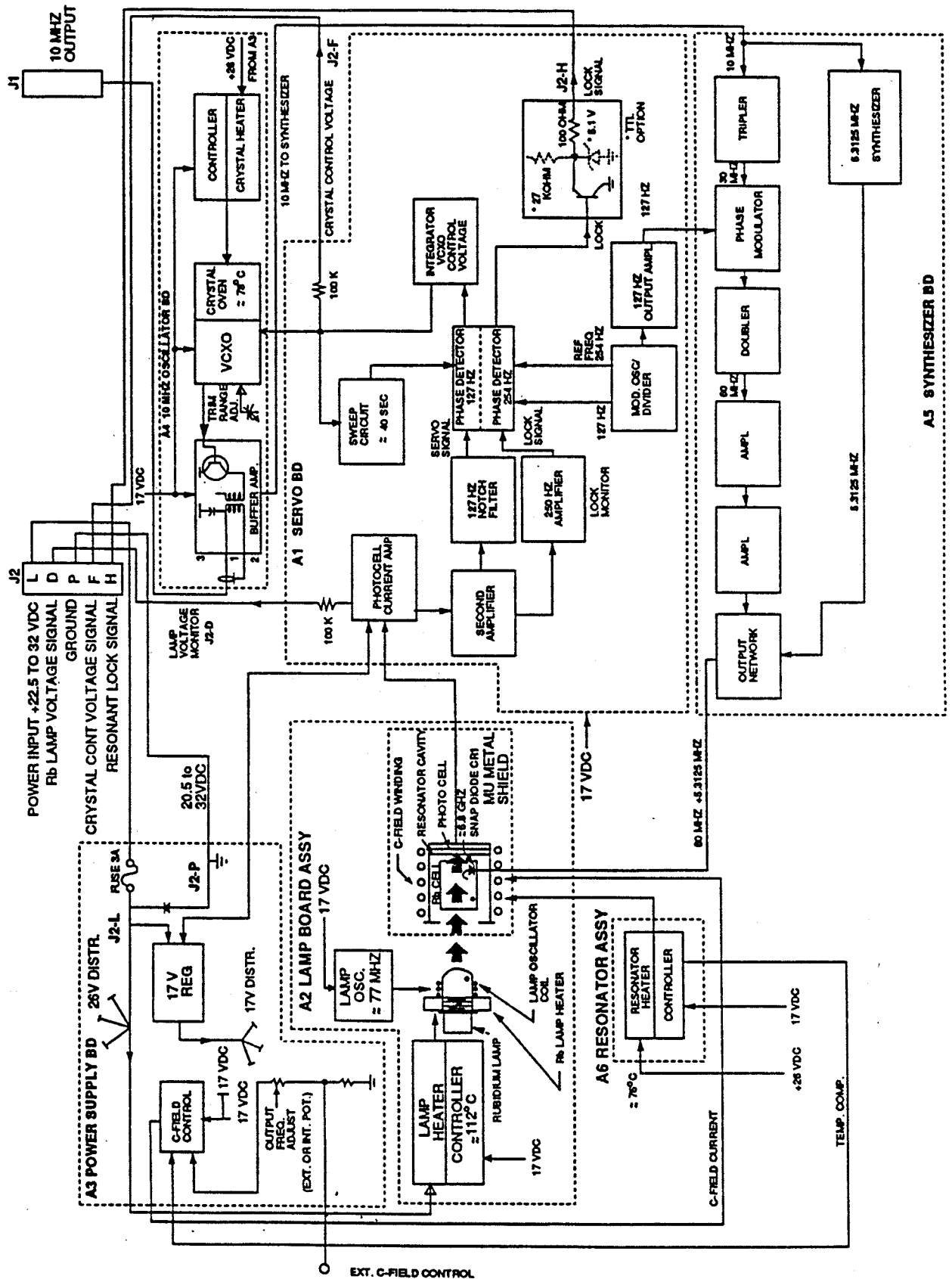


Figure 3-1. FRK Block Diagram

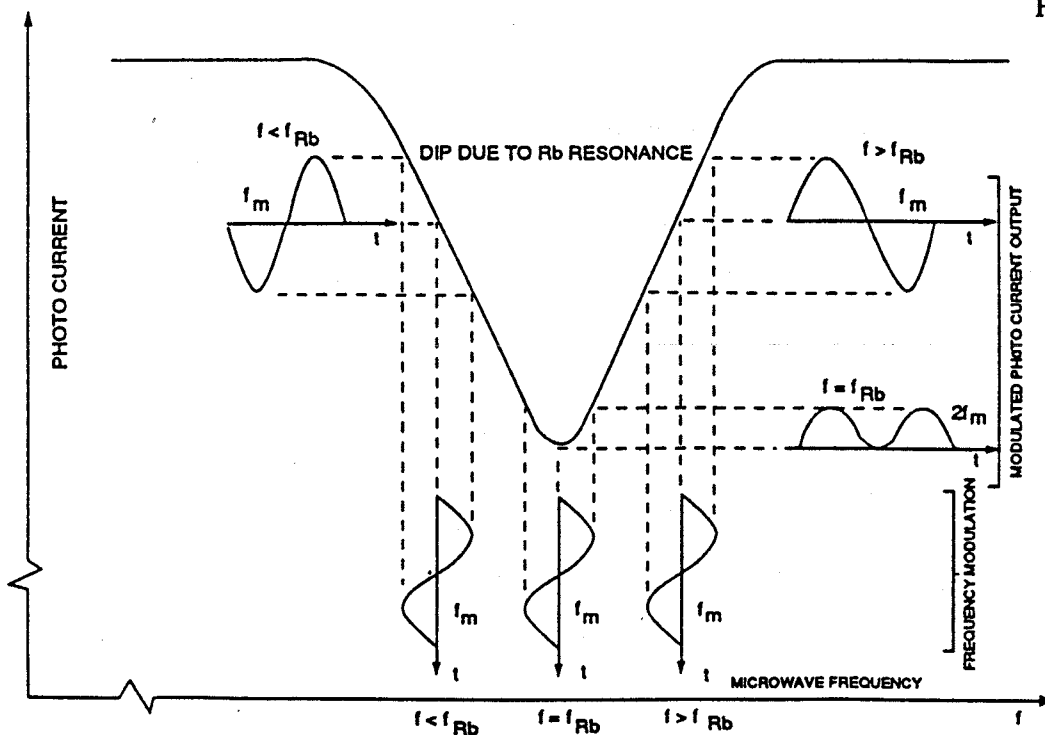


Figure 3-2. Derivation of Modulation Signal

The rubidium oscillator is a passive device, meaning that the atoms themselves do not produce a self-sustaining oscillation. Nevertheless, the atoms can be viewed in their simplest form as a high-Q, ($Q \sim 10^7$) series-resonant tank circuit that is resonant at the hyperfine frequency (~ 6.8 GHz for rubidium atoms). The voltage source driving the tank is the microwave input coming from the Modulator/Synthesizer of the FRK, and the LCR components are the rubidium atoms contained in the optical package of the FRK. The atomic resonance is detected by optical means and involves a process known as "optical pumping", by which the atoms are raised to a higher state through the absorption of light energy.

The two lower levels, A and B, are the ground state hyperfine levels. Statistically speaking, the rubidium atoms will be equally divided between these two levels in the initial state. But if the atoms are irradiated with microwave energy at the hyperfine frequency, then those atoms in Level A will make a transition to level B and vice versa, without changing the overall distribution between the two levels (statistically). The hyperfine frequency (f_{Rb}) is related to the hyperfine energy level separation E (joules) = $h f_{Rb}$ (Hz), where h = Planck's Constant = 6.6262×10^{-34} joule/Hz. A third and higher energy state exists that is referred to as level C.

Level C is an optically excited state of the atom that is normally vacant; (for rubidium, this C level state can be excited by infrared light energy at the proper wavelength). Transitions to level C are known as "optical transitions" and can occur from either of the two hyperfine energy levels, A or B. If only the spectral wavelength corresponding to one of the hyperfine levels is introduced, only the atoms at that hyperfine level will make the transition to level C. This condition can be generated by filtering out the spectral wavelength corresponding to one of the hyperfine levels.

If the light energy injected into the resonance cell corresponds to the wavelength required for level A to C transitions, the rubidium atoms at the A level will absorb some of the light. The absorption of light raises those atoms to the C-level energy state. After a short time, the atoms that were raised to the C level will emit a photon of the same wavelength that caused the energy level to increase; they then return to the ground state hyperfine level, redistributing themselves (statistically) equally between levels A and B. The atoms which return to level A will again absorb the light and be raised to level C, where they will remain for the short time before emitting the photon and again redistributing themselves between the two hyperfine energy levels A and B. By this means, optical pumping can be used to produce a population difference between the two hyperfine levels, whereby all of the atoms are pumped into one hyperfine level (for the preceding situation, level B). Once this condition exists, there are no atoms left in level A to be excited to level C and the light is

not the proper wavelength to excite the atoms in level B to level C, therefore the light is unattenuated after passing through the resonance cell.

As discussed earlier, if a microwave field corresponding to the hyperfine frequency were applied, the atoms at level B would make a transition to level A and be available for excitation to level C by the light beam. Since each excitation of an atom in level A is accomplished by the absorption of a light photon, the net effect of applying the microwave field is to cause attenuation of the light beam. Figure 3-3 pictorially illustrates the optical pumping process.

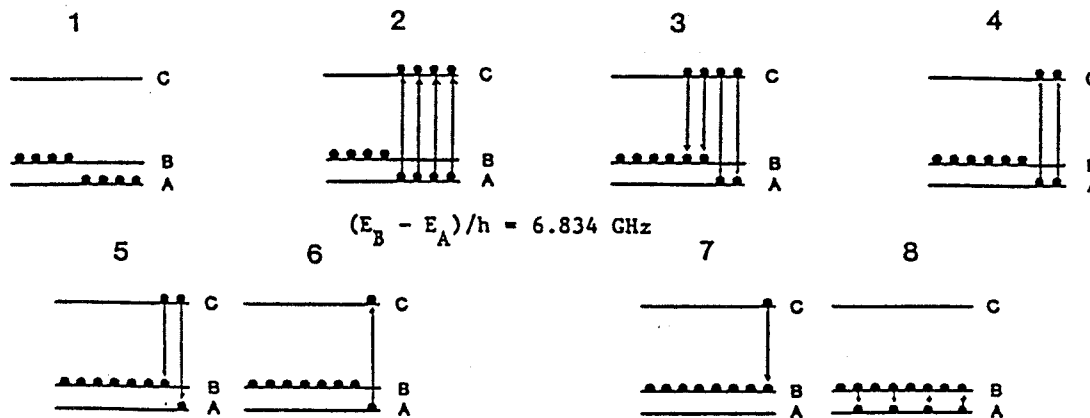


Figure 3-3. Optical Pumping Process Illustrated

If the overall energy level were to remain constant, there would be no way to generate an error signal for VCXO frequency correction. By frequency modulating the microwave signal, the light from the rubidium lamp appears to vary in intensity at the same modulation rate. This variation in the light intensity is effective at <0.1% of the overall intensity of the light. The photocell, within the cavity, detects the variation in light intensity. The servo board in the FRK uses this signal to indicate atomic lock and to generate the correction signal for the VCXO if the VCXO should drift off frequency.

Figure 3-4 is a block diagram of the FRK unit, which consists of a servo board assembly, lamp board assembly, power supply assembly, crystal oscillator assembly, synthesizer board assembly, and the physics package (consisting of the resonator assembly, Rb lamp, etc.).

3.3.1.1 Resonant Signal/Lock Signal Logic

When light from the rubidium lamp strikes the photocell contained within the resonator, the photocell generates a current proportional to the intensity of the light. By modulating the rf signal injected into the resonator, (at 127 Hz), the light striking the photocell will vary at the modulation rate, (127 Hz), and the photocell output current will vary at the same modulation rate (127 Hz).

When the rf being injected into the resonator is exactly equal to f_{Rb} , the 127 Hz modulation varies the light signal around the null point of the photocell current. (Minimum light = minimum photocell current.) When the light signal varies around the photo current null point, the photocell output varies at twice the fundamental frequency, or 254 Hz. It is this 254 Hz signal that is used to generate the lock indicator signal. The lock indicator signal is the primary indicator that the unit is operating normally. If the rf signal, (which is synthesized from the 10 MHz VCXO), drifts off frequency ($rf < f_{Rb}$ or $rf > f_{Rb}$), the photocell output reverts to the fundamental 127 Hz rate. The phase of the 127 Hz indicates if the rf is $< f_{Rb}$ or $> f_{Rb}$ and this phase information is used to servo the VCXO in the proper direction so that $rf = f_{Rb}$. This principle can be seen in the lower three sine waves labeled MODULATION (127 Hz), in Figure 3-2.

3.3.1.2 FRK Resonator

The function of the resonator is to provide the correct signal to the servo board in order to control the frequency of the crystal oscillator. The step recovery diode, the resonator coil, the resonator cavity, and the resonator thermostat all contribute to the overall functioning of the resonator in the following ways:

a. Step Recovery Diode

The 60 MHz and 5.3125 MHz signals from the synthesizer board are applied to the step recovery diode. When it conducts, it produces the harmonics of the 60 MHz and 5.3125 MHz signals (mixed). The fundamental frequency and harmonic frequencies are input to the resonant cell via a resonant loop. The resonant cell and loop are tuned to select the 114th harmonic, which corresponds to the resonant frequency of rubidium. The "response of the Atoms" is detected by the photocell that supplies the correcting signal to the servo board.

b. Resonator Coil

The resonator coil provides a magnetic field around the resonator cavity. This magnetic field is called the "C-Field". The strength of the C-Field is controlled by the voltage divider network located on the power supply board of the FRK. The adjustment of the C-Field is used for the fine tuning of the output frequency of the FRK.

c. Resonator Cavity

The resonator cavity temperature is elevated and maintained between 75° C and 78° C, depending upon the actual requirements of the FRK by the resonator thermostat.

3.3.1.3 Servo Board

The primary function of the servo circuit is to provide the crystal control voltage for the 10 MHz VCXO. The control voltage is derived by comparing the phase of the 127 Hz modulation signal with the phase of the photocell signal. The secondary function is to provide the monitoring signal for the lamp operation, the atomic resonant lock circuit, and the VCXO monitor control voltage.

Other major components of the servo board are the synchronous demodulator, integrator, sweep control circuit, and the lock monitor circuits.

3.3.1.4 Lamp Board

The lamp board contains the lamp exciter circuits and lamp-housing heater circuits. The function of the lamp board is to ignite and maintain ignition of the Rb lamp, and to provide the required heating necessary to maintain the lamp housing at approximately 115° C. The Rb lamp is mounted in a temperature-controlled housing.

3.3.1.5 Power Supply

The internal power supply provides the unregulated, filtered voltages for the Rb lamp heaters, oscillator heater, and resonator heaters, in addition to providing the filtered and regulated voltage for the unit's operation. The input voltage line is fuse and diode protected against reverse polarity inputs.

The power supply board accepts +22 to +32 Vdc input voltage, and provides +22 Vdc, until the Rb lamp ignites, at which time the power supply is switched to +17 Vdc.

3.3.1.6 10 MHz Oscillator

The purpose of the 10 MHz oscillator is to provide a stable 10 MHz signal to the output connector and to the synthesizer. The oscillator board contains the VCXO, the crystal oven and thermal control, and a buffer amplifier. The 10 MHz signals are transformer coupled to the output connector J1 and to the synthesizer circuit.

The 10 MHz VCXO crystal is mounted in a temperature controlled oven. The oven is heated by a heater transistor.

3.3.1.7 Synthesizer

The 10 MHz signal from the crystal oscillator is applied to the input of a frequency tripler. A portion of the 10 MHz sinewave signal from the crystal oscillator is converted to a TTL compatible trigger signal. Power for the TTL circuits is provided by the voltage regulator VR1. The 10 MHz TTL signal is divided down and recombined so that the final TTL signal is a 5.3125 MHz signal. This 5.3125 MHz signal is mixed with a 60 MHz output of the doubler/amplifier stage of the synthesizer, and routed to the step recovery diode in the resonator circuit.

SECTION IV

MAINTENANCE, TROUBLESHOOTING, AND REPAIR

4.1 INTRODUCTION

This portion of the manual provides procedures for performing maintenance on the FRK.

NOTE

If the unit should require service within the warranty period, contact Ball Corporation, Efratom Division for repairs. Refer to warranty page for addresses and phone numbers of the repair center closest to you.

4.2 TEST EQUIPMENT

The required test equipment to ensure normal operation is listed in Table 4.1. Test equipment other than those items listed may be used, providing that the substitute equipment meets or exceeds the "Minimum Use Specifications" as listed in Table 4.1. If the required test equipment or its equivalent is not available, it is recommended that the unit be sent back to the Efratom factory whenever service is required.

Table 4-1: Required Test Equipment - Performance Tests & Trouble-shooting (TS)

INSTRUMENT	REQUIRED CHARACTERISTICS	USE	MODEL (or equivalent)
DC Power Supply (optional)	Output Voltage: 0 to 30 Vdc. Output Voltage: 2.0 Amps Min.	Perf. Test	Hewlett-Packard 6433B or 6296A
Adj. Frequency Standard	A.V. (t = 1 sec) $\leq 5E \times 12$	Perf. Test	Hewlett-Packard 105B
DMM (Digital multimeter)	Voltage Range: 0 to 30 Vdc Accuracy: $\pm 1.25\%$ lv, Resistance Range: 0 to 150 Ohms	Perf. Test/TS	Fluke 8000A or 8020A
RF Voltmeter	10 MHz, true rms	Perf. Test/TS	Racal Dana 9300B
Freq. and Time Interval Analyzer	Internal Ref. Frequency: 10 MHz, $\pm 1E-12$, Stability: parts in 10^{12}	Perf. Test	Hewlett-Packard 5371A or 5372A (App. Note 358-12)
Phase Comparator	Analog voltage output	Perf. Test	Hewlett-Packard K34-59991A
Precision Potentiometer	500K	Perf. Test	
Resistive Load	Feed-thru type, 50 ohms	Perf. Test	Hewlett-Packard 10100C
Timer	Capable of indicating 1 to 15 mins.	Perf. Test/TS	Any timepiece
Ref. Freq. Standard	Output: 10 MHz, $\pm 2E-12$ Accuracy	Perf. Test	Must be traceable to NIST (1)
Linear Recorder	0-10 Vdc Full Scale, 1-10 cm/hr	Perf. Test	Tracor 888
Temp. probe	Capable of measuring -50°C to 150°C	Perf. Test	Fluke 80T-150
Frequency Counter	5 MHz . 125 MHz	Perf. Test/TS	Fluke 1910A
Decade Resistance	0 > 9.999999 Mohm	Perf. Test/TS	I.E.T. Model RS200
Mixer/IF Amp.	Low noise, wideband limiting amplifier	Perf. Test	HP K79-59992A

(1) Efratom Modular Frequency System with interface to a GPS receiver recommended.

4.3 PERFORMANCE VERIFICATION TESTS

4.3.1 Output Level Test

- (1) Connect the UUT as shown in Figure 4-1.
- (2) Apply dc power and allow the UUT to stabilize (> 10 minutes).
- (3) Measure output level with a rf voltmeter, using a 50 ohm resistive termination. Record the voltage level of output.
- (4) Observed voltage level must be .5 Vrms. +30%, -0%.

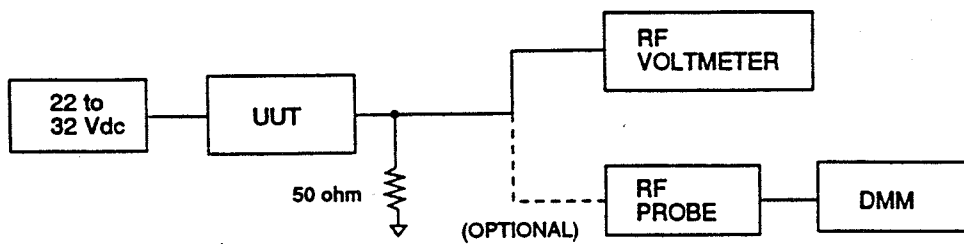


Figure 4-1. Output Level Test Configuration

4.3.2 Frequency Offset Test

- (1) Connect the Unit (UUT) and the test equipment as illustrated in Figure 4-2. (As an alternative, the HP5371A may be used to measure frequency offset. Contact a HP field engineer for details.)
- (2) Adjust chart recorder pen position to center scale for 0 volts input.

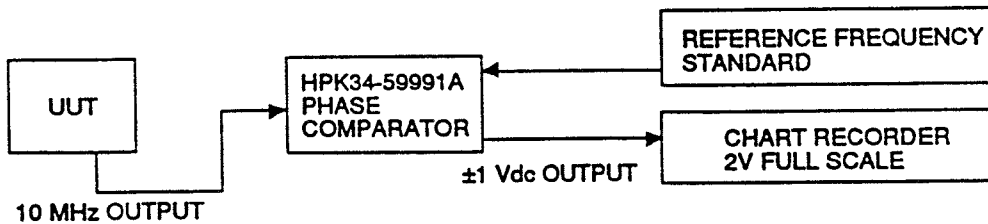


Figure 4-2. Frequency Offset Test & Long-term Stability Test Configuration

- (3) Ensure that the equipment has had sufficient time to warm-up. (The UUT requires 1 hour to stabilize.)

NOTE

The maximum temperature fluctuation must not exceed 2° C.

- (4) Monitor phase comparator output voltage on the chart recorder for 15 minutes. Calculate the the fractional frequency offset ($\Delta f/f$) from the phase comparator output voltage change over time ($\Delta V/\Delta t$) according to the equation:

$$\text{Fractional Frequency Offset} = \frac{\Delta V}{\Delta t} \cdot \frac{1}{10 \text{ MHz} \cdot V_{p-p}}$$

Where: $\Delta V/\Delta t$ = Slope of phase comparator output in volts/sec over a 15 min. interval (t in sec.).
 V_{p-p} = Output voltage swing of phase comparator for 360° phase shift.

For the HP K34-59991A, the fractional frequency offset = $\frac{\Delta V}{\Delta t} \times 5E-8$ sec/volt.

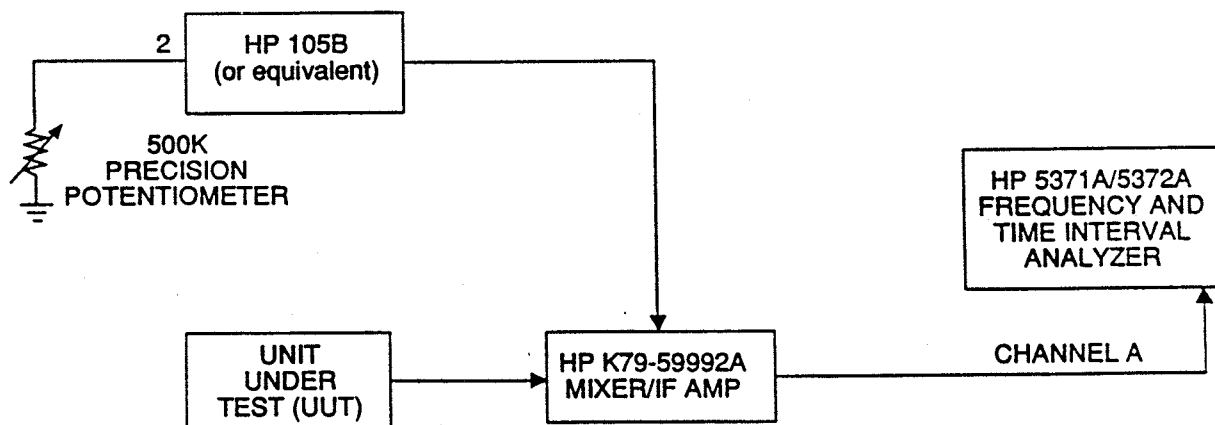
(5) Verify that the fractional frequency offset is within the required limit.

4.3.3 Frequency Retrace Test

- (1) Connect the UUT as shown in Figure 4-2.
- (2) Apply dc input power to the UUT.
- (3) Allow at least 1 hour for the UUT to stabilize. Measure and record the output frequency offset per Section 4.3.2, Step 4.
- (4) Disconnect input power to the UUT for 24 ± 2 hours.
- (5) Apply dc input power to the UUT.
- (6) After one hour of operation, measure and record the output frequency offset per Section 4.3.2, Step 4.
- (7) Determine the absolute value of the difference between the offsets marked in Step 3 and Step 6. The difference must be $\pm 2E-11$.

4.3.4 Short-term Stability (Root Allan Variance) Test

- (1) Connect the UUT as shown in Figure 4-3.



NOTE:

The 1 sec. Allan Variance of the Adjustable Frequency Standard must be much better than the 1 sec. Allan Variance of the UUT.

Figure 4-3. Short Term Stability and Signal Output Tests.

- (2) Apply dc input power. Allow UUT to stabilize (about 1 hour).
- (3) Refer to the HP 5371A/5372A manual and Application Note 358-12, for specific details regarding measurement of Root Allan Variance using the HP5371A/5372A. If necessary, contact local HP field engineer for assistance. Tune HP 105B to produce 10 Hz IF frequency. Measure the root Allan Variance (A.V.) at 1.0 second using 100 data samples. The measured A.V. must be $\leq 3 \times 1E-11$ (for FRK-H. Since the dominant source of frequency instability at 1 sec. through 100 sec. is white FM noise, root Allan Variance at 10 sec. and 100 sec. can be calculated using the expressions:

$$A. V._{(t=10 \text{ sec.})} = A. V._{(t=1 \text{ sec.})} / \sqrt{10}$$

$$(A. V._{(t=100 \text{ sec.})} = A. V._{(t=1 \text{ sec.})} / \sqrt{100})$$

The calculated A.V. for 10 sec. must be $\leq 1E-11$ ($4E-12$ for FRK-H). The calculated A.V. for 100 sec must be $\leq 3E-12$ ($1E-12$ for FRK-H)..

4.3.5 Long-term Stability Test

Long-term stability refers to slow changes in the average frequency, with time due to secular changes in UUT physics and or electrical circuitry. Long-term stability is usually expressed as fractional frequency offset ($\Delta f/f$), for a given period of time. The daily fractional frequency offsets can be plotted to show the long-term stability.

NOTE

The long-term stability test should be performed only after the UUT has been operating continuously a minimum of 48 hours. The frequency of the UUT should be measured and recorded each day to establish the drift rate.

- (1) Connect the equipment as shown in Figure 4-2.
- (2) Per Section 4.3.2, Step 4, compute and record the fractional frequency offset every 24 hours over a period of 15 days.

NOTE

It is recommended to plot the daily offset graphically and use this plot to estimate long-term aging (drift rate).

- (3) After completion of 1 month of aging, compute the drift rate of the UUT over the 1 month period.
- (4) If the drift rate over 1 month is $\leq 4E-11$ ($1E-11$ for FRK-H), the UUT has passed.
- (5) If the drift rate is $\geq 4E-11$ ($1E-11$ for FRK-H), the UUT has failed and must be retested (repeat step 2).
- (6) Depending on the off-time since the last operation, the environmental exposure, and the repairs performed, the unit may need to repeat this test a second time before meeting the original manufacturer's specifications.

4.4 FIELD MAINTENANCE, TROUBLESHOOTING, AND REPAIR

4.4.1 FIELD MAINTENANCE

Field maintenance consists of compensating for crystal aging and frequency adjustment. These are routine adjustments that may be made periodically to compensate for aging effects.

4.4.1.1 Crystal Aging Compensation

NOTE

The effects of crystal aging can be seen on a voltmeter. Attach a voltmeter probe to the crystal volts output monitor line of the FRK. A meter indication of $<+4$ Vdc or $>+12$ Vdc, indicates an adjustment of the crystal oscillator base frequency is required.

- (1) Ensure that the UUT has been operating continuously for at least 1 hour.
- (2) Locate the crystal trim adjustment on the FRK.
- (3) Unscrew the Philips head screw plug that acts as the adjustment access cover. The trimmer capacitor adjustment screw will now be visible.

NOTE

CLOCKWISE rotation of the adjustment will INCREASE the control voltage, while COUNTERCLOCKWISE rotation will DECREASE the control voltage.

- (4) Using the proper alignment tool, SLOWLY adjust the trimmer capacitor as necessary to obtain a $+8$ Vdc indication on a meter.

4.4.1.2 Frequency Adjustment

- (1) Monitor the fractional frequency offset per section 4.3.2.
- (2) Adjust POT (R21) on power supply board (accessed through baseplate) to obtain a fractional frequency offset that is within the required limits.

4.4.2 TROUBLESHOOTING AND REPAIR

Troubleshooting and repair consists of testing and repair of the FRK. This section contains information on fault identification and removal, repair, replacement, and calibration of the assemblies of the FRK.

NOTE:

THESE PROCEDURES ARE NOT ROUTINE ADJUSTMENTS AND PERFORMING THEM SHOULD BE CONSIDERED ONLY IN THE EVENT OF UNIT FAILURE.

a. Troubleshooting Flowcharts

A series of flow charts is provided to aid in the isolation of faults. Flowcharts are presented in logical fault isolation order and must be performed in the proper sequence given. The troubleshooting/repair procedures for the various subassemblies of the FRK are presented after each flowchart and are designed to permit the repair technician to identify the fault and replace and/or repair the subassembly.

b. FRK Disassembly

CAUTION

All FRK disassembly operations must be performed with power removed from the unit. Disassemble assemblies only as needed to make repairs.

- (1) Detach the cover from the FRK assembly by removing two 2mm screws on the connector face of the unit, then remove four 2mm screws that hold the bottom of the cover to the baseplate (see Figure 4-4). Once all six retaining screws are removed, hold the baseplate while gently pulling on the cover (it may be necessary to move the cover slightly from side to side as the FRK internal assembly is removed from the case).
- (2) Remove any of the outside PCB assemblies by removing the M2x6 screws that fasten the boards to the FRK frame at each corner (the servo and synthesizer boards have additional screws that must also be unfastened).
- (3) Once the mounting screws are removed, label all wires and coax (shielded wire) connections, and then remove each one (a soldering iron is required).
- (4) Disassemble the baseplate of the FRK by removing the lamp inspection cover and all other screws on the outside face of the baseplate. This frees the baseplate from the frame.

NOTE

The Q1 Pass Transistor will still be connected. Pulling the baseplate away from the frame rapidly may unintentionally break the wire connection of the transistor.

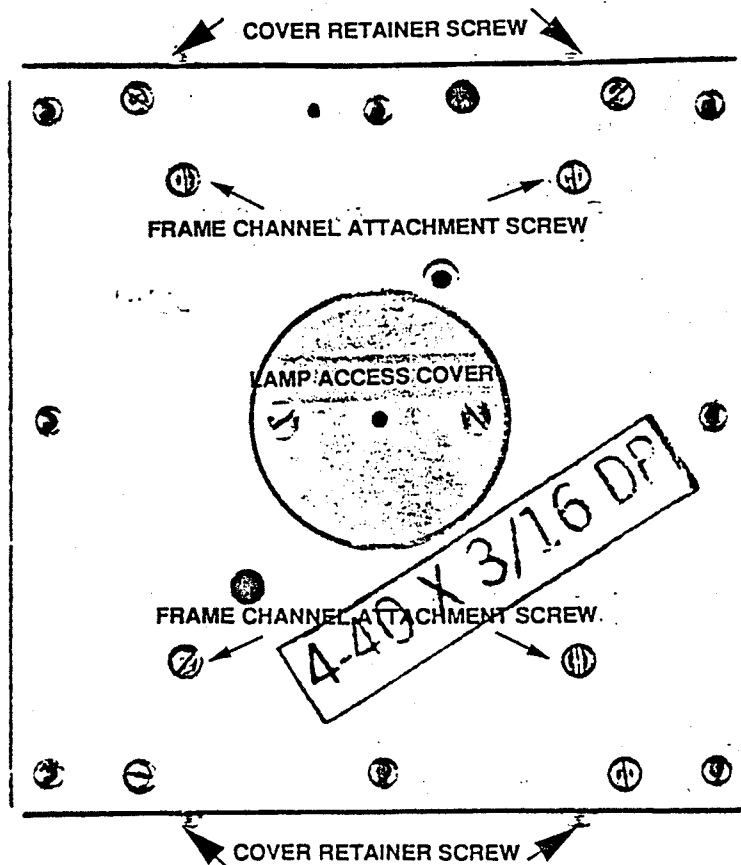


Figure 4-4. FRK Baseplate

FRK

- (5) The lamp board assembly and the metal container that is the exterior of the resonator assembly are located inside the frame channel. These two assemblies are accessed by removing four M2x6 screws from the four nut blocks that are located inside the frame channel. The resonator board is located inside the mu-metal canister of the resonator assembly. Figure 4-5 is a wiring diagram that illustrates how the FRK boards and the physics package are connected together.
- (6) Before the lamp assembly can be removed from the baseplate end of the FRK unit, all wires must be disconnected from each end of C1 and C2. These feedthrough capacitors (which are frame mounted) must be removed completely from the frame. Once this has been accomplished, removal of the two M2x6 screws at the opposite corners of the lamp PCB allows it to be lifted away from the interior frame channel.
- (7) Remove the resonator assembly from the connector end of the unit by unsoldering the 10 wires that connect the resonator to the other board assemblies of the unit. Disconnect the wires from the locations shown in Table 4-2.

Table 4-2. Resonator Disconnect Points

<u>Servo Bd.</u>	<u>Power Supply Bd.</u>	<u>Synthesizer Bd.</u>
A1E1	A3E21	A5E6
A1E5	A3E22	A5E7
	A3E23	
	A3E24	
	A3E25	
	A3E26	
	A3E27	
	A3E28	

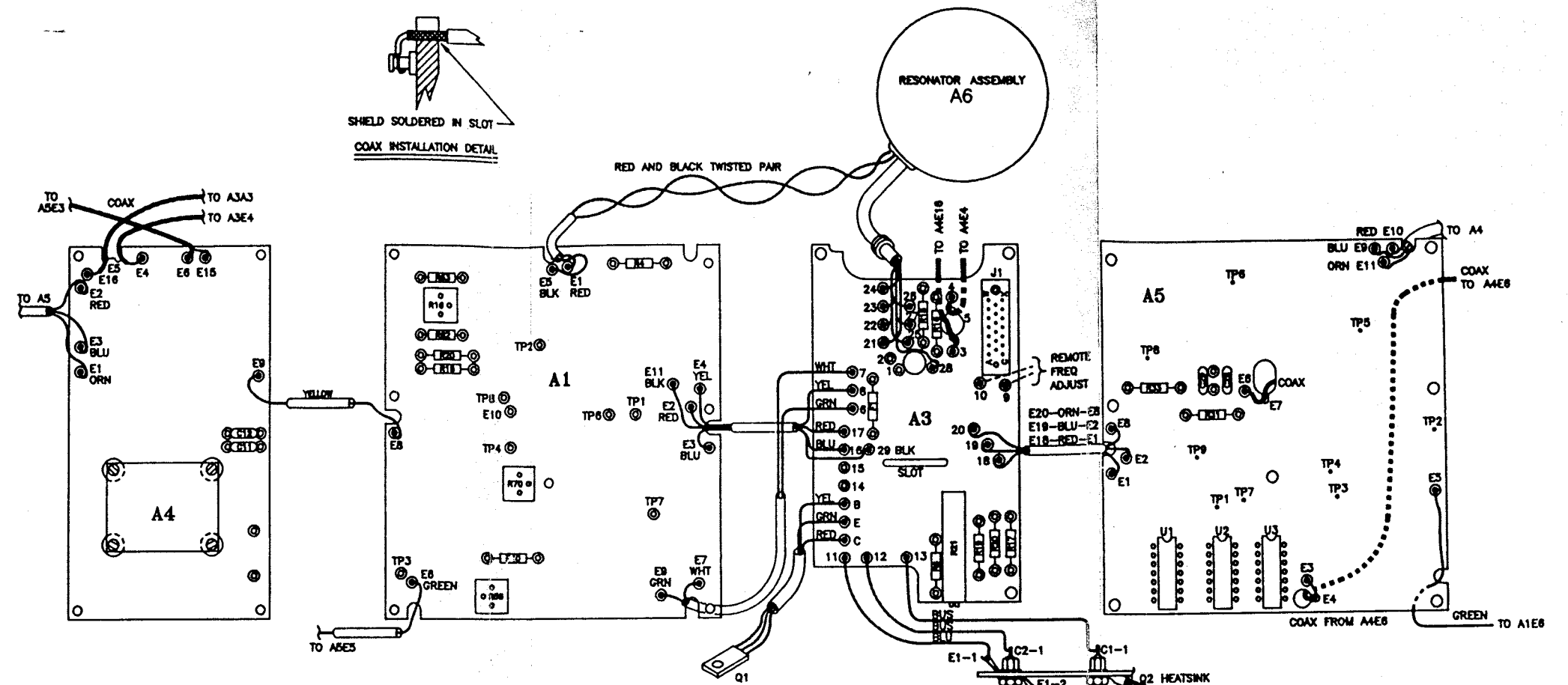
- (8) Remove the M2x6 screws at each corner of the resonator assembly PCB, allowing the entire resonator assembly to be removed from the interior frame channel.
- (9) The inner shield lid of the resonator can is assembled to the can with a tight mechanical fit. The lid is removed by gently tapping around the circumference of the lid's exposed lip.
- (10) Separate the resonator assembly's PCB from the inner shield can by removing the three M2 nuts spaced around the light entry hole in the PCB.
- (11) Having completed these steps, the resonator housing, with the heater control PCB attached, can be removed from the inner shield can for service.

The FRK can now be visually inspected for burned components or broken connections. Placed on a test bench and powered up, signal traces can also be obtained from the test points on the various board assemblies (refer to Section 4.4.2.5, Detailed FRK Circuit Descriptions).

NOTE

Disassembly of the FRK should be performed only to the level necessary to identify a fault (or faults). Excessive disassembly may introduce other problems into the unit, making it impossible to repair.

After repairs have been completed, and the FRK reassembled, refer to Section 4.3 for Performance Verification Tests that must be performed before the FRK is returned to service. Refer to Section 4.4.2.6 is alignment is required for any of the repaired or replaced assemblies.



WIRE LIST				
No.	FROM	TO	COLOR (AWG)	FUNCTION
1	A1E1	A6E9	RED (28)	PHOTOCELL
2	A1E2	A3E17	RED (24)	+17 VDC
3	A1E3	A3E18	BLU (24)	GND
4	A1E4	A3E8	YEL (24)	Rb LAMP MONITOR
5	A1E5	A6E8	BLK (28)	PHOTOCELL
6	A1E6	A5E5	GRN (24)	127 Hz SIGNAL
7	A1E7	A3E7	WHT (24)	RES LOCK SIGNAL
8	A1E8	A4E9	YEL (24)	XTAL CONT VOLTAGE
9	A1E9	A3E6	GRN (24)	XTAL OSC MONITOR
10	A1E10			TEST POINT-LAMP V
11	A1E11	A3E29	BLK (24)	
12				
13	A2E1	C1-2	ORN (24)	+28 VDC
14	A2E2	C2-2	RED (24)	+17 VDC
15	A2E3	E1-2	BLU (24)	GND
16				
17	A4E1	A5E11	ORN (24)	+28VDC (VA A3E20)
18	A4E2	A5E10	RED (24)	+17 VDC (VA A3E18)
19	A4E3	A5E9	BLU (24)	GND (VA A3E19)
20				
21				
22				
23	A4E15	A5E3	COAX	10 MHz
24	A4E6	A5E4	SHIELD	
25				
26	A5E1	A3E18	RED (24)	+17 VDC
27	A5E2	A3E19	BLU (24)	GND
28	A5E8	A6	COAX	RESONATOR
29	A5E7	A6	SHIELD	
30	A5E8	A3E20	ORN (24)	+28 VDC
31				
32				

WIRE LIST				
No.	FROM	TO	COLOR (AWG)	FUNCTION
33				
34	A3E11	E1-1	BLU (24)	GND
35	A3E12	C2-1	BUS (24)	+17 VDC
36	A3E13	C1-1	BUS (24)	+28 VDC
37				
38	A6E1	A3E21	ORN (28)	
39	A6E2	A3E24	BLU (28)	TWISTED PAIR
40	A6E4	A3E22	RED (28)	
41	A6E3	A3E23	YEL (28)	
42	A6E5	A3E25	WHT (28)	
43	A6E6	A3E26	BLK (28)	
44	A6E7	A3E28	GRN (28)	
45	A6E10	A3E27	BRN (28)	
46				
47				
48				

WIRE LIST					
No.	FROM	TO	COLOR (AWG)	FUNCTION	CONN PIN
104	A1E4	A3E8	YEL (24)	Rb LAMP MONITOR	J1-D
107	A1E7	A3E7	WHT (24)	RES LOCK SIGNAL	J1-H
108	A1E9	A3E6	GRN (24)	XTAL OSC MONITOR	J1-F
120	A4E4	A3E3	COAX	10 MHz OUTPUT	J1-W
121	A4E5	A3E5	SHIELD		J1-T
132	A3E1			GND INPUT	J1-P
133	A3E2			+28 VDC INPUT	J1-L
201	A4E16	A3E4	COAX	10 MHz OUTPUT	J1-X
202	A4E5	A3E5	SHIELD		
147	A3E9			REMOTE FREQ ADJ	J1-C
148	A3E10			REMOTE FREQ ADJ	J1-A

Figure 4-11. FRK Wiring Diagram

c. FRK Assembly Repair

If troubleshooting has indicated that the FRK assembly has failed and the assembly must be repaired instead of being replaced, the following sections provide repair guidelines.

SN6WRMAP3 SOLDER, per QQ-S-571, and a 35 to 40 watt soldering iron should be used to accomplish the soldering that might need to be done on the FRK.

CAUTION
Excessive heat can cause the etched circuit wiring to separate from the board material.

If it becomes necessary to solder in the general area of any of the high frequency contacts in the unit (terminal points), clean the contacts immediately upon completion of the soldering.

The adjustments, repair, or alignments required by the fault isolation flowcharts should be followed by the retesting of the procedure that led to the fault isolation to ensure the unit is functioning as required.

d. Overall FRK Troubleshooting (Fault Isolation Flowchart)

Figure 4-6 is the overall troubleshooting flowchart that should be followed to locate a fault in the FRK unit. For additional information, refer to the assembly drawings and schematics presented in Appendix B, and to the text in the following sections that describes the operation of the major FRK boards and circuits.

(1) Rubidium Lamp Replacement

Although this is seldom a cause for failure in the FRK (refer to 4.4.2.5 (2) for symptoms), the Rubidium lamp is replaceable. The Rubidium lamp is accessed by removing the two screws holding the Lamp Cover Plate to the baseplate (refer to Figure 4-8). A slotted access plate is beneath the cover plate. Once the access plate has been removed, the base of the lamp housing is visible.

CAUTION
The lamp housing is at the electrical potential of the unit (28 Vdc) and a short will occur if an attempt to remove the lamp is made with power applied to the unit. The lamp housing is extremely hot, as well. Extreme care must be exercised when removing the lamp to avoid burns.

Once all power to the unit is off, carefully unscrew the rubidium lamp and lift it from the housing (use a pair of needle nose pliers for this task). Make sure the replacement lamp is clean and that its surface is free of any oils or grease and screw the bulb into the housing. Once the bulb is firmly seated in the housing, replace the access plate and the Lamp Cover Plate, and replace the two screws previously removed.

Apply power to the FRK and, after allowing sufficient warm-up time, run a performance test to ensure that the unit is fully functional.

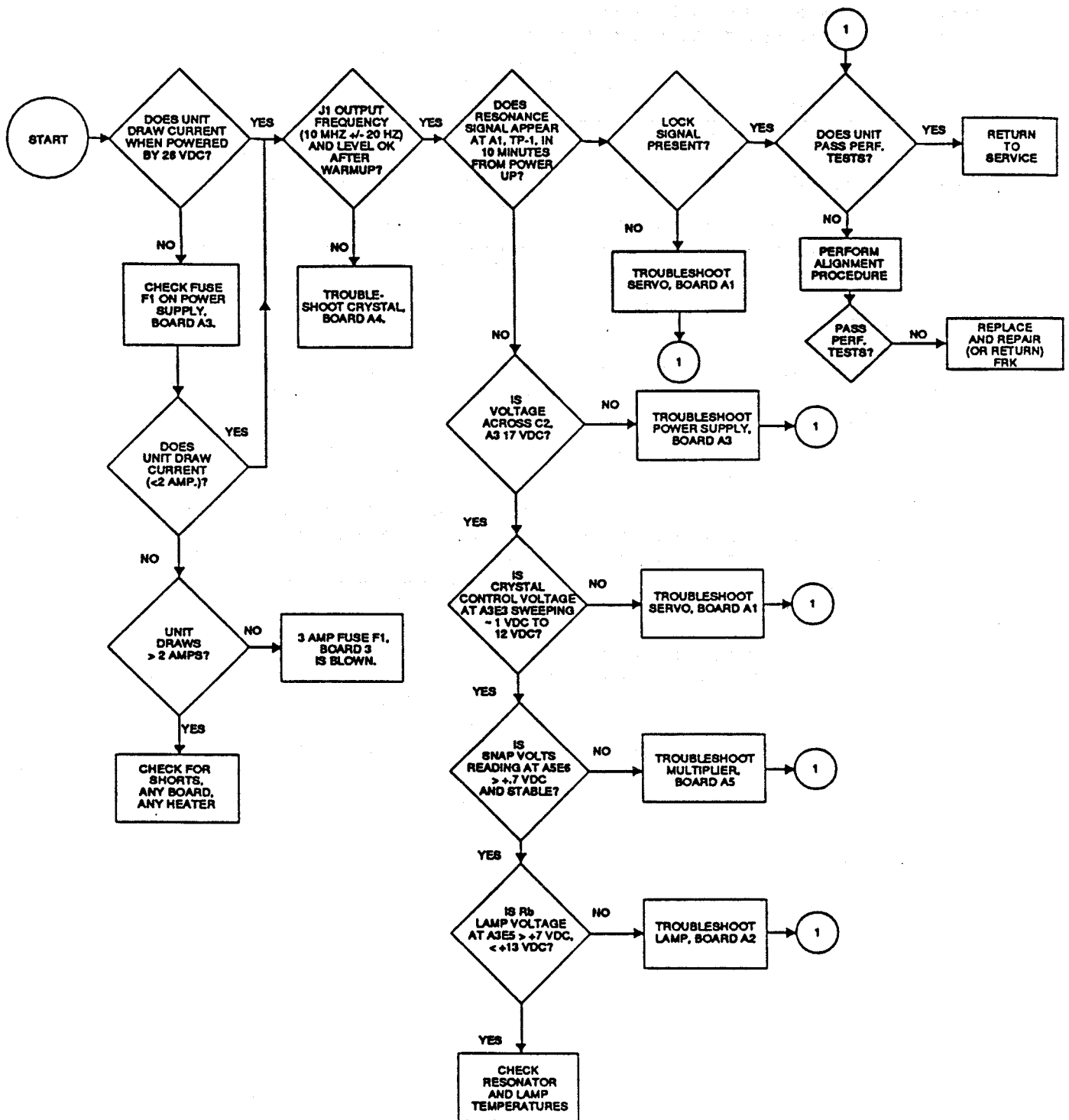


Figure 4-6. FRK Troubleshooting Overview

4.4.2.1 Detailed FRK Circuit Descriptions

a. Resonator Assembly (schematic 703-221)

The function of the resonator assembly is to compare the multiplied and synthesized output frequency of the crystal oscillator to the ground-state hyperfine transition frequency of ^{87}Rb . It provides a 127 Hz error signal to the servo board to lock the crystal frequency to the atomic transition.

(1.) Microwave Cavity - The microwave (resonator) cavity is constructed of silver plated copper and housed in a mu metal shield. It contains the rubidium resonance cell. The photocell is mounted in the bottom of the cavity and placed behind the Rb glass cell, directly in the light path of the Rb spectral lamp. The step recovery diode with coupling loop and the condenser assembly are located at the open end of the cavity. Cavity temperature is maintained by the resonator thermostat circuit. The C-field coil is wound on the outside of the copper microwave cavity.

(2.) Step Recovery Diode - The 60 MHz and 5.3125 MHz from the multiplier are summed at the output of the multiplier/synthesizer board and then applied to the step recovery diode. This diode, CR1, produces electromagnetic radiation having frequencies given by the expression $(60n + 5.3125m)$ MHz, where $n =$ a positive integer and $m =$ an integer. The diode is part of a tuned coupling loop, tuned to the 114th harmonic of 60 MHz ($n = 114$); the coupling loop is inside a microwave cavity that is tuned to the same frequency. The bandwidth of the microwave cavity assembly is wide in comparison with the bandwidth of the atomic transition (< 1 kHz), so that the atoms function as a narrow-band filter for the microwave signal. The diode can be replaced by gaining access to the light entry end of the resonator assembly PCB. An access hole in the PCB provides clearance to remove first the diode retaining screw and then the diode itself (refer to Figure 4-7).

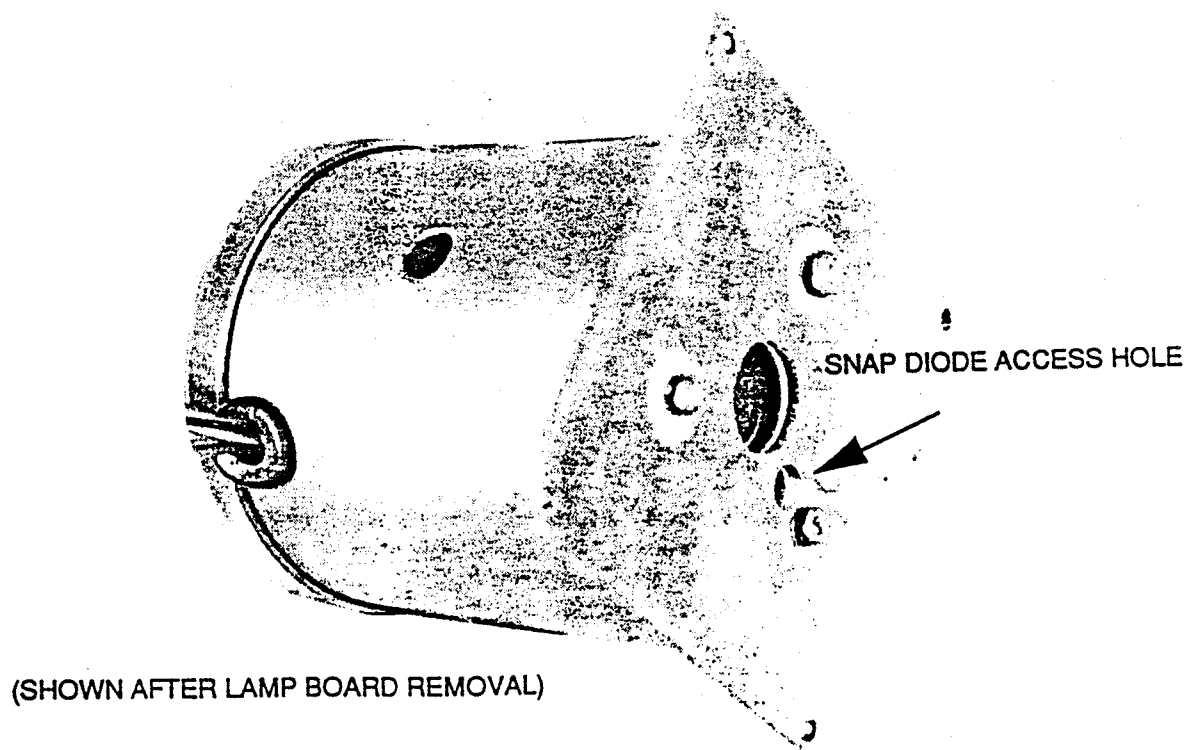


Figure 4-7. Snap Diode Access Hole on Resonator Assembly

(3.) Photocell - The photocell current is proportional to the total light incident on the photocell CR2. Minimum current results when a microwave field corresponding to the Rb hyperfine frequency is applied simultaneously with pumping light. Photocell problems are unlikely (always check the lamp assembly and power supply first), but manifest themselves as instable lamp monitor dc voltages, or as sporadic noise on the servo board's TP1 resonance signal. The photocell is replaced as part of the complete resonator assembly.

(4.) C-Field Coil - The C-field coil is wound on the microwave cavity and provides a dc magnetic field (the C-field) within the resonator cavity. Variation of this magnetic field allows fine tuning of the 10 MHz output frequency by shifting the Rb frequency hyperfine transition by the second order Zeeman effect. The "C-field" strength is determined by current from three sources:

R17 on the power supply board supplies a fixed current to the coil.

R21, the 24 turn potentiometer, on the power supply PCB, provides a variable current for frequency adjustment.

The temperature compensation circuit formed by Q2, Q3, R13 and R16 provides a current that varies with temperature. The power to heat the microwave cavity increases approximately 40 mW for every degree centigrade decrease of the ambient temperature. This results in a current change through resonator heater transistors Q2 and Q3, and through R13 on the resonator thermostat assembly. The voltage across R13 is routed to R16 on the power supply board and back to the C-field coil. Decreases in ambient air temperature causes the voltage across R13 to rise, providing more C-field current, and raising the output frequency.

The most common C-field problem is an open winding. An ohmmeter is used to check for this situation by removing power to the FRK and measuring from A3E27 to A3E19. A good C-field coil will give a reading of approximately 30 ohms.

(5.) Resonator Thermostat (part of resonator board assembly, refer to schematic 703-221) - the resonator thermostat consists of U1, Q1, and associated circuitry on the resonator PCB, and Q2, Q3, and RT1 mounted on the resonator cavity housing. U1 is the temperature control element, Q1 is a current limiting element, and Q2 and Q3 are the heat source.

U1 and the resistive bridge network on its inputs form the temperature control section. E1 receives +12 Vdc from the power supply board to power this section. R5 and R7 form a fixed voltage divider that references U1, pin 3. Thermistor RT1 and the series combination of R1 and the temperature select resistor form a voltage divider on the other op-amp input, U1, pin 2. The feedback network of R8 and C4 serves to control U1's output response when the inputs reach equilibrium.

During the high power dissipation period of the warm-up cycle, the current through Q2 and Q3 must be limited to a safe level of ~1 amp. This is done by sensing the current draw of Q2 and Q3 at R13. An increase in heater current causes an increase in voltage at the base of Q1. As Q1 turns on, it shunts a portion of Q2's base drive current to ground, allowing only the preset maximum current to flow. R11 and R12 form a voltage divider network that provides for the preset maximum current to be automatically shifted up or down, depending on the heater supply voltage. This is done to maintain a reasonably constant power dissipation during warm-up over the range of input voltage to the FRK.

As the thermostat circuit reaches equilibrium, the voltage output of U1 drops to a level that operates Q2 in a vernier control mode. The current through Q2 and Q3 folds back to a nominal 100 mA. The current foldback reduces the voltage drop across R13 to the point where Q1 does not conduct and effectively drops out of the circuit.

The resonator assembly is protected from a runaway heater control problem by thermal fuse F1, mounted on the resonator cavity housing.

b. Lamp, Assembly A2, (Schematic 703-209)

The lamp assembly consists of the lamp oscillator circuit, the lamp housing assembly, the lamp thermostat circuit, and the rubidium lamp. The function of the lamp assembly is to ignite and maintain the electrodeless plasma gas discharge of the rubidium lamp, and to maintain the temperature of the lamp housing at approximately 115°C.

FRK

The most common fault condition involving the lamp assembly is the generation of spurious noise on the unit output. This condition can be detected at TP1 of the servo board, where the lamp noise will cause severe disturbances to the resonance signal. If the disturbances are too severe, the unit may fail to lock. The spurious noise problem is very difficult to isolate due to the electro-mechanical aspects of the circuit and is typically remedied by replacing the entire lamp assembly. Occasionally, noise from the lamp can be eliminated by changing the oscillator frequency to a lower frequency, or by changing the rubidium lamp. The two most likely lamp failure modes are the loss of vacuum due to glass failure and Rb depletion. Glass failure will prevent lamp ignition (make sure the lamp oscillator circuit is functioning before lamp removal), whereas Rb depletion results in a whitish tint to the lamp light (another cause of this symptom is an improper lamp thermostat temperature). In case of Rb depletion and/or lamp thermostat failure, the FRK will not develop a resonance signal (refer to section 4.4.2.6, subsection h, Resonance Search).

NOTE

The loss of Rb cannot be detected by the decay of lamp voltage.

Lamp replacement is covered in Section 4.4.1.7 (1), FRK Lamp Replacement.

(1.) Lamp Oscillator - The lamp oscillator circuit is a modified Colpitts design consisting of Q2 as the active element, tank circuit L4 and C11 as the power transfer and primary resonant network, L3 as a secondary frequency control element, and associated bias circuitry.

Mechanical capacitor C11 provides for current/frequency adjustment of the oscillator and is accessible from outside the unit. Figure 4-8 illustrates the location of the adjustment port.

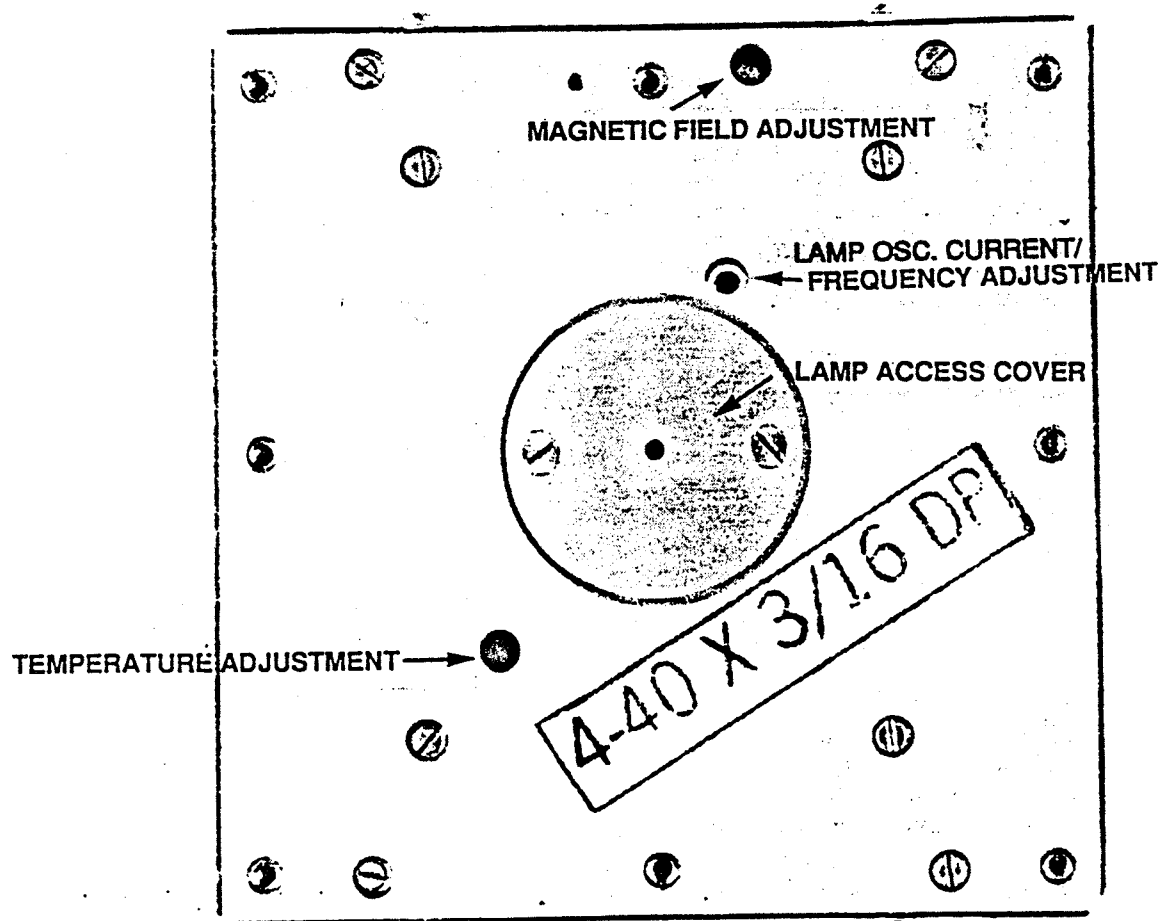


Figure 4-8. Lamp Adjustment Ports

FRK

Adjusting C11 tunes the oscillator's frequency over a range of approximately 70 MHz to 90 MHz. Within this range of adjustment there are specific optimum frequencies that should be used (refer to Section 4.4.1.7.2, Lamp Oscillator Tuning, part b, FRK Alignment Procedures). The operational frequency that is chosen is determined by finding the highest frequency setting that produces optimum ignition characteristics and noise free operation. In normal stabilized operation, the oscillator current draw from the regulated supply (E2) is a nominal 120 mA.

(2.) Lamp Thermostat - the lamp thermostat consists of U1, Q1, R5 and associated circuitry on the PCB, and Q3 and RT1 mounted on the lamp housing. U1 is the temperature control element, RT1 is part of the resistive bridge network at U1's inputs, Q1 is a current limiting element, and Q3 is the heat source element.

Op-Amp U1 is controlled by a balanced bridge circuit on its inputs. R3 and R6 form a fixed voltage divider that biases U1, pin 3. Thermistor RT1 and the series combination of R4 and R5 form the dynamic leg of the bridge. RT1 senses the temperature on the lamp housing and potentiometer R5 selects the stabilized temperature. The R5 potentiometer is accessible from outside the unit. Figure 4-14 illustrates the location of the adjustment port.

The operation of current limiter Q1 and heater transistor Q3 is essentially the same as the resonator thermostat circuit, which is discussed in detail in Section 4.4.2.5, part e.

c. Servo Board, Assembly A1 (schematic 10017)

The primary function of the servo circuit is to amplify and demodulate the photocell output to generate the crystal control voltage at E8 for the 10 MHz VCXO. The control voltage is derived by comparing the phase of the 127 Hz modulation signal with the phase of the photocell signal at E1 and E5. Secondary functions are to provide the monitoring signal for the Rb lamp operation at E4, the atomic resonant lock circuit at E7 and the VCXO control voltage monitor at E9.

(1.) Preamplifier - The photocell output, (dc bias together with the 254 Hz error signal when the unit is in the normal locked mode of operation, or 127 Hz error signal while the unit is obtaining a lock), is routed to E1 and E5 on the servo board A1. E1 and E5 tie to the input of dual stage amplifier U1 at pins 5 and 6 respectively. The output of the first stage of amplification is capacitively coupled to the input of the second stage of amplification (U1, pin 8) and directly coupled to E4 and U2-B, pin 5. E4 provides the Rb Lamp Monitor signal to the front panel connector.

U2-B senses the voltage at E4 and determines if the Rb lamp has ignited and if it is in "Correct Mode Ignition". Proper lamp ignition (~3 minutes after turn-on) will cause U2-B output, E11, to switch from <1 Vdc to >15 Vdc. The E11 voltage is fed to the power supply (Board 3, E29), where it switches the regulated unit power from 22 Vdc to 17 Vdc.

The output of the second amplifier (U1, Pin 13) is connected to Test Point (TP) 1, the primary oscilloscope monitoring point of the FRK. U1, pin 13, is also capacitively coupled to U2-A, the 127 Hz active bandpass filter, and to U6, the 254 Hz active bandpass filter.

(2.) Reference Signal Generation - 127 and 254 Hz Reference Signals - CMOS oscillator/divider U3 on the servo board, provides the 127 and 254 Hz reference signals and the 127 Hz signal which modulates the rf injected into the resonator. The primary oscillator frequency of 8.128 KHz is determined by C17, R19 and select-in-test resistor R20. The divider portion of U3 divides the primary oscillator frequency into the required 127 and 254 Hz signals. The 127 Hz reference signal is routed from U3, pin 4 to pin 11 of synchronous demodulator U4 and to pin 2, of U6, through the RC network R37/C24. The RC network R37/C24, the feedback network R38/C25, and the output RC filters (R39, C26, R40 on the servo board, and C2, R3, and C12 on the synthesizer board) serve to waveshape the 127 Hz signal into the sinewave that is coupled to the synthesizer to modulate the rf. R40 of the output RC filter is also used to adjust the modulation level to the multiplier and the phase of the correction signal at TP3.

The 254 Hz reference signal is routed from U3, pin 5 to pin 9 of synchronous demodulator U4. The 254 Hz reference signal is correlated with the photocell output to detect unit lock.

The dc voltage of approximately 6.8 Vdc generated by CR2 is also a reference signal. This DC level is used to bias the ac signals that are processed by U4 and U5, and to bias op-amps U6 and U5.

(3.) 127 Hz Signal Processing - As explained in the "pre-amplifier" section, the 127 Hz signal processing starts at the photocell inputs E1 and E5. U1-A and U1-B provide two stages of high gain amplification. The output of U1-B, pin 13, feeds both active bandpass filters, U2-A, the 127 Hz, and U6, the 254 Hz.

NOTE

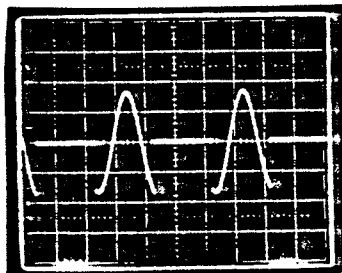
For troubleshooting purposes it is usually best to control the rubidium loop manually. Connect a potentiometer of 10 Kohms, or more, across C22 on the servo board. Disconnect the wire soldered to E8 and connect this wire to the wiper of the potentiometer. This technique provides for manual control of the VCXO's output frequency and critical servo functions.

The servo correction signal is amplitude modulated onto a 127 Hz subcarrier that passes through the 127 Hz filter, U2-A. When the system is locked, this signal (TP-2) appears as a 254 Hz sine wave, with a noticeable 127 Hz component. From TP2, the signal is routed to the synchronous demodulator U4, pin 12.

U4 is a triple two-channel CMOS analog switch that functions as a synchronous amplitude demodulator. The 127 and 254 Hz reference signals at pins 11 and 9 respectively, control the synchronous switching of two of the switches. A third switch is controlled by the level of the signal at U4, pin 10, from the lock detector circuit, U6, pin 8. U4, pins 5 and 13, receive the 6.8 Vdc reference level from CR2. When the unit sweeps near atomic lock, U4, pin 10 receives a "high" signal (>12 Vdc) that switches the output of the 127 Hz filter U2-A to the output of the demodulator, U4, pin 15, for dynamic tracking. The demodulator output is monitored at TP3 and appears as shown in Figure 4-15.

The signal from U4, pin 15 is direct coupled to U5, pin 2. U5 functions as the servo loop integrator. Its output voltage changes at a rate determined by the differential input voltage. For example, an input differential of -200 mV causes an output voltage change of +200 mV/sec. The change will continue until the differential input is nullified, (the crystal returns to center frequency), or until the Op amp reaches its maximum output voltage.

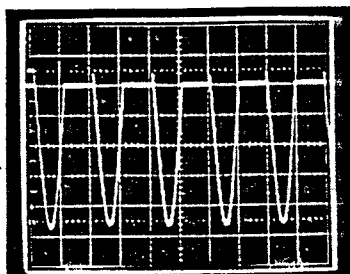
The output of the integrator, E8, is the crystal-control voltage that steers the frequency of the VCXO by means of a varactor diode in the oscillator tuning circuit. A portion of the integrator output is routed to the sweep control circuit at U6, pin 5.



TP-3 Normal Signal 1 volt/div., 50 ms./div.

Figure 4-9. Demodulator Output (Servo Board)

(4.) Lock Circuit - A portion of the photocell signal is applied to an input of the Lock Monitor circuit at U6, pin 12. U6-D, with its associated circuitry, forms a 254 Hz active bandpass filter that connects to pin 3 of the synchronous demodulator U4. The output signal at U4, pin 4 is coupled to U6, pin 9, and is monitored at TP6 (refer to Figure 4-10). With the unit locked, the negative offset at U6, pin 9 will cause the output at U6, pin 8 to go high. This provides the positive signal at U4, pin 10 that removes the sweep signal from the integrator, U5. It also biases Q1 into a conduct mode that provides the Lock Monitor signal at the front panel connector (pin H for the Winchester connector, pin 5 for the 8-pin connector with coax). When the unit is locked, the Lock Monitor line as a resistance of 150 ohms to ground. Otherwise the Lock Monitor is an open circuit.



Normal Signal 1 volt/div., 1 volt/div, 2 ms./div

Figure 4-10. Signal Waveform at TP6

(5.) Sweep Circuit - To allow the FRK to compensate for several years of crystal aging, in addition to frequency offsets of the crystal caused by environmental changes (e.g., temperature changes), the trim range of the oscillator is very wide compared to the width of the atomic resonance. To aid servo acquisition, the crystal frequency is swept over the entire trim range until atomic resonance can be detected.

This is accomplished by switching the integrator input (U5, pin 2) to U6, pin 7 via U4 (the unit is unlocked when U6, pin 14 is low). U6-B functions as a high hysteresis voltage comparator. The trigger points are controlled by R51 and R52 and the voltage reference. The lower trigger point is approximately 1.5 Vdc, the higher trigger point is approximately 16 Vdc. If the output of U5 is equal to or lower than the lower trigger point, the output of U6 becomes 0 Vdc, resulting in about a -.7 Vdc differential to the integrator. With R24 = 1 M and C18 = 1 μ F its output will rise .7 V/s until the upper trigger point of 16 Vdc is reached. At this point, the output of U6 will go high, resulting in about a +.7 Vdc differential at the integrator input. This will decrease U5's output by .7 V/s. The result is a sweep time of about 40 s. Due to the fast sweep, atomic resonance can be detected for only 100 ms at a time during each sweep cycle. Reliable transition from sweep to locked operation is facilitated by CR3.

d. Power Supply, board assembly A3 (schematic 703-254) - the internal power supply provides the unregulated, filtered voltages for the Rb lamp heaters, the crystal heater, and the resonator heaters, in addition to providing the filtered and regulated voltage to the unit's electronics. The input voltage line is fuse and diode protected against reverse polarity inputs.

The power supply board accepts the +22 to +32 Vdc input voltage at E2, and provides regulated +22 Vdc at E12, E17, and E18, until the Rb lamp ignites, at which time the power supply is switched to +17 Vdc. The switching occurs when U2-B, on the servo board, senses that the Rb lamp is ignited, in the correct mode, by the positive increase at U2-B, pin 5. The output of U2-B is routed to the power supply board at E29. The positive voltage increase provides reverse bias for CR6, effectively removing R24 from the circuit and setting the condition for the power supply output to be lowered to the +17 Vdc required for the internal circuits of the unit.

(1.) Regulated Power Supply - The +17 Vdc power supply consists of Q1 and U1 along with the components in their respective circuitry mounted on the power supply board and pass transistor Q1, which is mounted on the baseplate of the FRK.

The +22 to +32 Vdc input is routed across the 3 amp fuse (F1) to the voltage divider circuit that consists of R5 and R7. The input voltage is dropped to approximately 3 Vdc, which is coupled through CR3 to U1, pin 2. Before power is applied, U1, pins 2, 3 and 6, were at ground potential. With 3 volts at U1, pin 2, and U1, pin 3 still at ground potential, the resultant offset causes U1, pin 6 to go low, turning on the power transistor Q1. The +17 volt line is fed back through CR4 and R9 to the reference zener diode, CR5. CR5 develops approxi-

mately 6.3 Vdc at U1, pin 2. In addition, the 17 volt line is fed back to the voltage divider consisting of R6, R8 and R10 to apply a voltage to U1, pin 3. The voltage divider determines the voltage ratio of the 17 volt line to the voltage reference diode CR5, thus setting the voltage level of the 17 volt line.

Transistor Q1 on the power supply board functions as a current limiter by sensing the voltage drop across R14. If the current through the pass transistor becomes excessive, Q1 begins to conduct, decreasing the emitter-base bias on the pass transistor, thus limiting the current flow.

e. Crystal Oscillator (VCXO) Assembly (schematic 703-215) - the purpose of the 10 MHz oscillator is to provide a clean and stable 10 MHz signal to the output connector, and to the synthesizer. The oscillator board contains the Voltage Controlled Crystal Oscillator (VCXO), the crystal oven and thermal control, and a buffer amplifier. The 10 MHz signals are transformer coupled to the output connector J1 and to the synthesizer circuit.

(1.) Crystal Oscillator - the oscillator circuit consists of the 10 MHz crystal (Y1), transistors Q2, Q3, and Q4 with associated circuitry. Q3 is the primary oscillator transistor, working with the crystal (Y1) and the frequency tuning network that consists of C10, C11, C12, and varactor CR3. Q2 is a buffer/current driver that drives the T1, C3 tank circuit. The output of T1 is coupled to Q6, a FET buffer amplifier, and Q4, which provides automatic gain control by controlling the base bias on Q3. TP1 is a dc voltage monitoring point with a nominal voltage of about 1.1 Vdc. Transformer T1 is tuned by looking for a minimum voltage at TP1. The trim range and center frequency control voltage can be adjusted in the C10, C11, C12, CR3 network. The initial setup of these parameters is most easily accomplished by controlling E9 with an external adjustable voltage source. With 6 Vdc applied to E9 as a nominal center frequency voltage, and C10 set midway in its travel, C11 is selected to center the output frequency and C12 is selected for the proper trim range (approximately ± 7 Hz) over the control voltage range (approximately 2-14 Vdc).

(2.) Crystal Buffer Section - the buffer amplifier section consists of Q6, T2, Q7, Q8, and T3.

Q6 is a FET device used as a high input impedance decoupling stage between the oscillator circuit and the output drivers. The 10 MHz signal at the gate of Q6 is a nominal 1.4 v.p.p.

The Q6 drain drives transformer T2. The T2 primary circuit is a 10 MHz tuned tank. The secondary circuit is a low impedance source that drives the E15 output to the synthesizer, board A5, and the base of Q7. TP2 is the oscilloscope monitor point of this circuit and should read a nominal 2.8 v.p.p.

Q7 is a common collector amplifier. The current output of Q7's emitter is coupled into the emitter of Q8, a common base amplifier. Q8's collector output drives the T3, C16 tank. This waveform can be monitored at TP3 for troubleshooting purposes. However, the additional capacitance of most scope probes will detune the tank slightly, resulting in a slight loss of signal at TP3 and E4. The secondary winding of T3 transforms the buffer amplifier's output to a 50 ohm impedance. The output of E4 into a 50 ohm load is a nominal 2.8 v.p.p.

(3.) Crystal Thermostat - the crystal oven thermostat circuit consists of U1, Q5, and associated circuitry on the P.C.B, and Q1 and RT1 mounted on the oven assembly. U1 is the temperature control element, Q5 is a current limiting element, and Q1 is the heat source.

U1 and the resistive bridge network on its inputs form the temperature control section. Thermistor RT1, mounted on the crystal oven, is the sensing element in the input network and CR1 and R2 set the reference voltage. R8 functions as the temperature select component. R4 and R3 provide a 1 volt offset between the fixed voltage across R2 and the input side of R35. With a supply of +26 Vdc to the unit during warm-up, the voltage at E13 is ~20 Vdc. This output level corresponds to a full-on heater current condition. The oven heater transistor Q1 would be destroyed by runaway current if not for Q5, which serves as a current limiter. In the current limit mode, Q5 senses the voltage across R20 to determine Q1's emitter current. As the R20 voltage approaches ~.6 Vdc, Q5 starts conducting, raising the voltage at E11 to the level required to throttle Q1's current to a nominal 550 mA. The power delivered to the oven in the warm-up mode is kept constant over the range of supply voltages by the R33, R17 network. The higher the supply voltage, the less maximum current is allowed in Q1.

Most heater related failures resulting in Q1 being destroyed will also involve Q5. The most effective method of troubleshooting this circuit, one that minimizes the risk of damage, is to replace Q1 with a power rheostat and gradually allow the nominal heater current to flow while checking the operation of Q5.

f. Synthesizer - Board Assembly A5 (schematic 703-285-1)

The synthesizer assembly contains a frequency multiplier circuit and a frequency synthesis section. Q3 through Q8 make up the multiplier section and Q2, U1, and U2 perform the synthesis.

(1.) Multiplier - the 10 MHz signal from the crystal oscillator is applied to the input of a frequency tripler consisting of Q3, Q4, and associated circuitry. C9 and L3 are tuned to 30 MHz. R12 limits the Q of the tank to about 30. The 30 MHz signal is capacitively coupled through C13 to transformer T1. At this point, the 127 Hz modulation signal, biased at a nominal 6.5 Vdc, comes into E5 and modulates the rf signal via varactor CR6. The interaction of CR6 with the tuned tank circuit on the primary of T1 serves to phase modulate the rf at a 127 Hz rate. The secondary of T1 is center tapped to provide a split phase signal that drives the doubler circuit of Q5 and Q6. The result is a 60 MHz signal that is amplified by Q7 and Q8. C17/L5, C21/L8, and C27/L10 are tuned to 60 MHz. Q7 and Q8 are Class A inverting amplifiers. The 60 MHz signal at E6 drives the snap diode in the physics package through a coax cable. C29 matches the coax-cable to the driver stage. R31 and R34 provide the bias voltage for the snap diode.

Refer to Figure 4-11 for waveform and amplitude illustrations for the multiplier circuit's test points (T.P. 2, 3, 4, 5, 6, 8).

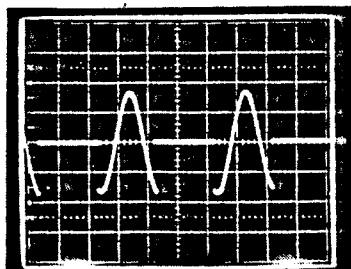
The adjustable parameters of the multiplier circuit include L3, T1, L5, L8, L11, C29, and R34. Adjustments of these component values should not be necessary except if other components are replaced during repairs. In this event, see section 4.4.2.6, subsection f., which covers the alignment procedures for the synthesizer, board A5.

(2.) Synthesizer Circuitry - the 10 MHz input signal from the crystal oscillator is applied to the base of Q2. Q2 converts the sine wave input to a TTL compatible trigger signal. This signal is coupled into U2-A, Pin 1. U2-A functions as a divide by "2" block, with a 5 MHz TTL signal coming out on pin 3. One branch of the 5 MHz signal goes to U2-B, pin 13. U2 functions as a divide by "16" block, producing a 312.5 KHz TTL signal output from pin 8 and passing to U1. U1-C is an "exclusive OR" gate which mixes the 5 MHz and 312.5 KHz input signals to produce an output at pin 8 that contains the upper and lower mixing products, 4.6875 MHz and 5.3125 MHz. The signals are then routed across tuned tank L11/C30. This tank is tuned at 5.3175 MHz and selects this frequency from the two that are injected. The capacitive coupling of C26 and the filtering action of L11/C30 converts the TTL signal at TP7 into a sine wave signal referenced to ground at TP-9. Finally, the signal leaves TP-9 and is summed with the 60 MHz at E6, from which both frequencies are routed to the step recovery diode.

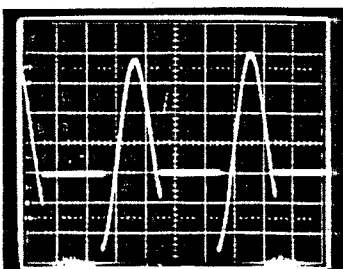
Refer to Figure 4-11 for waveform and amplitude illustrations for TP1, TP7, and TP9 of the synthesizer circuit.

NOTE: all signals monitored with X10 oscilloscope probe.

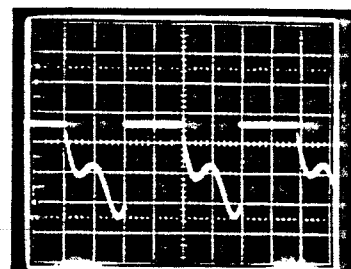
SERVO BOARD



TP-3: normal correction signal
500 mV/div., 2 ms/div

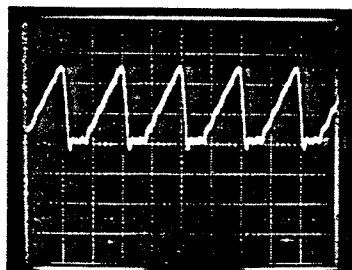


TP-3: 20 Mohm resistor
from C18 to Ground
500 mV/div, 2 ms/div

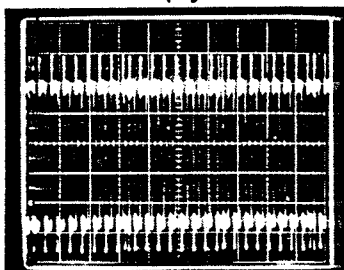


TP-3: 20 Mohm resistor
from C18 to +17 Vdc
500 mV/div., 2 ms/div.

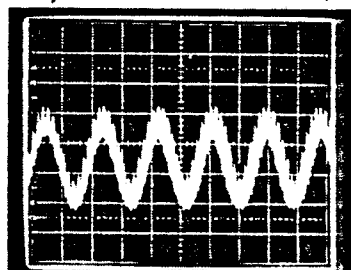
SYNTHESIZER BOARD (Synthesizer Section)



TP-1 dc coupled, 0 Vdc
at center scale, 1 V/div.,
50 ns/div.

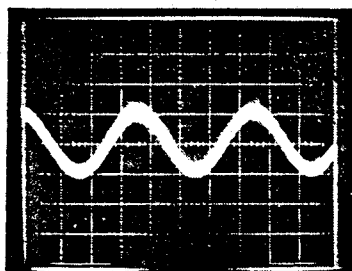


TP-7 dc coupled, 3.0 Vdc
at center scale, 1V/div.,
500 ns/div.

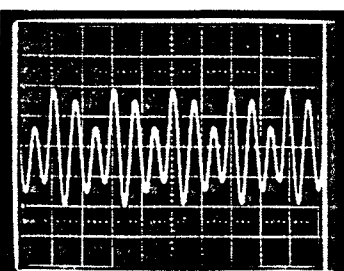


TP-9 normal signal
500 mV/div., 100 ns/div.

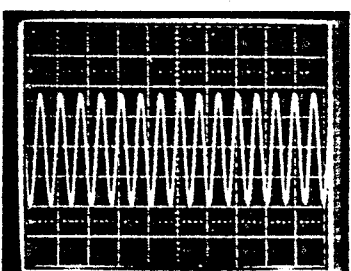
SYNTHESIZER BOARD (Multiplier Section)



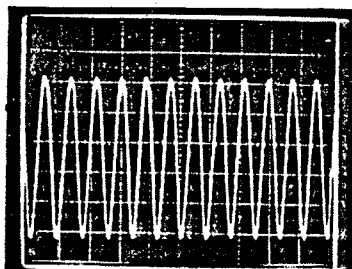
TP-2 Normal signal, 6.5 Vdc center
scale, 50 mV/div., 2 ms/div.,
20 MHz B.W. limit,



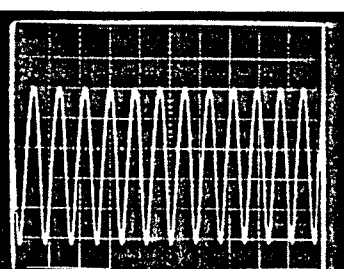
TP-3 normal signal
1 V/div., 50 ns/div.



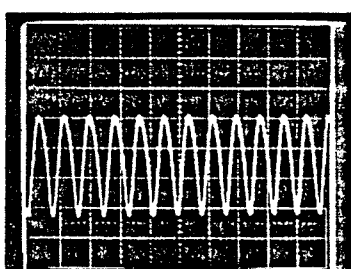
TP-4 normal signal
500 mV/div., 50 ms/div.



TP-5 normal signal
500 mV/div., 20 ns/div.



TP-6 normal signal
1V/div., 20 ns/div.



TP-8 normal signal
5V/div., 20 ns/div.

Figure 4-11. Waveform and Amplitude Traces for Servo and Synthesizer Boards.

4.4.2.2 FRK Alignment Procedures

NOTE

It is not necessary to perform all alignment procedures each time the FRK is repaired. Perform only those alignments that pertain to the board, or assembly, that has been repaired or replaced.

a. Regulated Voltage Supply:

- (1) Before power is applied to the FRK, connect a voltmeter across C2 of the Power Supply, Assembly A3. Observe the meter while applying power. At the instant of turn-on the voltmeter should read ~ 23 Vdc. Within 3 minutes the lamp should ignite, switching the regulated voltage to a lower level. If the unit has been warmed up previously to this test, the lamp will ignite instantly upon applying power and no voltage transition will be seen. The regulator output voltage at C2 should be $17.3 \text{ Vdc} \pm .3 \text{ V}$ after lamp ignition.
- (2) If the measured voltage falls outside the range of $17.3 \text{ Vdc} \pm .3\text{V}$, an adjustment will be necessary. Locate R6 on the power supply board, assembly A3. Increasing the value of R6 will increase the regulator output voltage.

b. Lamp Temperature Setting:

- (1) Apply power to the FRK and allow at least 15 minutes for temperature stabilization.
- (2) Remove the lamp access cover from the base plate.
- (3) Measure the temperature of the lamp housing by placing a temperature probe next to the rubidium lamp. Allow time for the temperature probe readings to stabilize. Turn off the power to the unit momentarily and record the probe reading. Remove the probe and reapply power. The temperature measured should be a nominal $113^{\circ}\text{C} \pm 2^{\circ}\text{C}$. If the recorded temperature is out of specification, an adjustment is necessary. Locate the temperature access hole in the baseplate and adjust A2R5. Repeat the temperature measurement and adjustment step until the proper lamp housing temperature is obtained.

c. Lamp Oscillator Tuning

- (1) Tuning the lamp oscillator requires that the regulated voltage supply to the lamp board (C2-1) be interrupted and a 0 to 500 milliamp meter be installed in series.
- (2) Locate the frequency access hole in the baseplate and insert an isolated tip driver until mechanical capacitor C11 is engaged.
- (3) The oscillator frequency can be monitored using a scope probe as an antenna. By holding the probe in close proximity to the rubidium lamp the probe signal can drive a frequency counter directly or after amplification from an oscilloscope buffer amplifier.
- (4) Apply power to the unit and allow at least 15 minutes for stabilization. Adjusting C11 will change the oscillator current and frequency.
 - (a) Set the lamp oscillator current to the low side of 125 to 145 mA, to a point that gives an oscillator frequency of 91.5, 87.0, 84.5, 79.0, 78.5, 77.5, 76.5, 71.0 or 69.5 MHz. After setting the frequency, remove power to the unit for 5 minutes. Then re-apply power and verify normal ignition and operation.

FRK

- (b) If parasitic oscillations (i.e. spurs) appear at A1TP1 (see 4.4.1.7.1 (2)), set the lamp oscillator frequency as far away from the parasitic point as practical.

d. Resonator Temperature Setting:

- (1) Apply power to the FRK and allow at least 15 minutes for temperature stabilization.
- (2) Locate the resonator temperature probe hole in the power supply board, assembly A3 (see Figure 4-19). Remove any foam or other material that prevents clear vision of the glass resonator cell through the probe hole. Install the temperature probe and read the temperature. The resonator temperature should be $+74^{\circ}\text{C} \pm 3^{\circ}\text{C}$.
- (3) If the temperature reading does not conform to the specified range, an adjustment is necessary. Locate R15 on the power supply board, assembly A3. Decreasing the value of R15 will increase the temperature of the resonator. Allow 5 minutes of stabilization time between temperature readings and adjustment steps.

e. Crystal Oscillator, Board Assembly 4

CRYSTAL OVEN TEMPERATURE SETTINGS

- (1) Apply power to the FRK and allow at least 15 minutes for temperature stabilization.
- (2) Locate the crystal oven assembly on the crystal oscillator board, assembly A4. There is a label on the top of each oven assembly and a slotted crystal inspection window. The label and the crystal are marked with a turning point temperature in $^{\circ}\text{C}$. The oven temperature, as monitored with a temperature probe, should be set at or slightly above the temperature marked on the crystal to optimize unit temperature coefficient. In the event no temperature reference can be found on the crystal, set the oven within $+75^{\circ}\text{C}$ and $+82^{\circ}\text{C}$.
- (3) If the reading obtained with the temperature probe does not correspond with the parameters described in Section 2., an adjustment is required.
- (4) Locate R8 on the crystal oscillator board, assembly A4. Increasing the value of R8 will lower the oven temperature. Allow 5 minutes of temperature stabilization after changing the setting of R8 before monitoring the result.

TRANSFORMER TUNING

- (1) Connect an oscilloscope probe across C11. Adjust the T1 tuning slug counterclockwise until it reaches the top of its travel. Slowly turn the slug clockwise until the 10 MHz signal at C11 reaches a minimum. Continue to rotate the tuning slug clockwise until the signal increases $\sim 10\%$.
- (2) Connect an oscilloscope probe at TP2 (E15). Adjust T2 for a maximum signal.
- (3) Connect the rf output jack of the FRK to an oscilloscope with 50 ohm coax terminated by a 50 ohm load. Adjust T3 for a maximum signal.

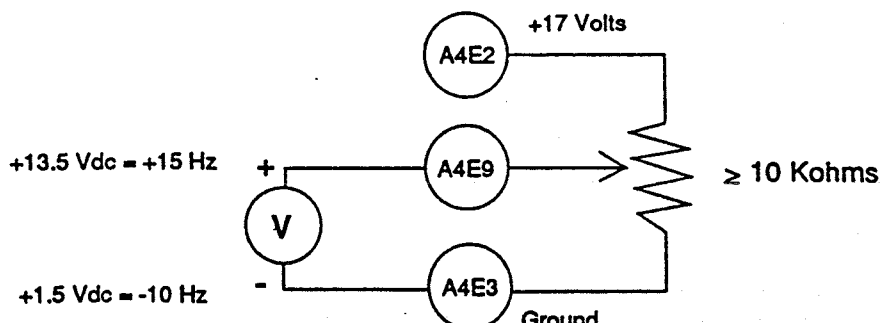
TRIM RANGE SETTINGS

- (1) Setting the trim range requires a manually adjustable voltage source providing input to A4E9. Disconnect the yellow wire that is terminated at E9 and fold it back out of the way.

NOTE

Do not allow the bare end of the wire to touch the chassis or other circuitry.

- (2) Connect a potentiometer of 10 Kohm or a greater value and a voltmeter as shown below:



- (3) Adjust the tuning slug of mechanical capacitor C10 to a point midrange of its travel.
- (4) Select C11 and C12 to provide a control range of 15 Hz above and 10 Hz below the center frequency of 10 MHz. The frequency control voltage at E9 should be ~13.5 Vdc when the output frequency is 10 Hz below center. The E9 voltage should be ~1.5 Vdc when the output frequency is 15 Hz above center.

C11 and C12 values are each adjusted for specific changes. The C11 component primarily adjusts the center frequency of the oscillator. C12 primarily adjusts the amount of frequency change over a given control voltage range. These components do interact slightly.

- (5) After the trim range is set, adjust the E9 voltage to ~8.0 Vdc. Adjust C10 for 10 MHz output.
- (6) Remove the potentiometer from E2, E3, and E9. Reconnect the yellow wire to terminal E9.

f. Synthesizer Board Alignment, Assembly A5

TRANSFORMER TUNING

- (1) Connect a dc voltmeter to E6 through a 10 Kohm isolation resistor. Apply power to the FRK. Adjust potentiometer R34 for the maximum dc voltage. Tune inductors L3, T1, L5 and L8 in sequence for the maximum dc voltage at E6.
- (2) Attach an oscilloscope probe to TP9. Tune L11 for a maximum signal of 5.312 MHz.

OUTPUT COAX MATCHING

- (1) If Multiplexer Board 5 has been replaced, transfer the C29 value from the old board.
- (2) If the Resonator assembly has been replaced, select C29.
- (3) Connect a dc voltmeter to E6 through a 10 Kohm isolation resistor. Apply power to the FRK. Adjust potentiometer R34 for the maximum dc voltage.
- (4) Select C29 for the maximum dc voltage at E6.

RESISTANCE TUNING

Refer to the Synthesizer board alignment procedure under "Resonance Search."

g. Servo Board Alignment, Assembly A1

LAMP VOLTS SETTING

- (1) Monitor E4 with a dc voltmeter. Apply power to the FRK and allow at least 15 minutes for temperature stabilization.
- (2) Locate R4 on the servo board. Adjust R4 for a nominal 11 Vdc ± 2 at E4.

127 HZ REFERENCE ADJUSTMENT

- (1) Monitor TP4 with a X10 oscilloscope probe. The probe will drive a frequency counter directly, or an oscilloscope with a buffered output to the counter.
- (2) Locate R20 and adjust for a frequency counter reading of 127 Hz ± 1 Hz.

MODULATION AMPLITUDE

- (1) Monitor E6 with an oscilloscope.
- (2) Adjust R58 for a signal amplitude of 400 mV ± 50 mV peak to peak.

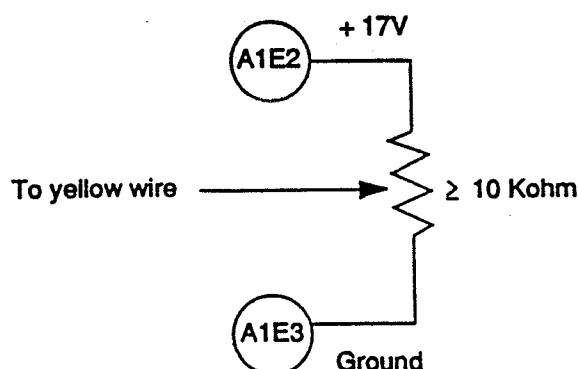
h. Resonance Search

BANDPASS FILTERS (This procedure is recommended only for replacement boards)

- (1) Disconnect power to the unit.
- (2) Locate R16 and R70 potentiometers on the servo board, assembly A1.
- (3) Adjust both potentiometers to a point approximately midway in their adjustment range. Lock should be obtained. If lock does not occur, move on to Bandpass Filter Tuning section and adjust the filters.

CRYSTAL CONTROL VOLTAGE

- (1) Disconnect the yellow wire terminated at A1E8 on the servo board assembly. Connect this yellow wire to a potentiometer as shown below:



- (2) Monitor the 10 MHz output of the unit with a frequency counter.
- (3) Apply power to the unit and allow at least 15 minutes for thermal stabilization.

- (4) Monitor A1TP1 on the servo board with an oscilloscope.
- (5) Adjust the output frequency with the test potentiometer to 1 Hz above or below 10 MHz.
- (6) Monitor the dc voltage at A5E6 through a 10 Kohm isolation resistor using a voltmeter.
- (7) Adjust potentiometer R34 on the synthesizer board, assembly A5, for maximum voltage, then decrease the voltage slowly, watching the oscilloscope for an ac waveform of 127 Hz.
- (8) At the first sign of a signal at A1TP1, adjust the output frequency for a maximum 127 Hz signal. Adjust R34 for the maximum signal amplitude.
- (9) Disconnect power to the FRK. Remove the test potentiometer and reconnect the yellow wire to A1E8. Apply power to the FRK. Atomic lock should be acquired automatically, resulting in a 254 Hz signal at A1TP1.

i. Bandpass Filter Tuning: Servo Board, Assembly A1

127 HZ ACTIVE BANDPASS FILTER (U2-A) ADJUSTMENT (SERVO LOOP)

- (1) Verify that the FRK is stabilized and locked.
- (2) Monitor A1TP3 with an oscilloscope.
- (3) Connect a 20 megohm resistance jumper between U5, pin 2 and E2.
- (4) Adjust potentiometer R16 to obtain a waveform as shown in Figure 4-12.

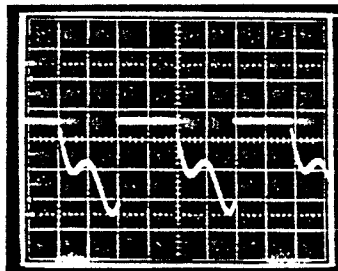


Figure 4-12. Waveform, Servo Board (TP-3)

254 HZ ACTIVE BANDPASS FILTER (U6) ADJUSTMENT (LOCK MONITOR)

- (1) Monitor A1TP6 with an oscilloscope.
- (2) Verify that the unit is stabilized and locked.
- (3) Adjust potentiometer R70 to obtain the most symmetrical negative cycle waveform possible (see Figure 4-13).

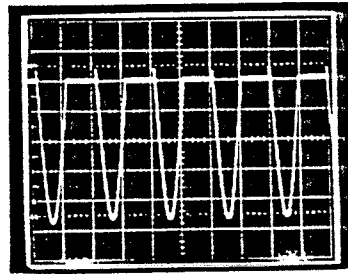
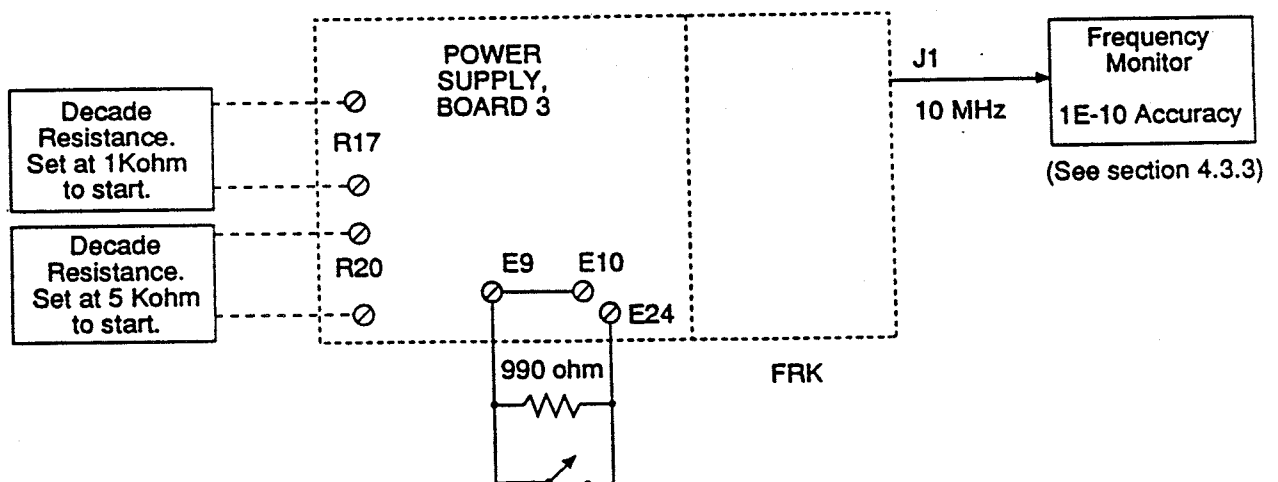


Figure 4-13. Waveform, Servo Board (TP-6)

j. C-Field Adjustments: Power Supply Board, Assembly A3

- (1) Set the magnetic field trim range and centering. R17 and R19 are the select components. R17 functions as the primary frequency centering control. R19 works in conjunction with potentiometer R21 to provide a means of manually adjusting the 10 MHz output frequency. R17 and R19 are slightly interactive during their adjustments, therefore the use of two decade boxes for this alignment is suggested (refer to schematic 703-254).
- (2) Start the adjustment by setting R17 to ~ 1.2 Kohm and R19 to ~ 120Kohm. Lower values of R17 shift the frequency higher, while lower values of R19 allow R21 to adjust over a wider range.
- (3) Select R17 and R19 so that R21 can adjust the output frequency $>1E-9$ above and below 10 MHz.
- (4) Connect the unit in the test configuration as shown below:



- (5) Apply power to the FRK and allow at least 1 hour stabilization time.

4.4.2.3 FRK Temperature Testing Procedure

FRK Temperature Testing Procedure - this test requires the UUT be placed in an environmental testing chamber. Connect the test equipment as shown in Figure 4-14.

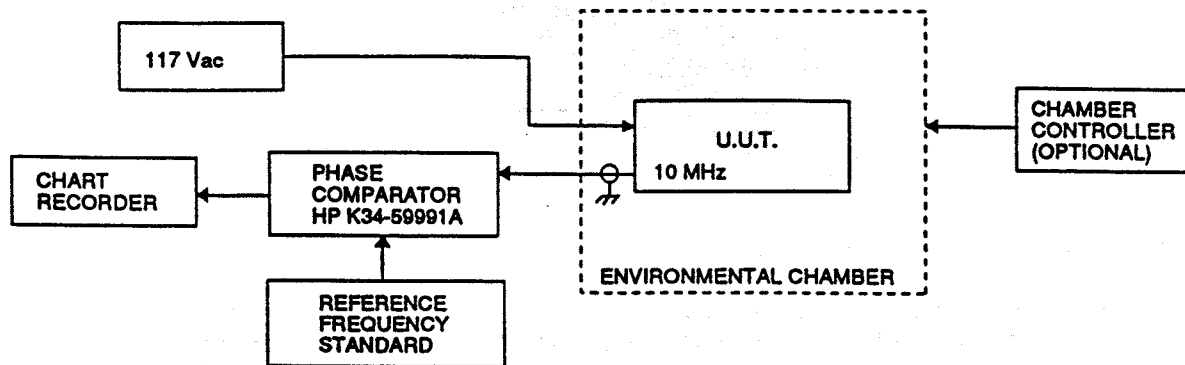


Figure 4-14. Environmental Test Chamber Set-up

- (1) Adjust the chamber controls so that the air temperature is maintained at +30° C ambient
- (2) Apply ac input power to the UUT. Allow sufficient warm-up time to allow the unit's output frequency to stabilize (> 60 min.). If the UUT was operated continuously for greater than 60 minutes prior to this test, no additional operation time is required.
- (3) Start frequency recording. This monitoring should continue throughout the test. The frequency resolution of the chart recorder must be $\Delta f/f = 1 \times 10E-11/\text{division}$.
- (4) The temperature chamber can be controlled manually or automatically. Set the temperature cycles for the chamber as shown in the "Required" column. Use the left column to document the actual test run conditions so they can be used for future reference.

	<u>Required</u>
A. Ambient _____ ° C	(+45 ± 2° C)
Cycle Time _____ hrs	(≥ 1.5 hr.)
B. Low Temperature _____ ° C	(+15 ± 2° C)
Cycle Time _____ hrs	(≥ 1.5 hr.)
C. High Temperature _____ ° C	(+30 ± 2° C)
Cycle Time _____ hrs	(≥ 1.5 hr.)

FRK

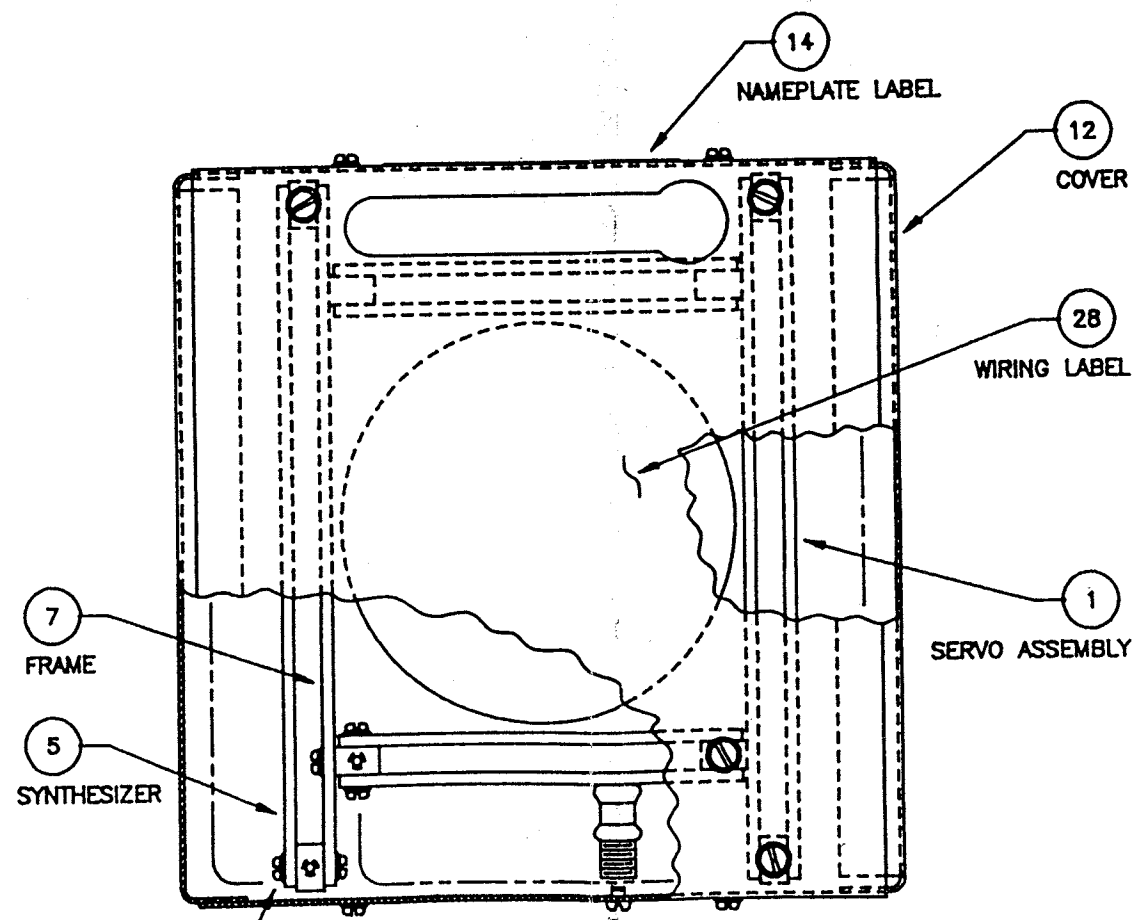
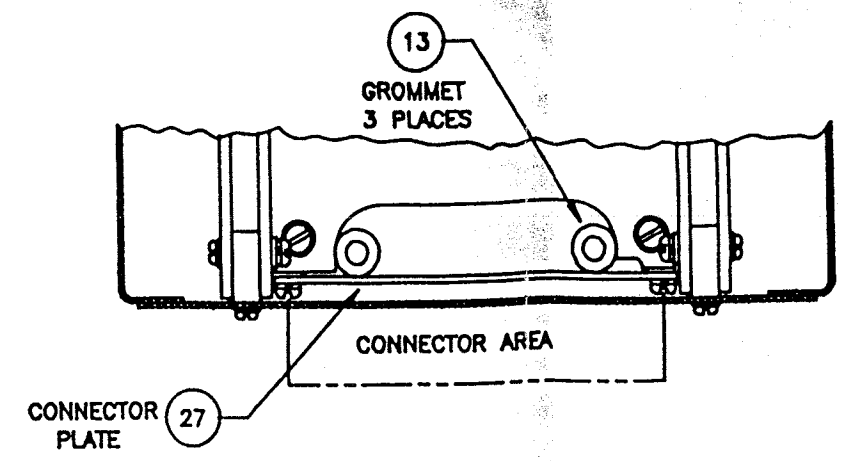
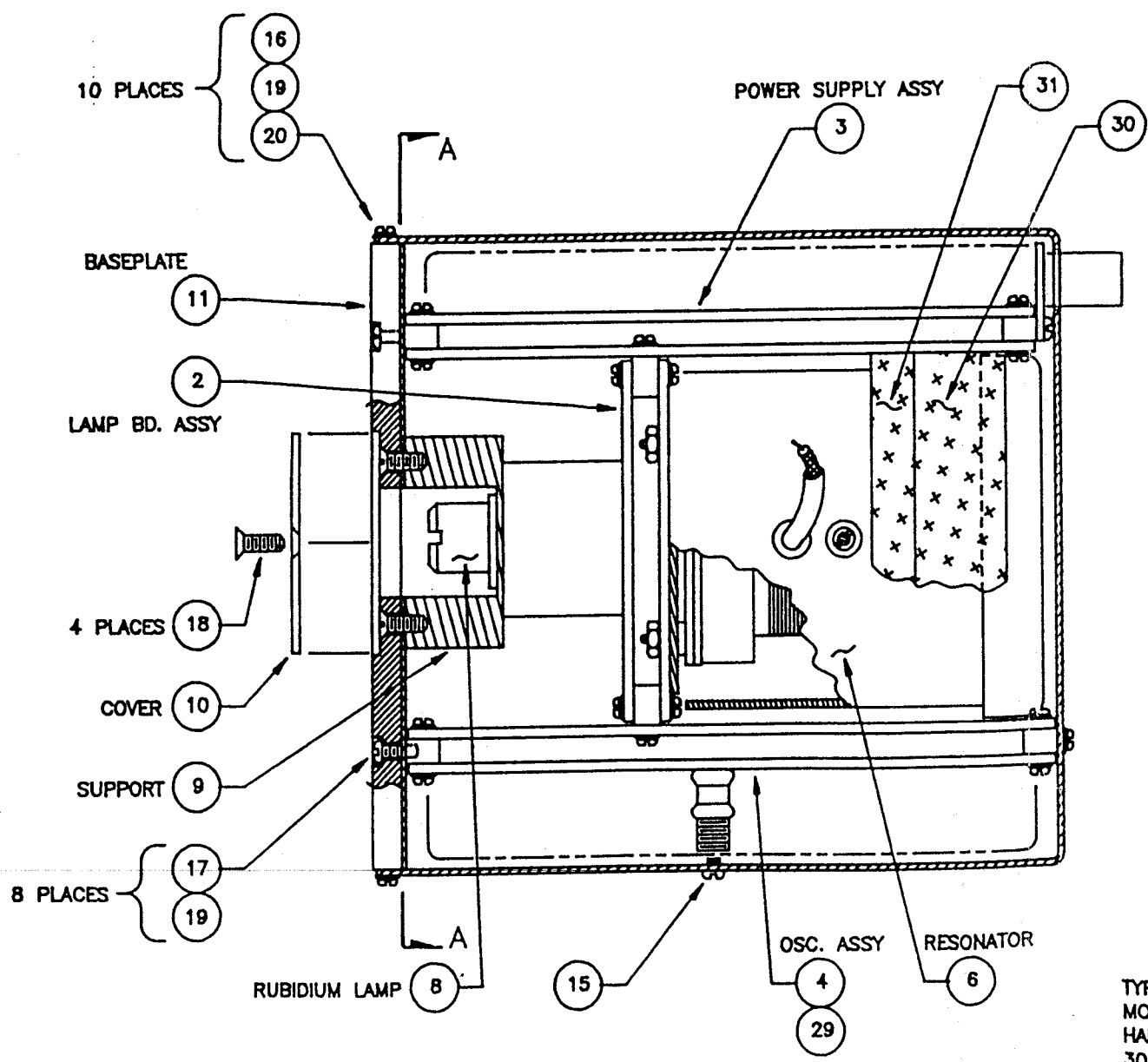
APPENDIX A:

FRK Assembly Schematics, Assembly Drawings, and Parts Lists

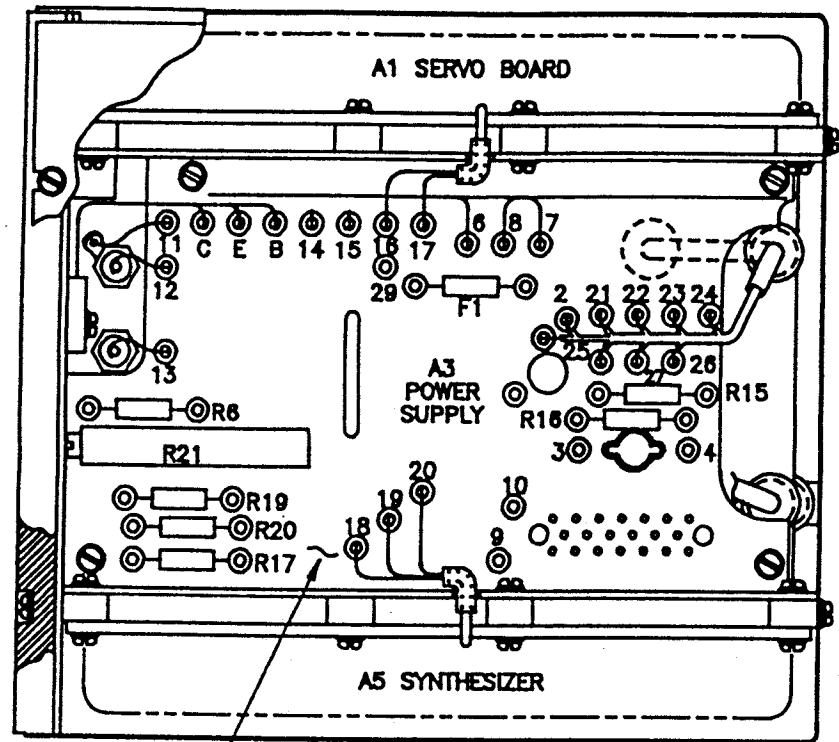
FRK

DRAWING LIST

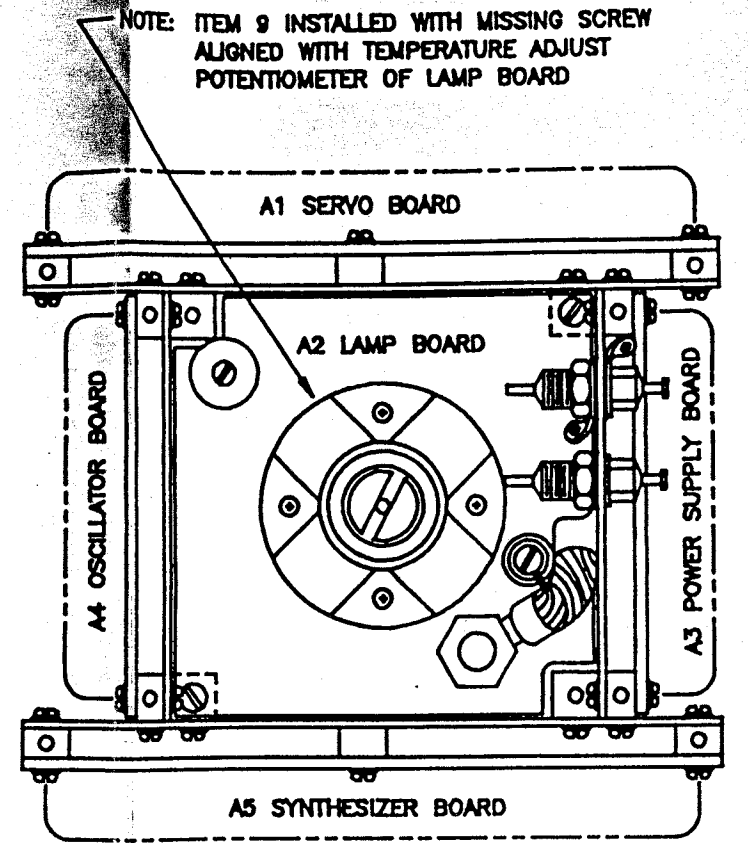
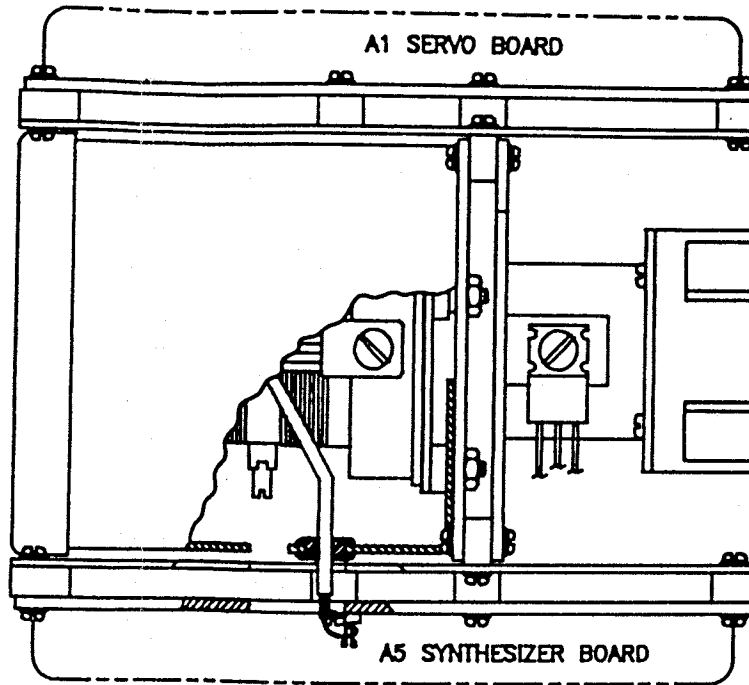
DRAWING NUMBER	DESCRIPTION	PAGE
703-200- PL703-200	FINAL ASSEMBLY, FRK PARTS LIST, FRK	A2, A3 A4- A5
100120 100117 PL100120-001	ASSEMBLY, SERVO BOARD SCHEMATIC, SERVO BOARD PARTS LIST, SERVO BOARD	A6 A7 A8-A11
703-208-1 703-209 PL703-208-1	ASSEMBLY, LAMP BOARD SCHEMATIC, LAMP BOARD PARTS LIST, LAMP BOARD	A12 A13 A14-A15
703-253-1 703-254 PL703-253-1	ASSEMBLY, POWER SUPPLY BOARD SCHEMATIC, POWER SUPPLY BOARD PARTS LIST, POWER SUPPLY BOARD	A16 A17 A18-A19
703-214-1 703-215-1 PL703-214-1	ASSEMBLY, CRYSTAL OSCILLATOR BOARD SCHEMATIC, CRYSTAL OSCILLATOR BOARD PARTS LIST, CRYSTAL OSCILLATOR BOARD	A20 A21 A22-A24
703-283-1 703-285 PL703-283-1	ASSEMBLY, SYNTHESIZER BOARD SCHEMATIC, SYNTHESIZER BOARD PARTS LIST, SYNTHESIZER BOARD	A25 A26 A27-A29
703-223-1 703-221-1 703-223-1	ASSEMBLY, RESONATOR BOARD SCHEMATIC, RESONATOR BOARD PARTS LIST, RESONATOR BOARD	A30 A31 A32-A33



TYPICAL PWB MOUNTING HARDWARE 30 PLACES { 16, 19, 20 }




POWER SUPPLY ASSEMBLY
SHOWN FOR REFERENCE ONLY
SEE PL FOR POWER SUPPLY USED.

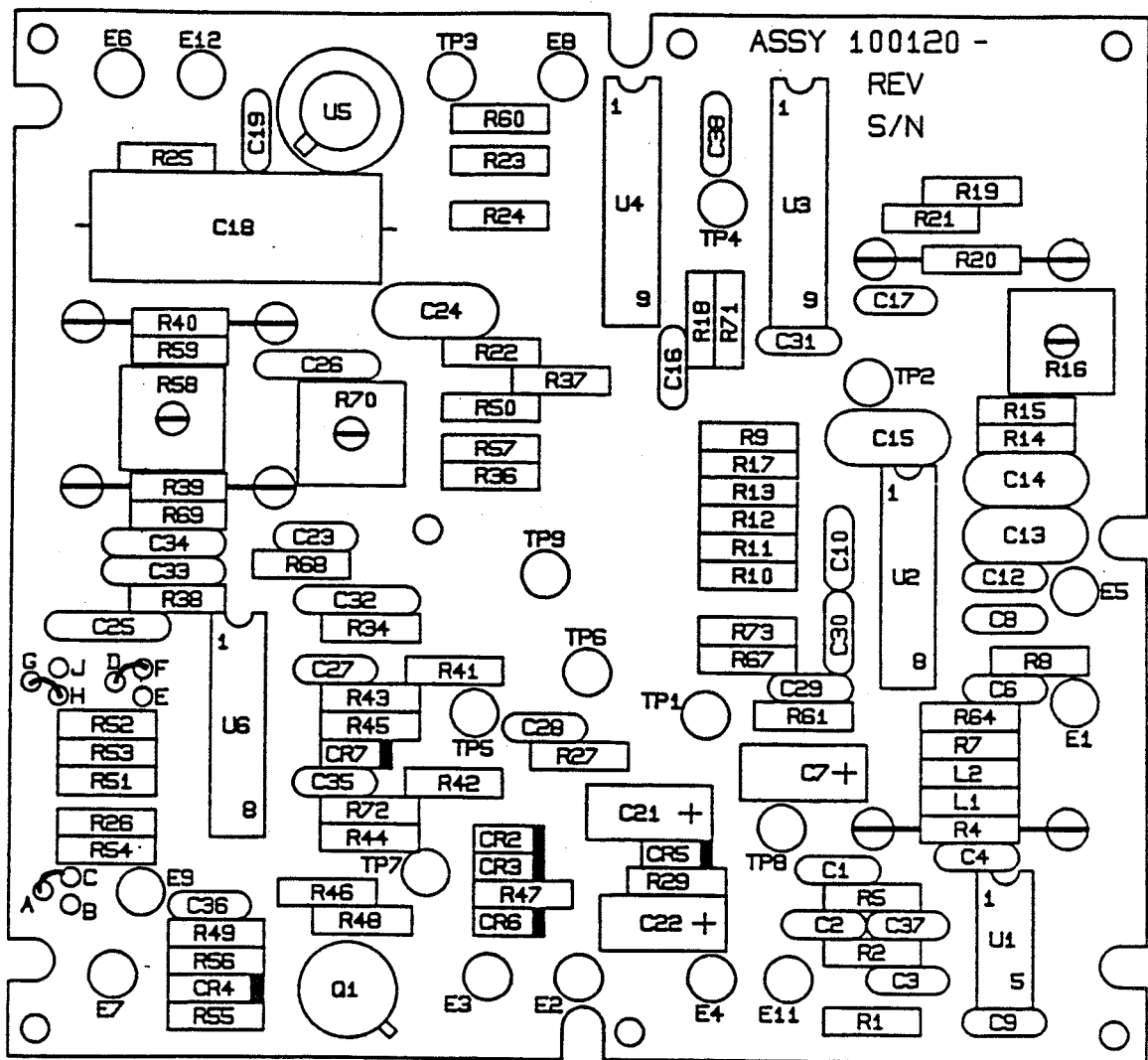


VIEW A-A
ROTATED 90° CW

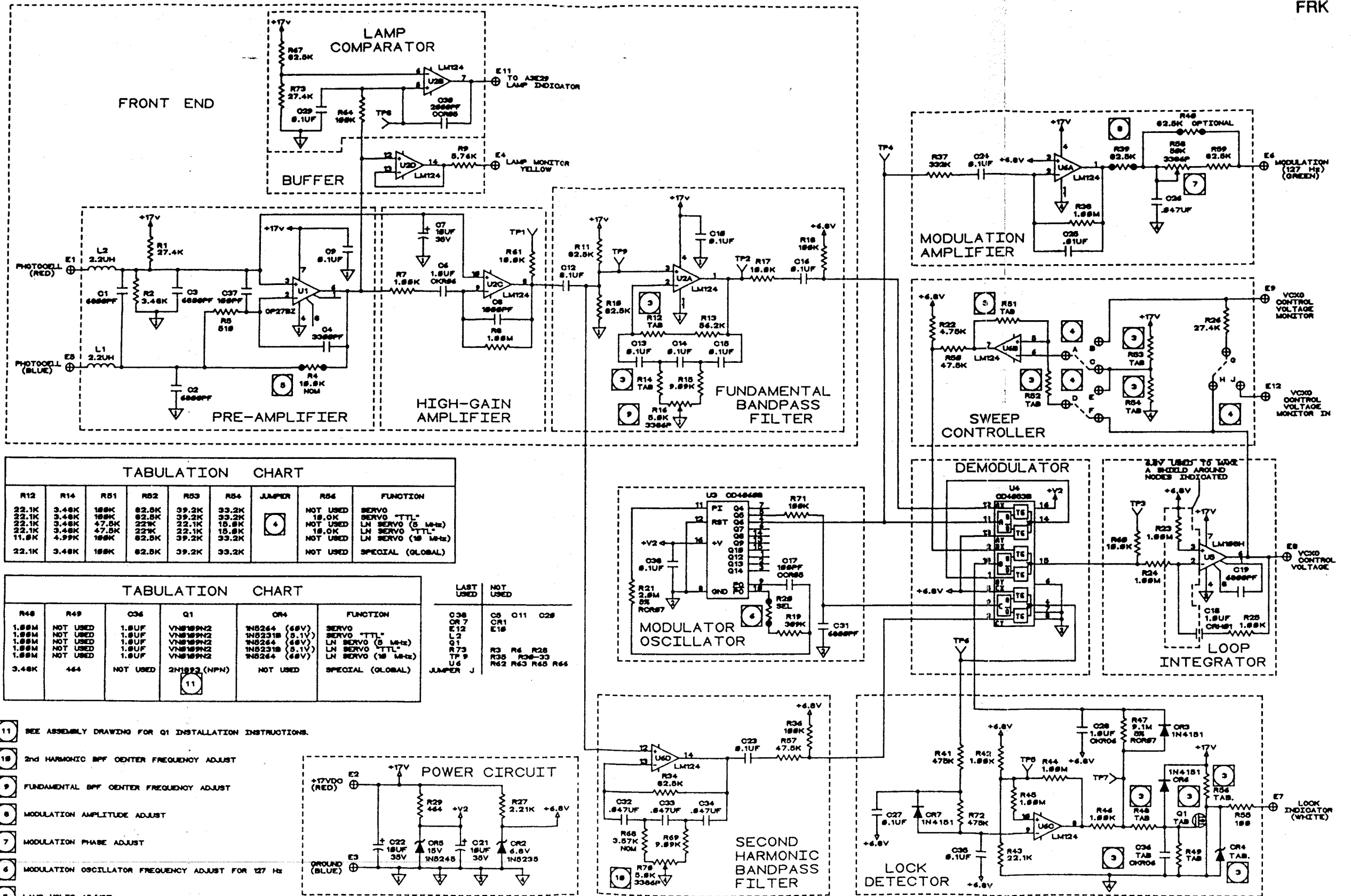
ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
1	1	100120	Servo Assembly		A1		9703-205-1
2	1	703-208-1	Lamp Board Assembly		A2		9703-208-1
3	1	703-253-1	Power Supply Assembly		A3		9703-253-1
4	1	703-214-1	Oscillator Assembly		A4		9703-214-1
5	1	703-283-1	Synthesizer Assembly		A5		
6	1	703-223-1	Resonator Assembly		A6		
7	1	703-226-1	Frame Assembly				
8	1	250-165-1	Rubidium Lamp Assembly				
9	1	703-239	Lamp Support				
10	1	703-242	Cover Plate				
11	1	703-245-3	Baseplate Assembly (4.40)				
12	1	250-091	Mu-Metal Cover				
13	3	MS35489-4	Grommet				2801398
14	1	705-150	Label - Nameplate				
15	1	MS51957-39	Screw, Pan Hd, 8-32 x 1/8				2821433
16	38	85ST-M2 x 4	Screw, M2 x 4				70425-1
17	8	85ST-M2 x 6	Screw, M2 x 6				70425-13
18	4	963ST-m2.5 x 10	Screw, Flat Hd m2.5 x 10				2820500
19	54	6798ST - IN2.2	Washer, Lock 2 mm (I.T.)				2820440
20	46	MW-400	Washer, Flat 2 mm				2821475
21	-	(NOT USED)					

 EFRATOM DIVISION		PARTS LIST		FSCM NO. 55761	PL 703-200-1	REV F
				LIST TITLE FINAL ASSY - RB OSC, FRK		

FRK



ASSEMBLY, SERVO BOARD



TABULATION CHART									
R12	R14	R51	R52	R53	R54	JUMPER	R56	FUNCTION	
22.1K	3.48K	189K	82.5K	39.2K	33.2K	4	NOT USED	SERVO "TTL"	
22.1K	3.48K	189K	82.5K	39.2K	33.2K	4	NOT USED	LN SERVO (5 MHz)	
22.1K	3.48K	47.5K	22K	22.1K	15.8K	4	NOT USED	LN SERVO "TTL"	
11.8K	4.99K	189K	82.5K	39.2K	33.2K	4	NOT USED	LN SERVO (16 MHz)	
22.1K	3.48K	189K	82.5K	39.2K	33.2K	4	NOT USED	SPECIAL (GLOBAL)	

TABULATION CHART						LAST USED				NOT USED				
R48	R49	C36	Q1	OR4	FUNCTION	C38	OR 7	E12	L2	Q1	C29	C5	O11	C28
1.89M	NOT USED	1.8UF	VN8189N2	1N5244 (68V)	SERVO	C38	OR 7	E12	L2	Q1	C29	C5	O11	C28
1.89M	NOT USED	1.8UF	VN8189N2	1N5231B (5.1V)	SERVO "TTL"	Q1	OR 7	E12	L2	Q1	C29	C5	O11	C28
1.89M	NOT USED	1.8UF	VN8189N2	1N5244 (68V)	LN SERVO (5 MHz)	R73	OR 7	E12	L2	Q1	C29	C5	O11	C28
1.89M	NOT USED	1.8UF	VN8189N2	1N5231B (5.1V)	LN SERVO "TTL"	TP 9	OR 7	E12	L2	Q1	C29	C5	O11	C28
3.48K	444	NOT USED	2N1522 (NPN)	1N5244 (68V)	LN SERVO (16 MHz)	U6	OR 7	E12	L2	Q1	C29	C5	O11	C28
					SPECIAL (GLOBAL)	JUMPER J	OR 7	E12	L2	Q1	C29	C5	O11	C28

- 11 SEE ASSEMBLY DRAWING FOR Q1 INSTALLATION INSTRUCTIONS.
- 18 2nd HARMONIC BPF CENTER FREQUENCY ADJUST
- 9 FUNDAMENTAL BPF CENTER FREQUENCY ADJUST
- 8 MODULATION AMPLITUDE ADJUST
- 7 MODULATION PHASE ADJUST
- 6 MODULATION OSCILLATOR FREQUENCY ADJUST FOR 127 Hz
- 5 LAMP VOLTS ADJUST
- 4 INSTALL JUMPERS A-C, D-F, G-H FOR LOW NOISE UNITS ONLY; INSTALL JUMPERS A-B, D-E, G-J
- 3 SEE TABULATION CHART FOR COMPONENT VALUES.

2. CAPACITORS ARE 50V MIN. OF CERAMIC. (OR908K—K8)
 1. RESISTORS ARE 1/4W, 1% FIXED FILM. (M2 —)

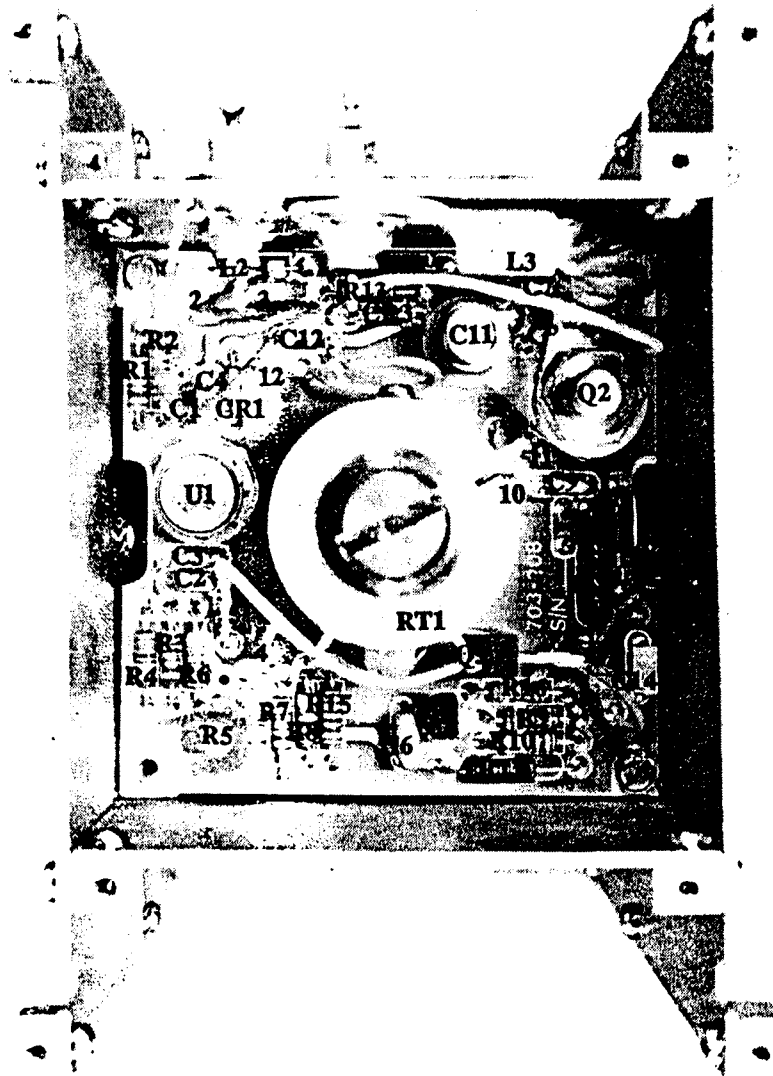
NOTES: UNLESS OTHERWISE SPECIFIED.

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
1	1	100118	PRINTED WIRING BOARD		C17,37		
2	1	EDPT 100 PF NPO	CAPACITOR 100 PF NPO	STETTNER-TRUSH	C8		
3	1	CKR05BX102 KS	CAPACITOR 1000 PF	MIL-C-39014	C1,2,3,19,31		
4	7	CKR06BX682 KS	CAPACITOR 6800 PF +/- 10%	MIL-C-39014	C9,10,12,16,23,27,29,35,38		
5	8	CKR05BX104 KS	CAPACITOR 0.1 uF	MIL-C-39014	C6,28		
6	3	CKR06BX105 KS	CAPACITOR 1.0 uF	KEMET	C7,21,22		
7	3	T322D106M035AS	CAPACITOR 10 uF 35V	S & EI	C25		
8	1	22NA103K	CAPACITOR 0.01 uF	S & EI	C26,32,33,34		
9	4	22NA473J	CAPACITOR 0.047 uF	S & EI	C13,14,15,24		
10	4	22NA104J	CAPACITOR 0.1 uF	S & EI	C18		
11	1	M83421/01-12525	CAPACITOR 1.0 uF	MIL-C-83421	CR3,6,7		
12	3	1N4151	DIODE	FAIRCHILD	CR2		
13	1	IN5235B	DIODE, 6.8V ZENER	MOTOROLA	CR5		
14	1	IN5245	DIODE, 15V ZENER	MOTOROLA			
15	1	VN01092N	NOT USED				
16	2	MS75084-2	INDUCTOR 2.2 uF	MIL-C-15305	L1,2		
17	1	OP27BZ	INTEGRATED CIRCUIT, OP AMP		U1		
18	1		NOT USED				
19	1	CD4060BF	INTEGRATED CIRCUIT	RCA	U3		
20	1	CD4053BF	INTEGRATED CIRCUIT	RCA	U4		
21	1	LM108H/883B	INTEGRATED CIRCUIT, OP AMP	NATIONAL SEMI.	U5		

EFRATOM DIVISION		PARTS LIST		FSCM NO. 55761	PL100120-001 REV -
		LIST TITLE		SERVO BOARD	
				SH	1 OF 4

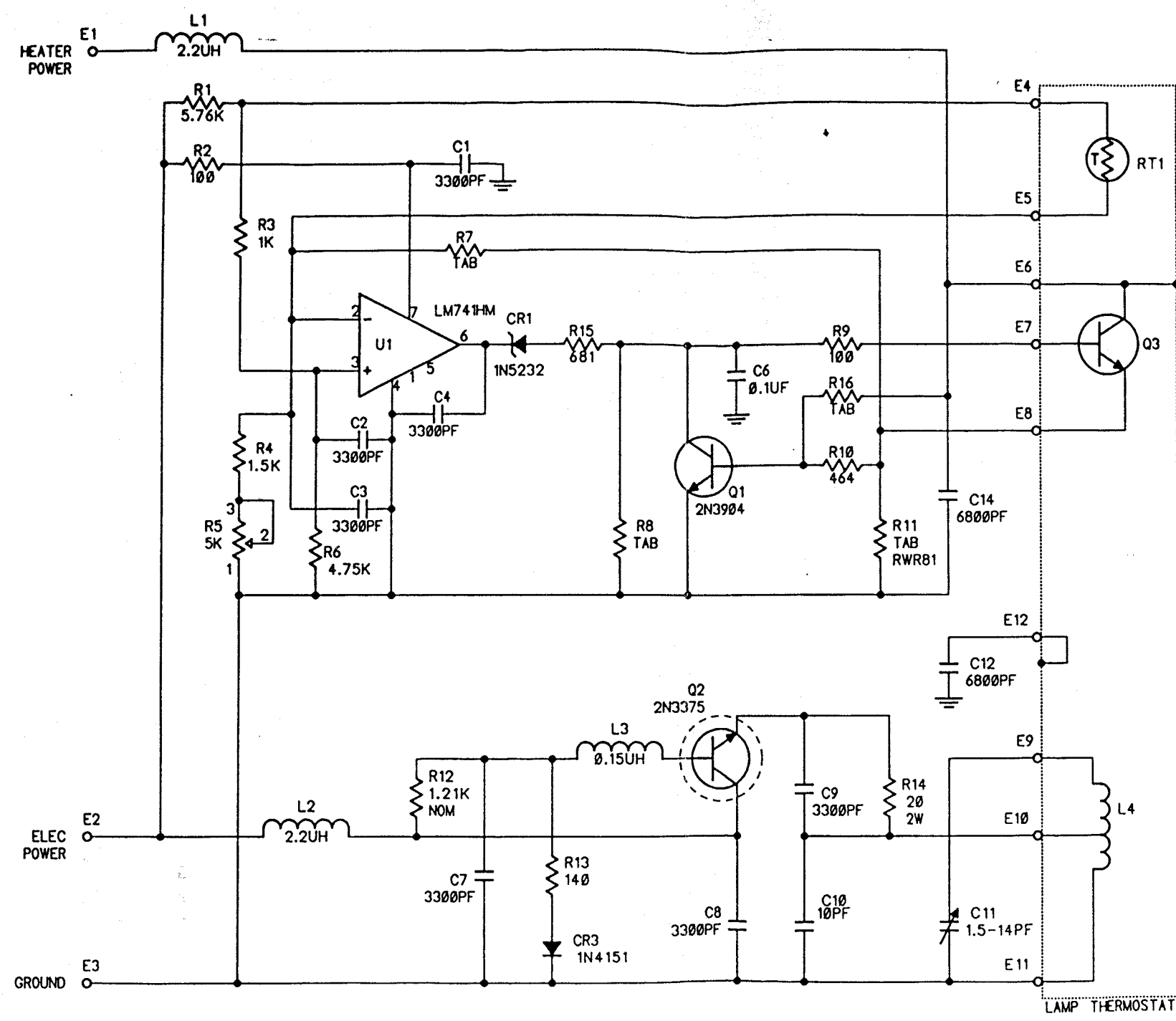
ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
22	1	LM124J	INTEGRATED CIRCUIT, OP AMP	NATIONAL SEMI.	U2,6		
23	1	7717-4N	SPACER, TO-5, (3 LEAD)	THERMALLOY			
24	2	7717-107N	SPACER, TO-5, (8-LEAD)	THERMALLOY			
25	AR	SN63WRMAP3	SOLDER	QQ-S-571			
26	AR	70416-3	TERMINAL	KEMET	TP1-9, E1-9, E11-12		
27			NOT USED				
28	1	MK-2	RESISTOR 100 OHM	STETTNER	R55		
29	1	MK-2	RESISTOR 464 OHM	STETTNER	R29		
30	4	MK-2	RESISTOR 1 K	STETTNER	R7,25,42,46		
31	1	MK-2	RESISTOR 2.21 K	STETTNER	R27		
32	2	MK-2	RESISTOR 3.48K	STETTNER	R2		
33	1	MK-2	RESISTOR 3.57 K NOM. SELECT	STETTNER	R68		
34	1	MK-2	RESISTOR 4.75 K	STETTNER	R22		
35	1	MK-2	RESISTOR 5.76 K	STETTNER	R9		
36			NOT USED				
37	2	MK-2	RESISTOR 9.09 K	STETTNER	R15,69		
38	4	MK-2	RESISTOR 10.0 K	STETTNER	R4,17,60,61		
39	2	MK-2	RESISTOR 22.1 K	STETTNER	R43		
40	2	MK-2	RESISTOR 27.4 K	STETTNER	R1,26		
41			NOT USED				
42			NOT USED				
EFRATOM DIVISION				PARTS LIST		FSCM NO. 55761	PL 100120-001 REV -
				LIST TITLE		SERVO BOARD	

ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
43	3	MK-2	RESISTOR 47.5 K	STETTNER	R50,57		
44	2	MK-2	RESISTOR 56.2 K	STETTNER	R13		
45	5	MK-2	RESISTOR 82.5K	STETTNER	R10,11,34,39,52,59,67		
46	5	MK-2	RESISTOR 100 K	STETTNER	R18,36,64,71		
47	1	MK-2	RESISTOR 332 K	STETTNER	R37		
48	1	MK-2	RESISTOR 309 K NOMINAL	STETTNER	R19		
49	2	MK-2	RESISTOR 475 K	STETTNER	R41,72		
50	1	MK-2	RESISTOR SELECT VALUE		R20		
51	7	MK-2 1 MEG	RESISTOR 1 MEG		R8,23,24,38,44,45		
52	1	RCR07G915JS	RESISTOR 9.1 MEG 1/4W	MIL-R-39008	R47		
53	2	3386P-1-502	RESISTOR VARIABLE	BOURNES	R16,70		
54			NOT USED				
55	1	3386P-1-503	RESISTOR VARIABLE	BOURNES	R58		
56	1	RCR07G20GJS	RESISTOR 2M OHM	MIL-R-39008	R21		
57	1	CRR05BX33KR	CAP CER, 100V, 10% 3300PF	MIL-C-39014	C4		
58	1	MK2 510	RES, MF, 1/4W, 1%, 510	STETTNER	R5		
59	1	CCR05CG202JR	CAP, NPO, 50V, 5% 2000PF	MIL-C-20	C30		
60	AR	QQW3435265IT	WIRE, UNINSULATED 26 AWG	QQ-W-343	JUMPERS A-C, D-F, G-H		
61	1	MK2	RES, MF, 1/4W, 1% 22.1K	STETTNER	R12		
62	1	MK2	RES, MF, 1/4W, 1% 3.48k	STETTNER	R14		
63	1	MK2	RES, MF, 1/4W, 1%, 100K	STETTNER	R51		
EFRATOM DIVISION				PARTS LIST		FSCM NO. 55761	PL100120-001 REV -
				LIST TITLE		SERVO BOARD	



ASSEMBLY, LAMP BOARD

A12





TABULATION					
ASSEMBLY	R7	R8	R11	R16	USED ON
703-208-1	8.25K	332	1	39.2K	FRK-H
703-208-2	12.1K	681	0.619	4.32K	FRK-HLN(12VDC)

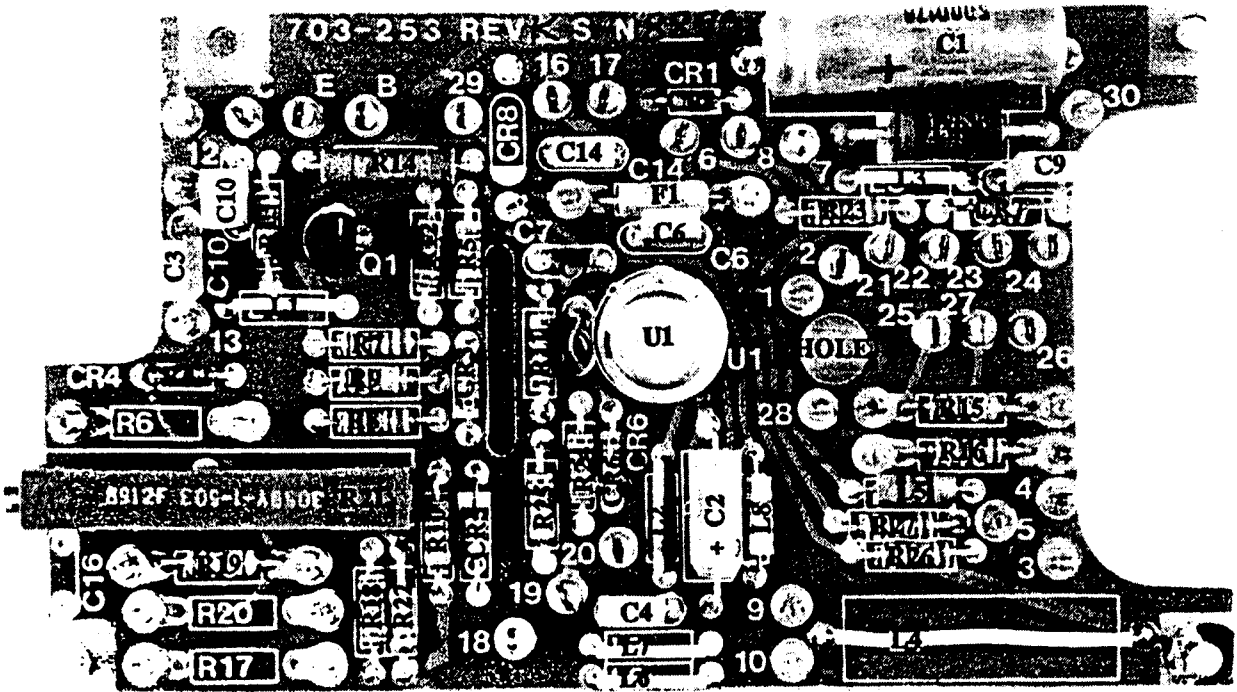
LAST USED	NOT USED
U1	-
C14	C5,13
R16	R15
CR3	CR2
Q3	-
E12	-
RT1	-
L4	-

2. RESISTANCE VALUES ARE OHMS.
 1. FOR ASSEMBLY SEE DWG# 703-208.
 NOTES: UNLESS OTHERWISE SPECIFIED.

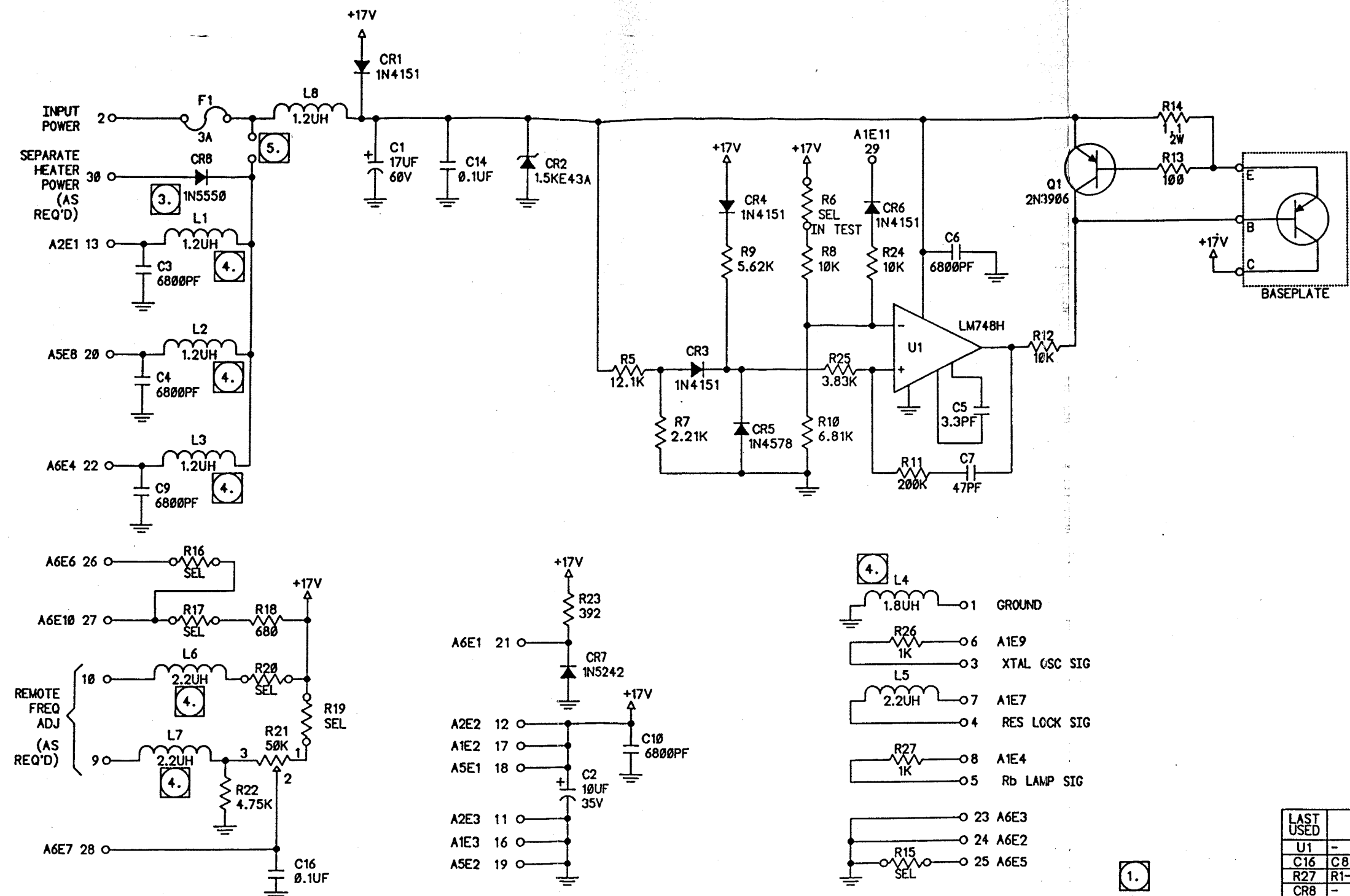
SCHMATIC, LAMP BOARD

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE
1	1	703-210-1	PRINTED WIRING BOARD			
2	1	EDPT 10 PF NPO	CAPACITOR 10 PF	STETTNER-TRUSH	C10	
3	7	C322C332K1G5CA	CAPACITOR 3300 PF	KEMET	C1-4,C7-9	
4	1	PC32T140	CAPACITOR, VARIABLE 1.5-14 PF	JOHANSON MFG CO.	C11	
5	1	IN5232B	DIODE, ZENER	MOTOROLA	CR1	
6	1	IN4151	DIODE, SWITCHING	FAIRCHILD	CR3	
7	1	MS75083-3	INDUCTOR 0.15 uH	DALE	L3	
8	2	MS75084-4	INDUCTOR 2.2 uH	DALE	L1,L2	
9	1	2N3904	TRANSISTOR	MOTOROLA	Q1	
10	1	JAN2N3375	TRANSISTOR	RCA	Q2	
11	1	LM741HMQB	INTEGRATED CIRCUIT	FAIRCHILD	U1	
12	2	MK-2 100 OHM	RESISTOR 100 OHM	STETTNER-TRUSH	R2,9	
13	1	MK-2 681 OHM	RESISTOR 681 OHM	STETTNER-TRUSH	R15	
14	1	MK-2 1 K	RESISTOR 1 K	STETTNER-TRUSH	R3	
15	1	MK-2 1.5K	RESISTOR 1.5 K	STETTNER-TRUSH	R4	
16	1	MK-2 4.75 K	RESISTOR 4.75 K	STETTNER-TRUSH	R6	
17	1	MK-2 5.76 K	RESISTOR 5.76 K	STETTNER-TRUSH	R1	
18	1	MK-2 8.25 K	RESISTOR 8.25 K	STETTNER-TRUSH	R7	
19	1	MK-2 39.2 K	RESISTOR 39.2 K +/- 1% 1/4 W	STETTNER-TRUSH	R16	
20	1	RW80U20ROF	RESISTOR 20 OHM 2 W	MILSPEC	R14	
21	1	RWR81SIR00FS	RESISTOR 1.00 OHM 1 W	MILSPEC	R11	
 EFRATOM DIVISION			PARTS LIST		FSCM NO.	PL 703-208-1 REV T
					55761	
			LAMP BOARD		SH 1 OF 2	

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
22	1	3339P-1-502	RESISTOR, VARIABLE 5 K	BOURNES	R5		
23	1	MK-2 332 OHM	RESISTOR 332 OHM	STETTNER-TRUSH	R8		
24	2	CKRO5BX682KS	CAPACITOR 6800 PF +/- 10 %	AVX	C12,14		
25	1	70331-1	THERMOSTAT ASSEMBLY				
26	1	250-169	MICA WINDOW				
27	3	70425-3	SCREW, M2x6				
28	3	70414-4	WASHER, FLAT, M2				
29	3	6798ST-IN22	WASHER, LOCK, M2				
30	1	70334	HEATSINK CABLE				
31	1	MS35650-304	NUT, HEX, 10-32				
32	1	MS35333-73	WASHER, IT LOCK, NO. 10				
33	1	MK-2 140 OHM	RESISTOR 140 OHM 1/4 W +/- 1%	STETTNER-TRUSH	R13		
34	1	C330C104KIR5CA	CAPACITOR 0.1 uF	KEMET	C6		
35	1	7717-107N	TRANSISTOR PAD (8 PIN)		XV1		
36	1	MK2 464 OHM	RESISTOR 464 OHM +/- 1 % 1/4 W	STETTNER-TRUSH	R10		
37	1	MK2 1.21 K NOM	RESISTOR 1.21K NOMINAL	STETTNER-TRUSH	R12		
38	AR	MIL-W-16878.ET	WIRE, 24 AWG, TEFLON, RED,BLUE,ORN				
39							
40							
41							
42							
 EFRATOM DIVISION			PARTS LIST		FSCM NO. 55761	PL 703-208-1 REV T	
					LIST TITLE LAMP BOARD		SH 2 OF 2

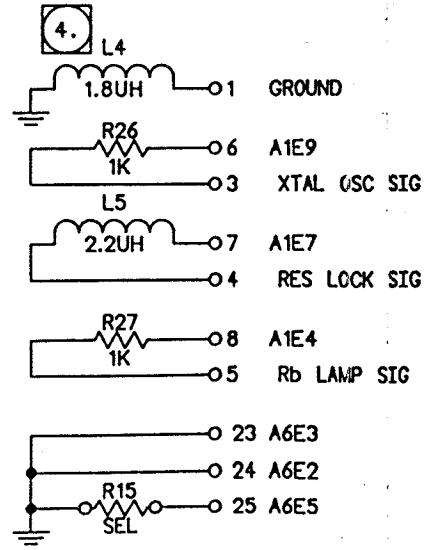
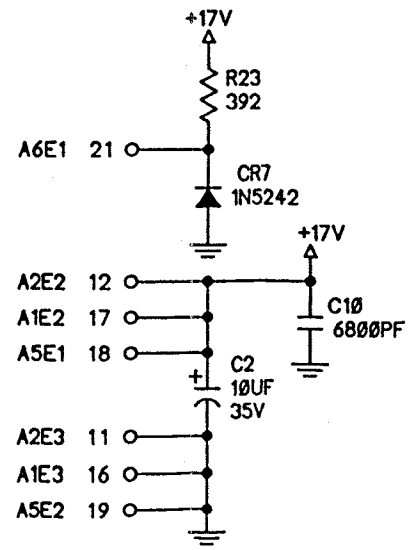


ASSEMBLY, POWER SUPPLY BOARD



- 5. REMOVE JUMPER FOR SEPARATE HEATER POWER.
- 4. L1,L2,L3,L4,L6,L7 INSTALLED WITH FILTER CONNECTOR. JUMPERS INSTALLED WITHOUT FILTER CONNECTOR.
- 3. INSTALL CR8 WITH SEPARATE HEATER POWER ONLY.
- 2. RESISTANCE VALUES ARE OHMS.
- 1. FOR ASSEMBLY SEE DWG# (TABULATION).

NOTES: UNLESS OTHERWISE SPECIFIED.




ASSEMBLY TABULATION	
703-253-1	STANDARD
703-253-2	W/ FILTER CONNECTOR
703-253-3	SEPARATE HEATER POWER


LAST USED	NOT USED
U1	-
C16	C8, 11-13, 15
R27	R1-4
CR8	-
Q1	-
L8	-
F1	-

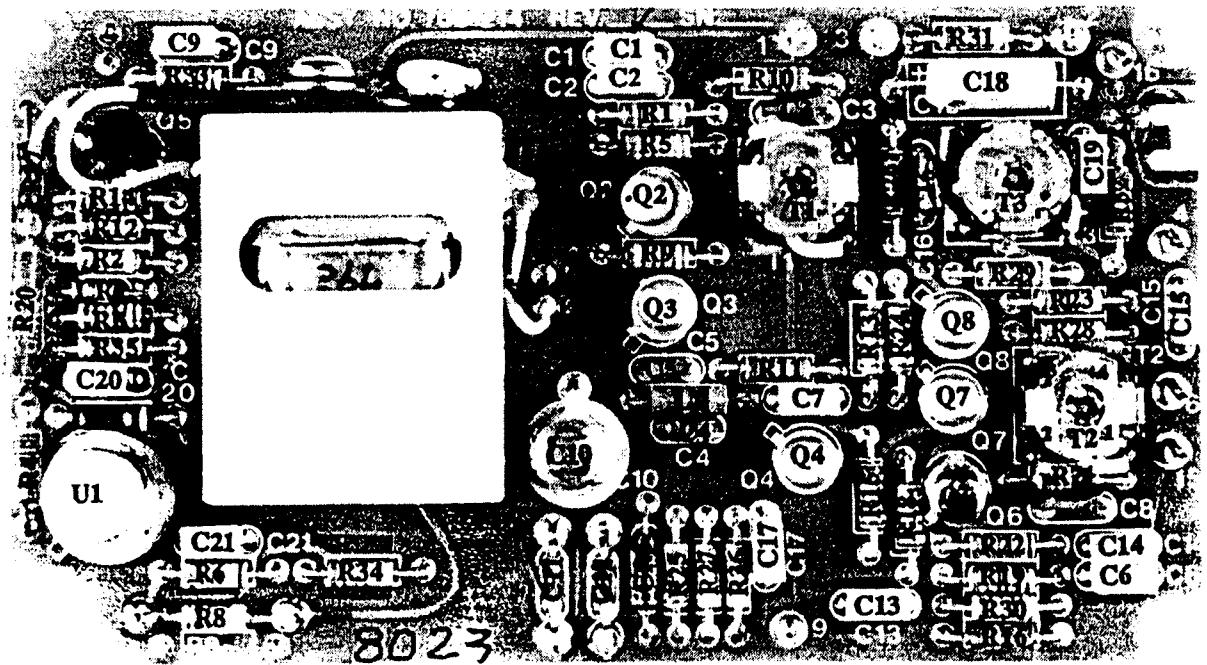
SCHMATIC, POWER SUPPLY BOARD

ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
1	1	703-255	PRINTED WIRING BOARD				
2	1	EDPT 3x4 3.3PF NPO	CAPACITOR 3.3PF		C5		
3	1	EDPT 5x6 47PF NPO	CAPACITOR 47PF		C7		
4	5	CKR05BX682K	CAPACITOR 6800PF +/-10%	AVX	C3,4,6,9,10		
5	2	CKR05BX104KS	CAPACITOR .1uF		C14,16		
6	1	T322D106M035AS	CAPACITOR 10uF 35V	KEMET	C2		
7	1	600D176G060KD4	CAPACITOR 17uF 60V	SPRAGUE	C1		
8	1	1.5KE43A	DIODE	G.S.	CR2		
9	1	1N 4578	DIODE, ZENER REF.		CR5		
10	4	1N4151	DIODE		CR1,3,4,6		
11	1	1N5242	DIODE, ZENER.		CR7		
12	1	251003	FUSE 3 AMP	LITTLE FUSE	F1		
13	1	MK2 100 OHM	RESISTOR 100 OHM		R13		
14	1	MK2 392 OHM	RESISTOR 392 OHM		R23		
15	1	MK2 2.21K	RESISTOR 2.21 K		R7, NOMINAL		
16	1	MK2 3.83K	RESISTOR 3.83 K		R25		
17	1	MK2 4.75K	RESISTOR 4.75 OHM		R22		
18	1	MK2 6.81K	RESISTOR 6.81 K		R10		
19	3	MK2 10K	RESISTOR 10 K		R12,24,8		
20	1	MK2 12.1K	RESISTOR 12.1 K		R5		
21	1	MK2 5.62K	RESISTOR 5.62 K		R9		

 EFRATOM DIVISION		PARTS LIST		FSCM NO. 55761	PL 703-253-1 REV M
				LIST TITLE POWER SUPPLY ASSEMBLY	

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
22	1	MK2 200K	RESISTOR 200K		R11		
23	6	MK2 XXX	RESISTOR SELECT		R6,15,16,17,19,20		
24	1	RW80U1R10F	RESISTOR 1.1 OHM 2W WIREWOUND	D	R14		
25	1	3059Y-1-503	POTENTIOMETER 50K	BOURNES	R21		
26	1	2N3906	TRANSISTOR		Q1		
27	1	MS75084-1	INDUCTOR 1.2 uH	DALE	L8		
28	1	LM748H	INTEGRATED CIRCUIT		U1		
29		NOT USED					
30	1	7717-107N	PAD - 8 PIN SPREADER	T	XU1		
31	42	70416-3	SOLDER TERMINAL	K			
32		NOT USED					
33	1	MK-2 1K	RESISTOR 1K		R26		
34	1	MK-2 1K	RESISTOR 1K		R27		
35	1	MS75084-4	INDUCTOR 2.2 uH	DALE	L5		
36	1	MK2 681 OHM	RESISTOR 681 OHM		R18		
37					R25		
38					R22		
39					R10		
40					R12,24,8		
41					R5		
42					R9		

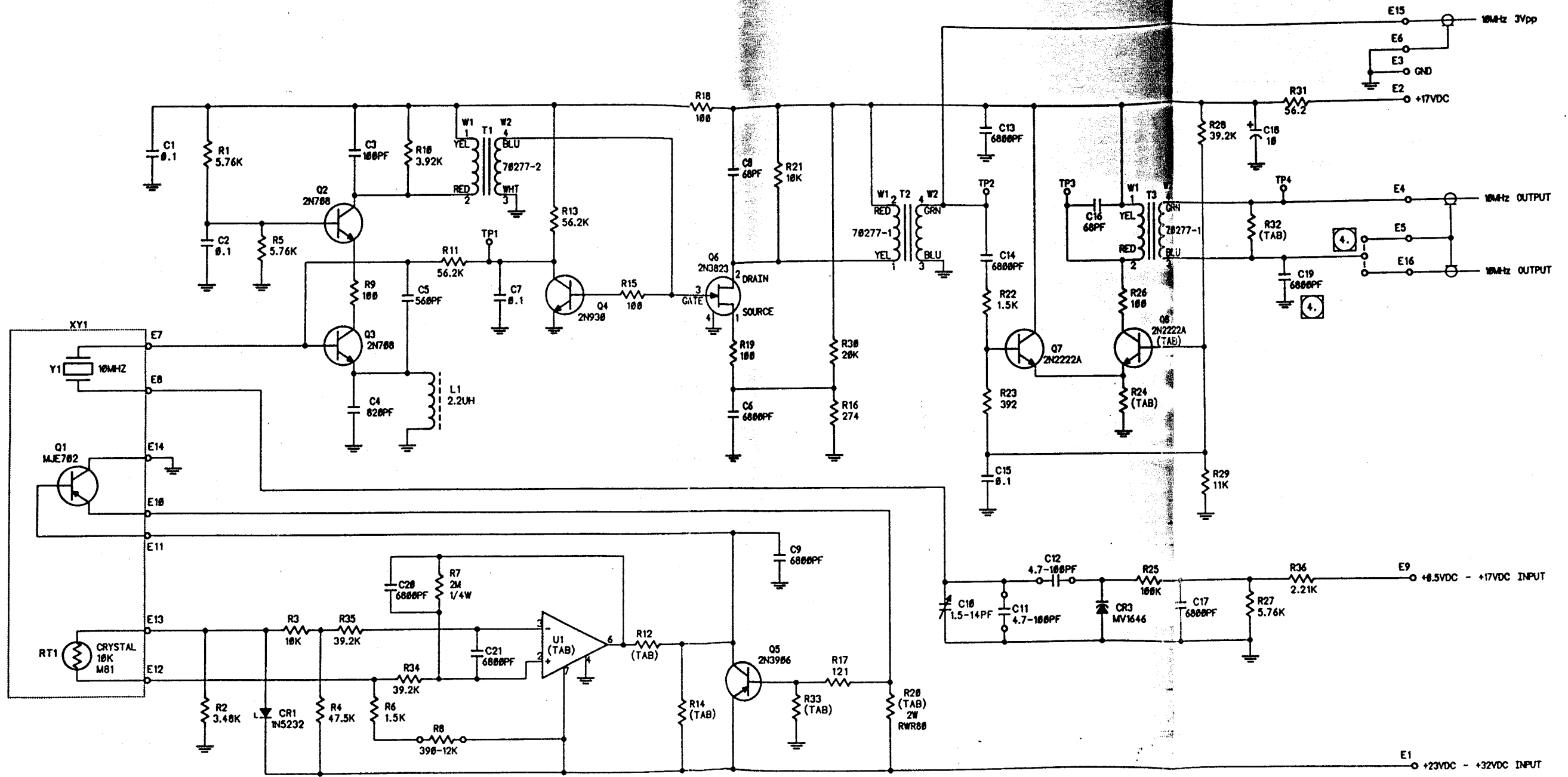
 EFRATOM DIVISION	PARTS LIST	FSCM NO. 55761	PL 703-253-1 REV M
		LIST TITLE POWER SUPPLY ASSEMBLY	



ASSEMBLY, CRYSTAL OSCILLATOR BOARD

A20

TABULATION								
DASH #	U1	R12	R14	R20	R24	R32	R33	Q8
-1	7498M	6.81K	1K	1.1	221	100	10K	NO HEATSINK
-2	LM143H	6.81K	1K	1.1	221	100	10K	NO HEATSINK
-3	7498M	3.09K	2K	0.006	221	100	5.76K	NO HEATSINK
-4	7498M	6.81K	1K	1.1	107	392	10K	HEATSINK



4. WHEN USING SINGLE 10MHz OUTPUT, INSTALL C19 AND INSTALL JUMPER TO E3. WHEN USING DOUBLE 10MHz OUTPUT, OMIT C19 AND INSTALL JUMPER TO E4.
- ALL RESISTANCE VALUES ARE OHMS.
 - ALL CAPACITANCE VALUES ARE MICROFARADS.
 - FOR ASSEMBLY SEE DWG# 703-214.
- NOTES: UNLESS OTHERWISE SPECIFIED.

LAST USED	NOT USED
U1	-
C21	-
R36	-
CR3	CR2
Y1	-
Q8	-
L1	-
T3	-
RT1	-
E16	-

SCHEMATIC, CRYSTAL OSCILLATOR BOARD

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
1	1	703-216	PRINTED WIRING BOARD	EFRATOM			
2	1	70218	CRYSTAL THERMOSTAT ASSEMBLY	EFRATOM			
3	2	EDPT 69PF NPO	CAPACITOR 68 PF	STETTNER-TRUSH	C8, C16		
4	1	EDPT 100PF NPO	CAPACITOR 100 PF	STETTNER-TRUSH	C3		
5	1	EDPT 560PF Y5P	CAPACITOR 560 PF	STETTNER-TRUSH	C5		
6	1	EDPT 820PF Y5P	CAPACITOR 820 PF	STETTNER-TRUSH	C4		
7	8	CKR05BX682KS	CAPACITOR 6800 PF +/- 10%	AVX	C6,9,13,14,17,19,20,21		
8	4	CKR05BX104KS	CAPACITOR .1 UF	KEMET	C1,2,7,15		
9	1	T322D106M035AS	CAPACITOR 10 UF +/- 20% 35V	KEMET	C18		
10	2	EDPT - SELECT	CAPACITOR SELECT	STETTNER-TRUSH	C11,12		
11	1	PC32T140	CAPACITOR VARIABLE	JOHANSON MFG CO.	C10		
12	1	1N5232B	CAPACITOR ZENER	MALLORY	CR1		
13	1	MV1646	DIODE VARACTOR MOTOROLA		CR3		
14	1	MS75084-4	INDUCTOR 2.2 UH	DALE	L1		
15	2	2N708	TRANSISTOR	MALLORY	Q2,3		
16	1	2N930	TRANSISTOR	FAIRCHILD	Q4		
17	2	JAN2N2222A	TRANSISTOR	FAIRCHILD	Q7,8		
18	1	2N3823	TRANSISTOR	FAIRCHILD	Q6		
19	1	2N3906	TRANSISTOR	FAIRCHILD	Q5		
20	1	MK2 56.2 OHM	RESISTOR 56.2 OHM	STETTNER-TRUSH	R31		
21	1	MK2 11 KOHM	RESISTOR 11 KOHM	STETTNER-TRUSH	R29		

FSCM NO. 55761 PL 703-214-1 REV K


PARTS LIST

OSCILLATOR BOARD

LIST TITLE

SH 1 OF 3



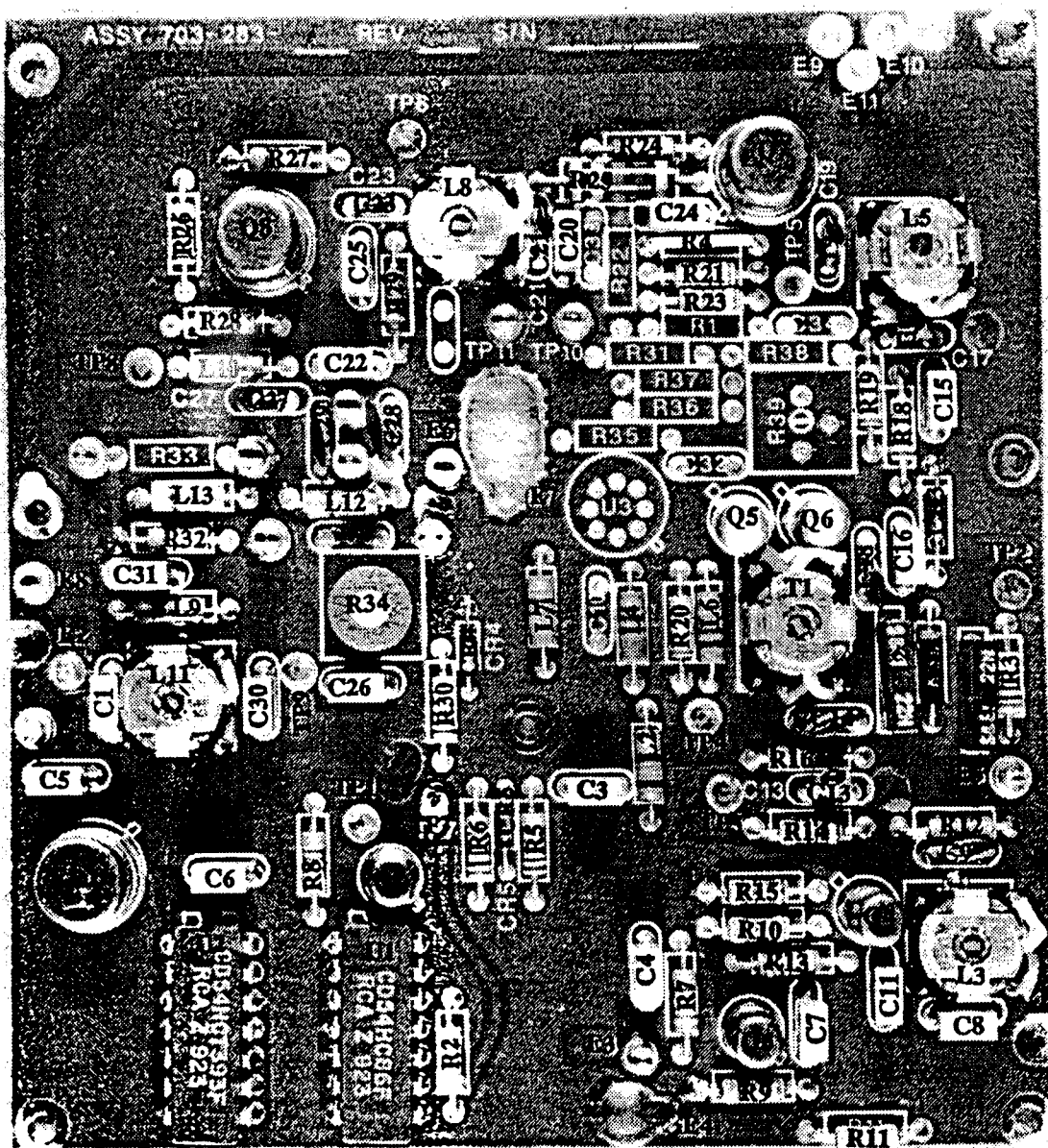
ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
22	6	MK2 100 OHM	RESISTOR 100 OHM	STETTNER-TRUSH	R9,15,18,19,26,32		
23	1	MK2 121 OHM	RESISTOR 121 OHM	STETTNER-TRUSH	R17		
24	1	MK2 274 OHM	RESISTOR 274 OHM	STETTNER-TRUSH	R16		
25	1	MK2 1 KOHM	RESISTOR 1 KOHM	STETTNER-TRUSH	R14		
26	2	MK2 1.5 KOHM	RESISTOR 1.5 KOHM	STETTNER-TRUSH	R22,6		
27	1	MK2 392 OHM	RESISTOR 392 KOHM	STETTNER-TRUSH	R23		
28	1	MK2 2.21 KOHM	RESISTOR 2.21 KOHM	STETTNER-TRUSH	R36		
29	1	MK2 3.48 KOHM	RESISTOR 3.48 KOHM	STETTNER-TRUSH	R2		
30	1	MK2 3.92 KOHM	RESISTOR 3.92 KOHM	STETTNER-TRUSH	R10		
31	3	MK2 5.76 KOHM	RESISTOR 5.76 KOHM	STETTNER-TRUSH	R1,5,27		
32	1	MK2 6.81 KOHM	RESISTOR 6.81 KOHM	STETTNER-TRUSH	R12		
33	3	MK2 10 KOHM	RESISTOR 10 KOHM	STETTNER-TRUSH	R3,21,33		
34	1	MK2 20 KOHM	RESISTOR 20 KOHM	STETTNER-TRUSH	R30		
35	3	MK2 39.2 KOHM	RESISTOR 39.2 KOHM	STETTNER-TRUSH	R28,34,35		
36	1	MK2 47.5 KOHM	RESISTOR 47.5 KOHM	STETTNER-TRUSH	R4		
37	2	MK2 56.2 KOHM	RESISTOR 56.2 KOHM	STETTNER-TRUSH	R11,13		
38	1	MK2 100 KOHM	RESISTOR 100 KOHM	STETTNER-TRUSH	R25		
39	1	MK2 SELECT	RESISTOR SELECT	STETTNER-TRUSH	R8		
40	1	RW80U1R10F	RESISTOR 1.1 OHM 2 W		R20		
41	1	RCR07G205JS	RESISTOR 2 MEG +/- 5% 1/4 W	ALLEN-BRADLEY	R7		
42	1	LM741HMQB	INTEGRATED CIRCUIT	FAIRCHILD	U1		
 EFRATOM DIVISION				PARTS LIST		FSCM NO. 55761	
						PL 703-214-1 REV K	
				LIST TITLE OSCILLATOR BOARD		SH <u>2</u> OF <u>3</u>	

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	
						UNIS PART NO.	
43	2	70277-1	TRANSFORMER (YEL,RED)(BLU,GRN)	EFRATOM	T2,3		
44	1	70277-2	TRANSFORMER (YEL,RED)(BLU,GRN)	EFRATOM	T1		
45	14	70416-3	TERMINAL	KEMET			
46	6	7717-133N	PAD TSTR (TO-18)	THERMALLOY	XQ2,3,4,6,7,8		
47	1	7717-107N	PAD TSTR (8-PIN)	THERMALLOY	XU1		
48	4	70425-3	SCREW M2X6				
49	4	70414-19	WASHER SPRING M2				
50	4	2191	WASHER FIBER	HERMAN H. SMITH			
51	AR	00-W-343, TYPE S	WIRE TINNED 30 AWG				
52	AR	AMS-3655	SLEEVING, 30 AWG TEFLON				
53	AR	SN63WRMAP3	SOLDER		(UNDER C10)		
54	1	5622-1-007	WASHER, MYLAR				
55	1	MK2 221 OHM	RESISTOR 221 OHM	STETTNER-TRUSH	R24		
56							
57							
58							
59							
60							
61							
62							
63	:						

FSCM NO. 55761 PL 703-214-1 REV K


PARTS LIST
LIST TITLE OSCILLATOR BOARD
SH 3 OF 3

 EFRATOM DIVISION



ASSEMBLY, SYNTHESIZER BOARD

ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE UNIS PART NO.
1	1	703-284	PRINTED WIRING BOARD			
2	1	EDPT 3.9 PF NPO	CAPACITOR 3.9 PF	STETTNER-TRUSH	C13	
3	1	EDPT 15 PF	CAPACITOR 15 PF	STETTNER-TRUSH	C21	
4	2	EDPT 22 PF NPO	CAPACITOR 22 PF	STETTNER-TRUSH	C19,27	
5	1	EDPT 33 PF NPO	CAPACITOR 33 PF	STETTNER-TRUSH	C23	
6	1	EDPT 27 PF NPO	CAPACITOR 27 PF	STETTNER-TRUSH	C17	
7	1	EDPT 47 PF NPO	CAPACITOR 47 PF	STETTNER-TRUSH	C18	
8						
9	1	EDPT 68 PF NPO	CAPACITOR 68 PF	STETTNER-TRUSH	C9	
10	1	EDPT 82 PF NPO	CAPACITOR 82 PF	STETTNER-TRUSH	C29	
11	2	EDPT 100 PF NPO	CAPACITOR 100 PF	STETTNER-TRUSH	C14, C28	
12	1	CO52C272K5G5CA	CAPACITOR 2700 PF	KEMET	C30	
13	12	CKR05BX682KS	CAPACITOR 6800 PF	KEMET	C1,3,4,7,8,11,16,22,24,25,26,31	
14						
15	2	22NA473J	CAPACITOR .047 UF	S & EI	C2,12	
16	4	CKR05BX104K	CAPACITOR 0.1 UF		C5,6,15,20	
17	3	1N4151	DIODE		CR3,4,5	
18	1	MV1638	DIODE, VARACTOR		CR6	
19	2	MS75083-3	INDUCTOR 0.15 UH		L6,10	
20	5	MS75084-9	INDUCTOR 5.6 UH		L4,7,9,12,13	
21	1	MS75084-15	INDUCTOR 18 UH		L2	

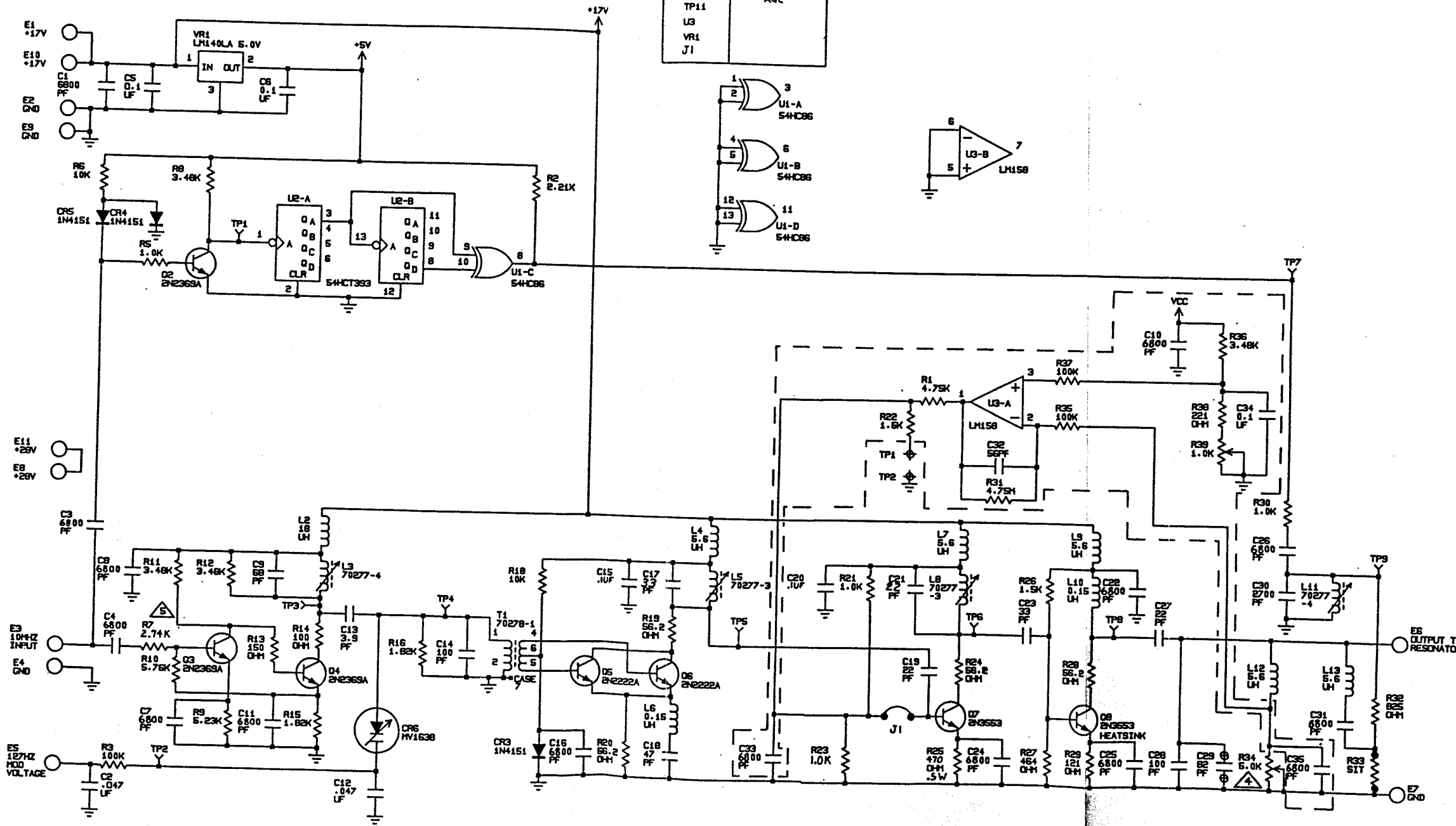
 EFRATOM DIVISION	PARTS LIST		FSCM NO. 55761	PL 703-283-1 REV C
	LIST TITLE		SYNTHESIZER BOARD	
			SH	1 OF 3

NOTES: UNLESS OTHERWISE SPECIFIED
 RESISTORS ARE 1/4W, 1%, MK-2, METAL FILM
 1. RESISTORS ARE 1/10W, 1%, MK-2, METAL FILM.
 2. CAPACITORS ARE CERAMIC, VALUES ARE IN MICRO FARADS.
 3. FOR ASSEMBLY DRAWING SEE DRAWING 703-283

⚠ R31 IS NOT USED WHEN VARIABLE RESISTOR R34 IS USED.
 ⚠ R7 VALUE: -1 (NORMAL) = 2.7K
 -2 (LOW NOISE) = 4.8K

LAST USED	NOT USED
C34	CR1, CR2
CR6	
E11	
L13	L1
Q8	Q1
R39	R17, R4
T1	AGC
TP11	
U3	
VR1	
J1	

POWER CHART		
DEVICE	PIN NO.	
	+5V	+17V GND
U1	14	7
U2	14	7
U3	8	4



SCHEMATIC, SYNTHESIZER BOARD

ITEM NO.	QTY RECD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
22	2	70277-3	INDUCTOR, VAR (RED, YEL)		L5,8		
23	2	70277-4	INDUCTOR, VAR (GRN, YEL)		L3,11		
24	2	2N222A	TRANSISTOR		Q5,6		
25	3	2N2369A	TRANSISTOR		Q2,3,4		
26	2	2N3553	TRANSISTOR		Q7,8		
27	4	MK2 56.2 OHM	RESISTOR 56.2 OHM		R19,20,24,28		
28	1	MK2 100 OHM	RESISTOR 100 OHM		R14		
29	1	MK2 121 OHM	RESISTOR 121 OHM		R29		
30	1	MK2 150 OHM	RESISTOR 150 OHM		R13		
31	1	MK2 221 OHM	RESISTOR 221 OHM		R25		
32	1	MK2 464 OHM	RESISTOR 464 OHM		R27		
33	1	MK2 825 OHM	RESISTOR 825 OHM		R32		
34	2	MK2 1.0 KOHM	RESISTOR 1.0 KOHM		R30		
35	1	RCR206471JS	RESISTOR 470 OHM 1/2 W		R25		
36	1	MK2 1.50 KOHM	RESISTOR 1.50 KOHM		R26		
37	2	MK2 1.82 KOHM	RESISTOR 1.82 KOHM		R15,16		
38	1	MK2 2.21 KOHM	RESISTOR 2.21 KOHM		R2		
39	3	MK2 3.48 KOHM	RESISTOR 3.48 KOHM		R8		
40	1	MK2 2.21 KOHM	RESISTOR 1.0 KOHM		R23		
41	1	MK2 5.23 KOHM	RESISTOR 5.23 KOHM		R9		
42	1	MK2 5.76 KOHM	RESISTOR 5.76 KOHM		R10		

FSCM NO. 55761 PL 703-283-1 REV C

PARTS LIST

LIST TITLE SYNTHESIZER BOARD

SH 2 OF 3

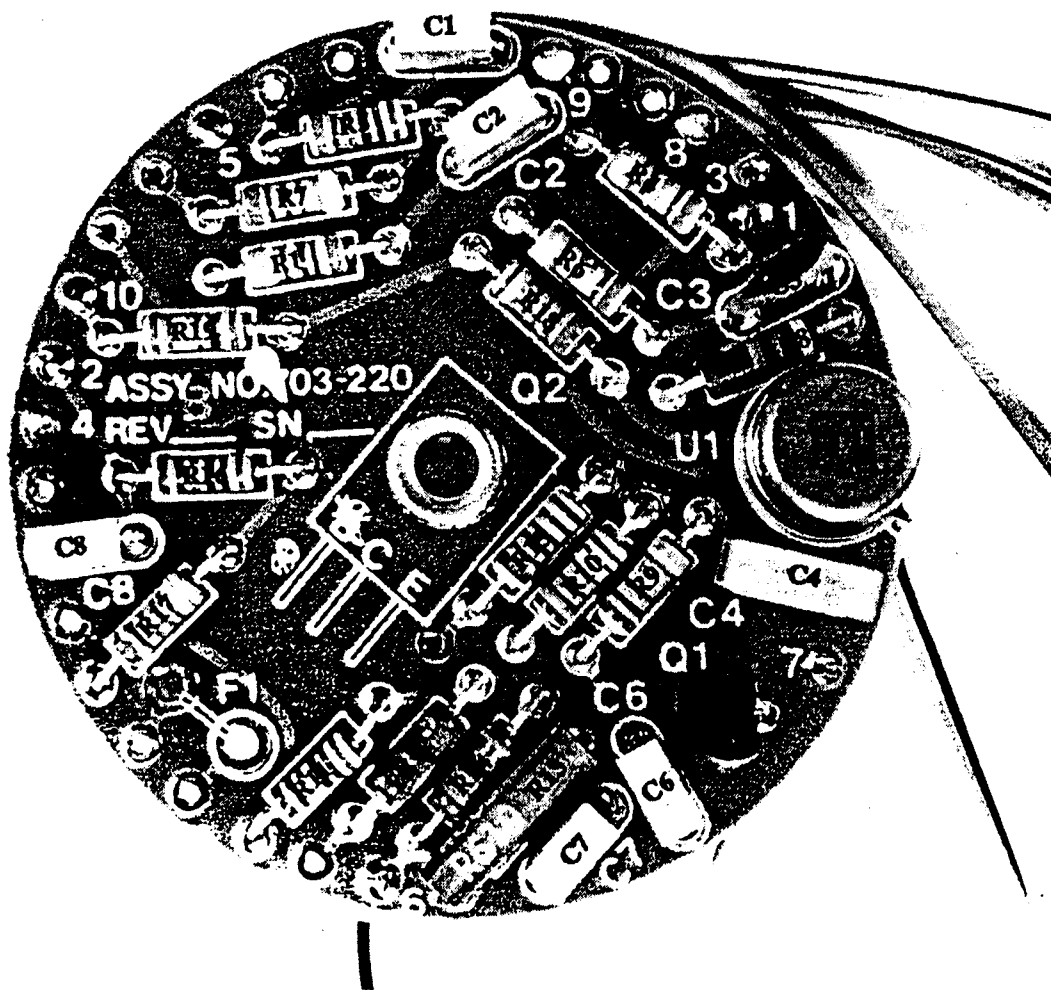


REFRATOR FORM NO. 6-6586

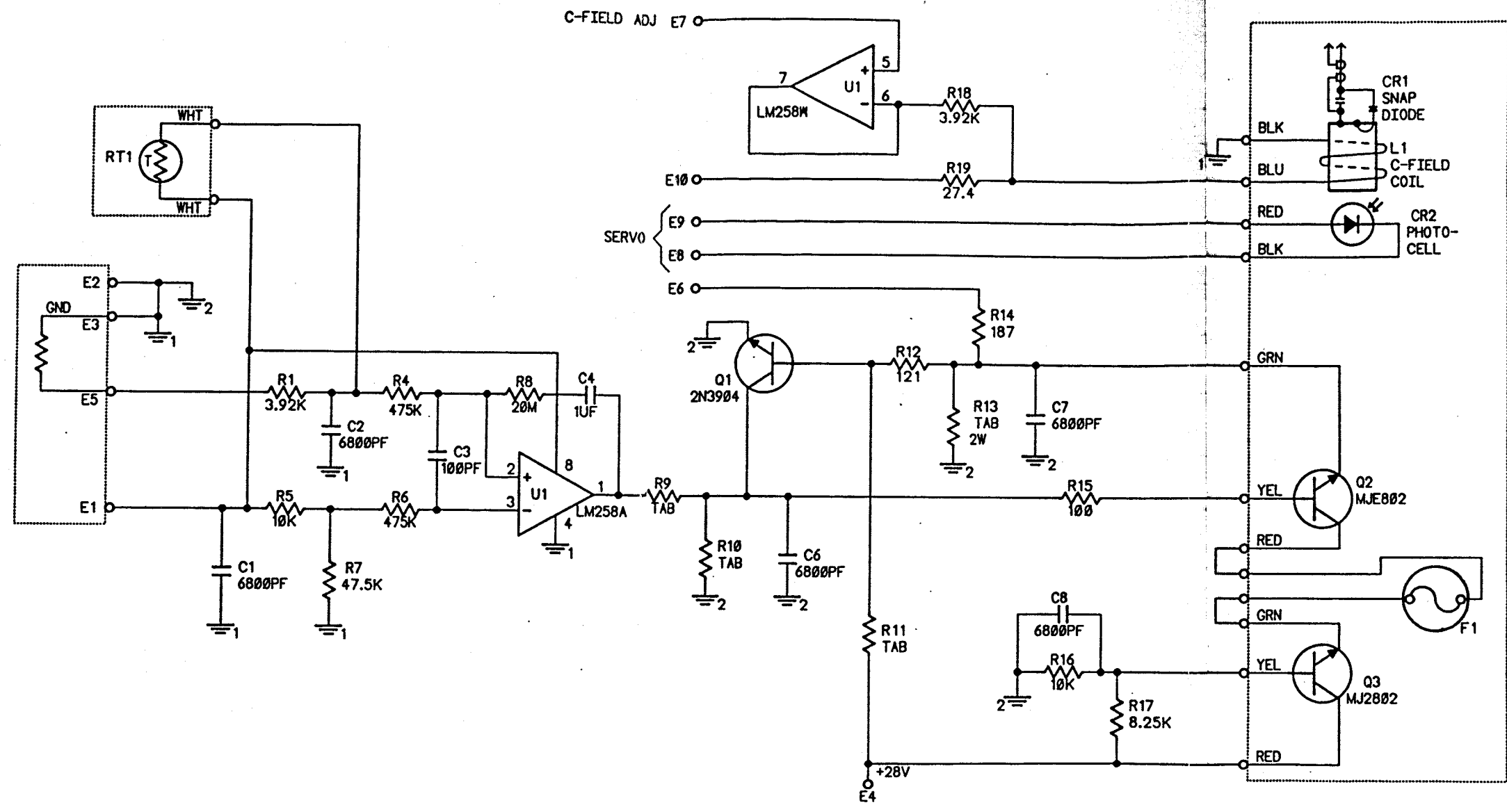
ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
43	2	MK2 10.0 KOHM	RESISTOR 10.0 KOHM	STETTNER-TRUSH	R6,18		
44	1	MK2 100 KOHM	RESISTOR 100 KOHM	STETTNER-TRUSH	R3		
45	1	MK2 SELECT	RESISTOR SELECT	STETTNER-TRUSH	R33		
46							
47							
48	1	3339P-1-502	RESISTOR, VAR 5.0 KOHM (4 TURN)	BOURNES	R34		
49	1	MK2 1.0 K	RESISTOR 1.0 KOHM		R21		
50	1	70278-1	TRANSISTOR		T1		
51	1	54HC86J	INTEGRATED CIRCUIT		U1		
52	1	54HCT393F	INTEGRATED CIRCUIT		U2		
53							
54	1	LM140LAH 5.0V	VOLTAGE REGULATOR		VR1		
55	1	200-250-.318	HEATSINK		XQ8		
56	4	7717-4N	TRANSISTOR PAD (TO-5)				
57	4	7717-93N	TRANSISTOR PAD (TO-18)				
58	16	70416-3	TERMINAL, BIFURCATED		E1-E11		
59	AR	SN63WRMAP3	SOLDER				
60	1	MK2 2.74 KOHM	RESISTOR 2.74 KOHM		R7		
61							
62							
63							

PARTS LIST
 LIST TITLE: **SYNTHESIZER BOARD**
 FSCM NO. **55761** PL **703-283-1** REV **C**
 SH **3** OF **3**


EFRATOM
DIVISION
EFRATOM FORM NO. 4-5946




ASSEMBLY, RESONATOR BOARD



TABULATION					
ASSEMBLY	R9	R10	R11	R13	USED ON
703-220-1	3.2K	1K	10K	0.619	FRK-H
703-220-3	2.32K	845	4.75K	0.402	FRK-HLN(12VDC)

LAST USED	NOT USED
U1	-
C8	C5
R19	R2,3
CR2	-
Q3	-
F1	-
RT1	-
L1	-

2. RESISTANCE VALUES ARE OHMS.
 1. FOR ASSEMBLY SEE DWG# 703-220.
 NOTES: UNLESS OTHERWISE SPECIFIED.

ITEM NO.	QTY REQD	MIL PART NO. OR MFR PART NO.	NAME, DESCRIPTION	MIL-SPEC OR MFR NAME	DESIGNATOR	REFERENCE	UNIS PART NO.
1	1	703-222	PRINTED WIRING BOARD				
2	1	EDPT 100PF NPO	CAPACITOR 100PF		C3		
3	5	CKR05BX682KS	CAPACITOR 6800PF +/-10%		C1,2,6,7,8		
4	1	CKR06BX105KS	CAPACITOR 1.0 VF		C4		
5	1	2N3904	TRANSITOR		Q1		
6	1	MK-2 27.4 OHM	RESISTOR 27.4 OHM		R19		
7	1	MK-2 100 OHM	RESISTOR 100 OHM		R15		
8	1	MK-2 121 OHM	RESISTOR 121 OHM		R12		
9	1	MK-2 187 OHM	RESISTOR 187 OHM		R14		
10	1	MK-2 1.0 K	RESISTOR 1.0 K		R10		
11	2	MK-2 3.92 K	RESISTOR 3.92 K		R1,18		
12		NOT USED					
13	1	MK-2 3.24 K	RESISTOR 3.24 K		R9		
14	1	MK-2 8.25 K	RESISTOR 8.25 K		R17		
15	3	MK-2 10 K	RESISTOR 10 K		R5,16,11		
16	1	MK-2 47.5 K	RESISTOR 47.5 K		R7		
17	2	MK-2 475 K	RESISTOR 475 K		R4,6		
18	1	RCR07G206JS	RESISTOR 20 MEG, 1/4 W		R8		
19	1	RWR80SR619FR	RESISTOR .619 OHM, 2 W		R13		
20	1	LM258A	INTEGRATED CIRCUIT		U1		
21	1	D139-002	THERMAL CUTOFF, MTP	3-M	F1		
 EFFRATOM DIVISION			PARTS LIST LIST TITLE		FSCM NO. 55761		PL 703-220-1 REV K
					RESONATOR HEATER		

