

TECHNICAL MANUAL
TM0107

RUBIDIUM FREQUENCY STANDARD
MODEL FE-5650A SERIES

OPERATION AND MAINTENANCE INSTRUCTIONS

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Section 1. TECHNICAL DESCRIPTION

EQUIPMENT DESCRIPTION

1-1

General

1-1.1

The **Rubidium Frequency Standard (RFS) FE-5650A Series** consists of self-contained, solid-state, modular, atomic frequency standards available in various options, depending on the output frequency, package, and supply voltage requirements. The entire series may be grouped into several versions according to the output interface, which can be adapted to different requirements.

The simplest version provides a sine wave output at 50.255+ MHz (FE-5650A Option 01).

Another version uses a factory-set direct digital synthesizer (DDS) in the output interface allowing virtually any user specified output frequency from 1 Hz to 10 MHz for square wave and 5 MHz to 20 MHz for sine wave. The standard sinusoidal frequency generated by the **RFS** is 10 MHz. The following standard

frequencies are also available: 2.048, 5, 10.23,13 and 15 MHz.

A third version incorporates a digital communication link in addition to the DDS output. This enables remote adjustment of the output frequency by computer through an RS-232 interface.

Refer to Table 1 for a summary of the FE-5650A Series by option. Different options may be combined to form customized configurations based on output frequency, packaging and supply voltage requirements.

Controls

1-1.2

There is one external frequency adjustment control on the **RFS**. With the external frequency adjust potentiometer, the setting resolution is 1×10^{-11} over a range of 3×10^{-9} .

Packaging/Connectors

1-1.3

The standard **RFS** package is illustrated in Figure 1, and measures 1.44 x 3.00 x 3.03 inches, allowing installation within a standard 1.75 inch-height rack-mount chassis.

Two additional package configurations are available, and are shown in Figures 2 and 3. These include a heatsink mounting plate, for regular or right angle orientation.

All connectors are located on the mounting surface. Input power is supplied through a 9-pin D-subminiature connector. The RF output is supplied on an SMA coax connector.

Input/Output functions for the **RFS** are defined in Table 2.

Reference Data

1-1.4

Reference data applicable to the **RFS** are listed in Table 3. The data include output signal characteristics, environmental requirements and input requirements.

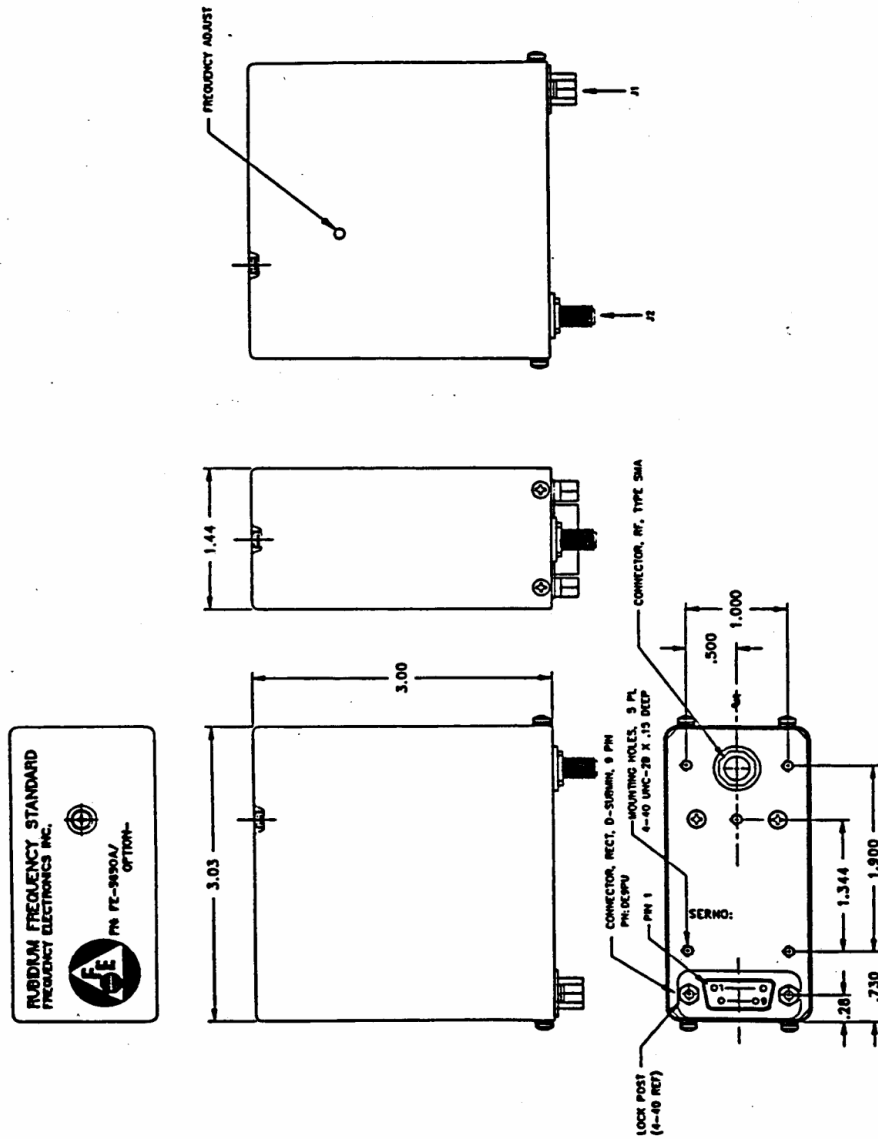


FIGURE 1. RUBIDIUM FREQUENCY STANDARD MODEL FE-5650A

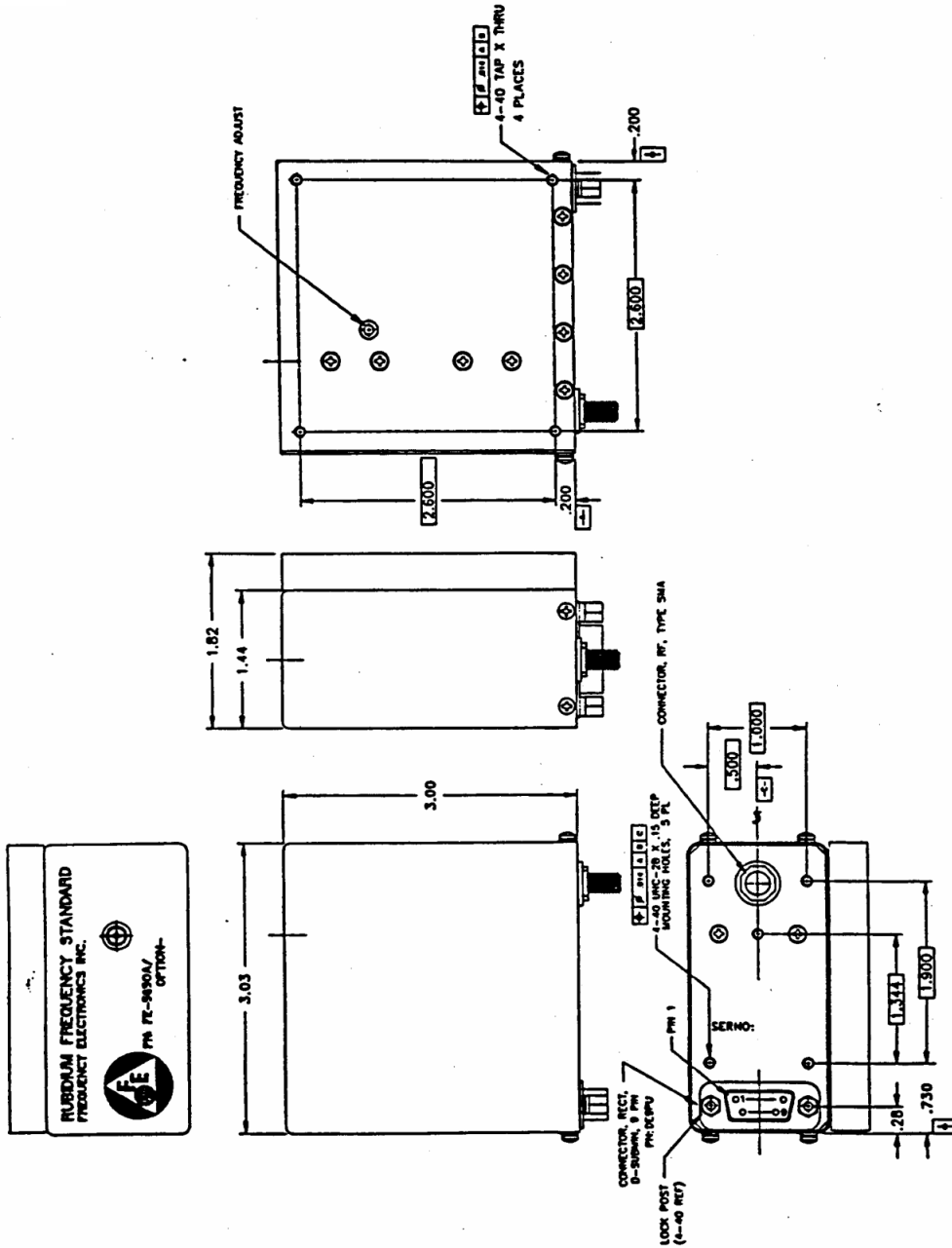


FIGURE 2. RUBIDIUM FREQUENCY STANDARD MODEL FE-5650A WITH HEATSINK MOUNTING PLATE (OPTION 14)

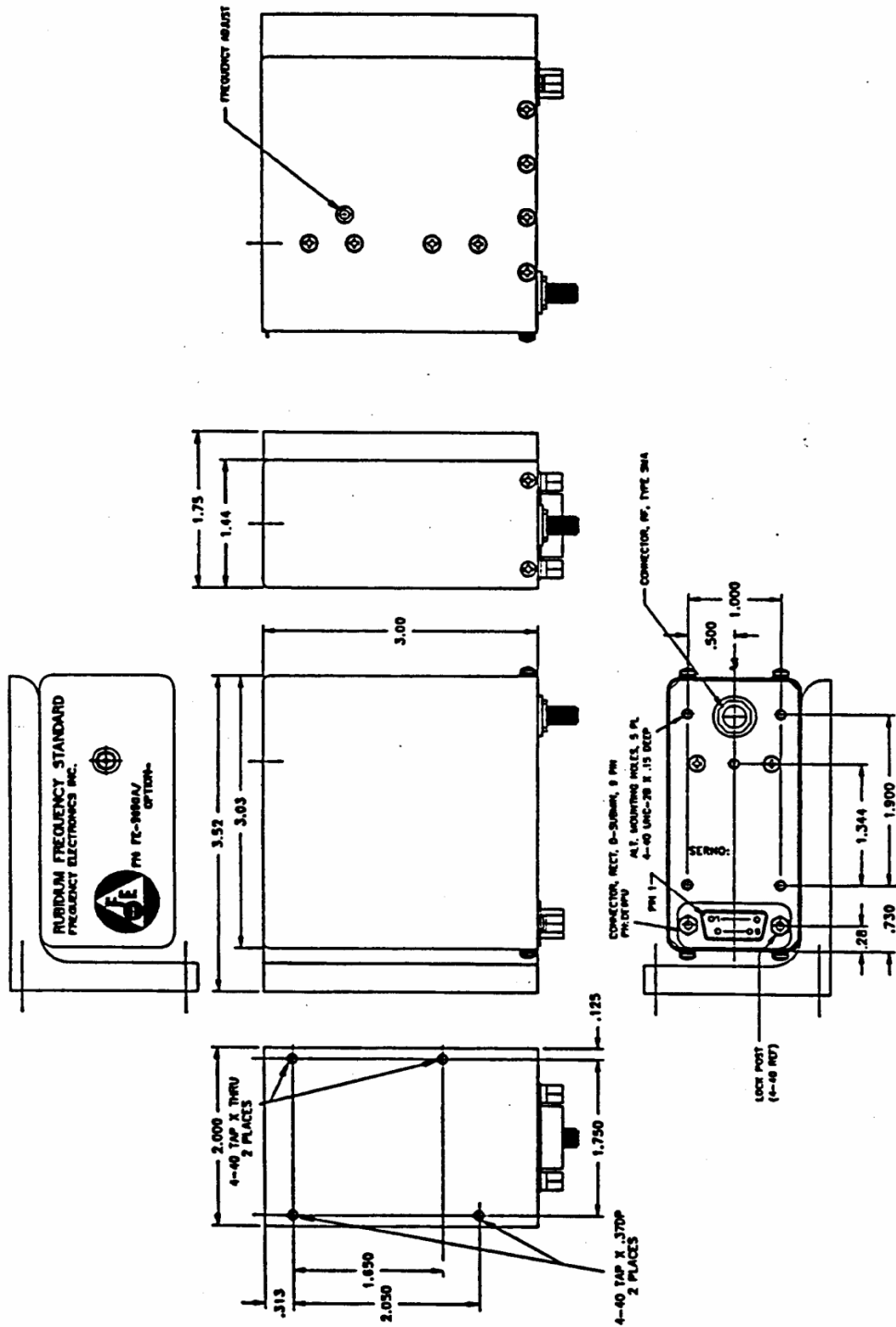


FIGURE 3. RUBIDIUM FREQUENCY STANDARD MODEL FE-5650A WITH HEATSINK MOUNTING PLATE (OPTION 15)

**TABLE 1. RUBIDIUM FREQUENCY STANDARD FE-5650A SERIES
SUMMARY**

OPTION	DESCRIPTION
01	50.255055 MHz Sine Wave
02	Remote Digital Control - RS-232; Range: 2×10^{-7} , Resolution: 3×10^{-12}
	The RS-232 option permits control of the output frequency by means of a PC or RS-232 Ported Data Terminal Equipment. Baud rate and byte format are selected by internal digiswitches. Also, lock/unlock indication is transmitted by the option 02 interface for system monitoring of Rubidium Standard status.
03	5 MHz-FEI Standard Frequency
04	15 MHz-FEI Standard Frequency
05	13 MHz-FEI Standard Frequency
06	2.048 MHz-FEI Standard Frequency
07	10.23 MHz-FEI Standard Frequency
08	Customer Specified Frequency - Setting Resolution: 0.012 Hz. Any frequency from 1 Hz to 10 MHz for square wave and 5 MHz to 20 MHz for sine wave.
09	Square Wave Output: TTL, 50%
11	Wideband Digital Tuning (DDS Output)
	The Wideband Digital Tuning option permits selecting any frequency from 1 Hz to 20 MHz in steps of 2×10^{-12} Hz. The +3 dBm output is a stepped approximation to a sine wave at the desired frequency. Precision of the steps in the approximation is 0.1% and spurs are below -60 dBc. A 25 MHz low pass filter reduces harmonic content in the output for higher output frequencies. The RFS is tuned through an RD-232 interface.
14	Mechanical package as shown in Figure 2 with heatsink mounting plate.
15	Mechanical package as shown in Figure 3 with right angle heatsink mounting plate.
16	Improved Spurious: -80 dBc at ± 5 MHz from carrier.
17	Temperature Range: -31°C to $+55^{\circ}\text{C}$
18	Conformally-coated PC Boards
19	LED Monitor on top of unit to indicate loop lock condition.
20	Operates on a single +15 Vdc supply voltage instead of +15 and +5 Vdc.
21	Increased RF output level of 1.0 Vrms (+13 dBm).
22	Unit is foamed for operation in severe shock and vibration environment.
23	Temperature Range: -55°C to $+71^{\circ}\text{C}$.
25	Operates on a single +22 to 32 Vdc supply voltage instead of +15 and +5 Vdc.

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**TABLE 1. RUBIDIUM FREQUENCY STANDARD FE-5650A SERIES
SUMMARY**

OPTION	DESCRIPTION
26	Loop Lock Indicator reversed < 1 Vdc = Unlocked > 3 Vdc = Locked
27	Temperature Range: -10°C to +65°C
28	Improved Drift Stability: 4×10^{-12} /day and 5×10^{-10} /year
29	Improved Drift Stability: 2×10^{-10} /year after 1 year
30	Analog Tuning: 0 to 10V
31	Short Term Stability: $5 \times 10^{-12} \sqrt{\tau}$
32	Frequency vs. Temperature: $\pm 1 \times 10^{-10}$
33	Frequency vs. Temperature: $1 \times 10^{-12}/2$ °F (65 to 85 °F)
35	Analog Tuning: 7×10^{-9} range
36	Temperature Operation to -10°C
37	Temperature Operation to -20°C.
38	Temperature Operation to -30°C.
39	Temperature Operation to -40°C.
40	Temperature Operation to -55°C.
41	Temperature Operation to +55°C.
42	Temperature Operation to +60°C.
43	Temperature Operation to +65°C.
44	Temperature Operation to +71°C.
46	Reverse Voltage Protection.
47	Horizontal Heaksink # 2.
48	Frequency vs. Temperature: $\pm 5 \times 10^{-11}$.
49	Improved Phase Noise: phase locked to OCXO
51	Horizontal Heaksink # 2.
52	Filtered +15 V input
53	+15 Vdc @ 1 amp maximum

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TABLE 2A. CONNECTOR FUNCTIONS (EXCEPT OPTIONS 20 & 25)

PIN	FUNCTION	NOTES
J1-1	+15V	DC power input
J1-2	+15V Return	Provides DC return
J1-3	Loop Lock Indicator	Indicates whether or not the output frequency is stabilized to the Rb atomic reference
J1-4	+5V	DC power input
J1-5	+5V Return	Provides DC return
J1-6	NOT USED	
J1-7	Analog Voltage Tuning Return	
J1-8	+ Analog Voltage Tuning	
J1-9	NOT USED	
J2	Frequency Output	

TABLE 2B. CONNECTOR FUNCTIONS: OPTION 20

PIN	FUNCTION	NOTES
J1-1	+15V	DC power input
J1-2	+15V Return	Provides DC return
J1-3	Loop Lock Indicator	Indicates whether or not the output frequency is stabilized to the Rb atomic reference
J1-4-6	NOT USED	
J1-7	Analog Voltage Tuning Return	
J1-8	+ Analog Voltage Tuning	
J1-9	NOT USED	
J2	Frequency Output	

TABLE 2C. CONNECTOR FUNCTIONS: OPTION 25

PIN	FUNCTION	NOTES
J1-1	+22 TO 32 Vdc	DC power input
J1-2	DC Return	Provides DC return
J1-3	Loop Lock Indicator	Indicates whether or not the output frequency is stabilized to the Rb atomic reference
J1-4-6	NOT USED	

J1-7	Analog Voltage Tuning Return	
J1-8	+ Analog Voltage Tuning	
J1-9	NOT USED	
J2	Frequency Output	

TABLE 3. REFERENCE DATA for RUBIDIUM FREQUENCY STANDARD FE-5650A

PARAMETER	SPECIFICATION
Frequency	10 MHz*
Type	Sinusoidal
Amplitude (minimum)	0.5 Vrms into 50Ω (+7dBm)
Adjustment Resolution (Total C-field and DDS switches)	1×10^{-11} over range of 2×10^{-7}
C-field potentiometer Resolution	1×10^{-11} over range of 2×10^{-9}
Internal DDS switches Resolution	1.2×10^{-9} steps over range of 2×10^{-7}
Drift	2×10^{-9} /year 2×10^{-11} /day
Short Term Stability: 1 sec ≤ 100 sec	1.4×10^{-11} /
Retrace	5×10^{-11}
Phase Noise (fo = 10 MHz)	@ 10 Hz: -90 dBc @ 100 Hz: -125 dBc @ 1000 Hz: -145 dBc
Analog Tuning	0 to 5V for 2×10^{-9} range
Input Voltage Sensitivity	2×10^{-11} / (15V to 16V)
Frequency vs. Temperature (-5°C to +50°C)	$\pm 3 \times 10^{-11}$
Spurious Outputs	-60 dBc
Harmonics	-30 dBc
Loop Lock Indication	> 3Vdc = Unlocked < 1Vdc = Locked
Input Power (@ 25°C)	8 watts steady state, 32 watts peak
DC Input Voltage/Current	15V to 18V @ 1.7A peak and 0.5A steady-state 5V @ ma; except Opt 20: +15V @ 1.7A peak, 0.6A s-state except Opt 25: +2V to +32V @ 1.25 peak, 0.45A s-state
Ripple	+15V: <0.1 Vrms +5V: <0.02 Vrms
Warm-up Time	< 4 minutes to lock @ 25°C
Size	36.6 x 77 x 76.2 mm 1.44 x 3.03 x 3.0 inches
Weight	338 grams 12 Oz.

*May be factory set at any frequency from 1 Hz to 10 MHz for square wave, and 5 MHz to 20 MHz for sine wave

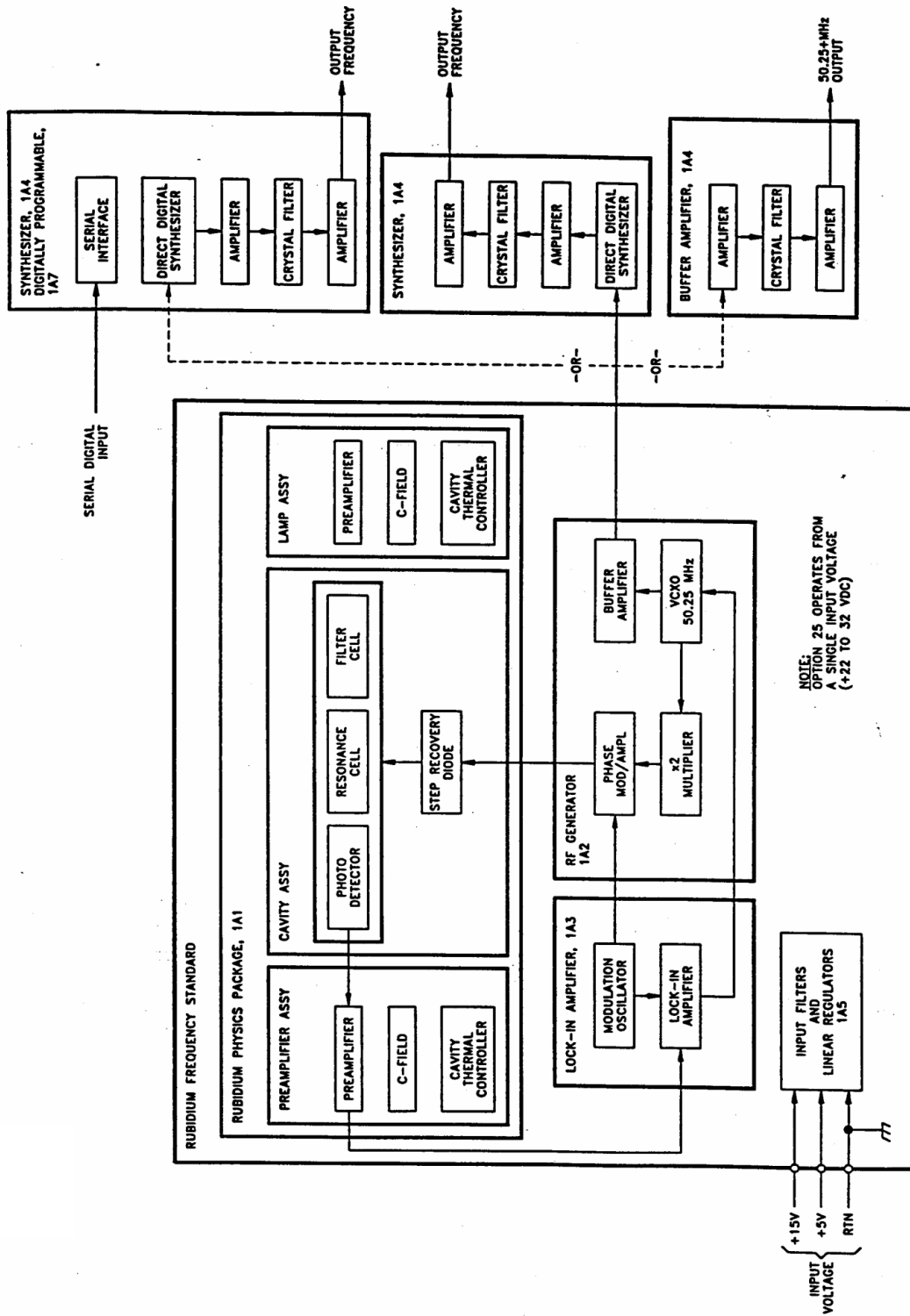


FIGURE 4. RUBIDIUM FREQUENCY STANDARD, BLOCK DIAGRAM

FUNCTIONAL DESCRIPTION

1-2

Frequency Lock Loop

1-2.1

The RFS uses the property of atomic resonance in a Rubidium Physics Package to control the output frequency of a 50.255x MHz Voltage Controlled Crystal Oscillator (VCXO) with a Frequency Lock Loop (FLL). The FLL functional blocks consist of the RF Generator, Lock-in Amplifier, and the Rubidium Physics Package. Figure 4 provides a functional block diagram of the RFS. Frequency locking of the VCXO is accomplished by operating the Rubidium Physics Package as a frequency discriminator, where deviations of the frequency derived of the 50.255x MHz VCXO input signal from the Rubidium atomic resonance center frequency produce a DC output signal control voltage. This dc output signal has a magnitude and polarity directly related to the magnitude and direction of deviation from the defined Rb center frequency. Once the FLL has been established, the system generates a loop-locked indication which can be monitored on pin 3 of the J1 connector. Depending on the option selected, the 50.255x MHz VCXO output is used as the clock input for direct digital synthesis within the Synthesizer or the Digitally Programmable Synthesizer, or the Buffer Amplifier.

Voltage Regulator

1-2.2

The RFS is powered by the Linear Regulator which requires both +15 Vdc and +5 Vdc input voltages. Input current requirements are 1.7A peak and 500 mA steady state for the +15 V input and 150 mA for the +5 V input. Option 20 requires only a single +15 Vdc supply voltage capable of providing 1.8A peak and 600 mA steady-state.

Option 25 is powered by a Switching Regulator which accepts a single +22 to +32 Vdc input voltage and supplies +14V and +5V operating voltages for the RFS. The peak input current requirement is 1.25A: steady state operating current is 450 mA.

Rubidium Physics Package Operation

1-2.3

The Rubidium Physics Package incorporates a rubidium cell, rubidium lamp, and servo electronics to utilize the ground-state hyperfine transition of the rubidium atom, at approximately 6.834x GHz. The VCXO is locked to the rubidium atomic resonance in the following manner. The VCXO frequency of 50.255x MHz is an exact sub-multiple ($\div 136$) of the atomic resonance frequency at 6.834x GHz. A microwave signal, having a frequency in the vicinity of 6.834x GHz, is generated from the nominal 50.255x MHz VCXO input. This microwave signal is used to resonate vaporized rubidium atoms within a sealed glass Rb resonance cell that is placed in a low

Q microwave cavity. The microwave frequency generation method is designed so that the VCXO frequency is exactly 50.255x MHz when the microwave frequency is exactly equal to 6.834x GHz. The frequency of the signal applied to the microwave cavity can be maintained equal to 6.834x GHz by generating an error signal when the frequency varies, and using this error signal to servo the VCXO via its control voltage.

The error signal is generated in the physics package. Light from the rubidium lamp, produced by an excited plasma discharge, is filtered and passed through the rubidium resonance cell where it interacts with rubidium atoms in the vapor. After passing through the resonance cell, this light is incident upon a photodiode. When the applied microwave frequency is equal to 6.834x GHz, the rubidium atoms are resonated by the microwave field in the cavity; this causes the light reaching the photodiode to decrease. The decrease in light, when the microwave frequency is equal to the sharply defined Rubidium frequency, is then converted electronically to an error signal with phase and amplitude information that is used to steer the VCXO via its control voltage and keep it on frequency at 50.255x MHz.

VCXO Operation

1-2.4

The VCXO operates nominally at 50.255x MHz. The VCXO has two isolated outputs; one output is provided to the Rubidium Physics Package for comparison purposes, and the other output is provided to either the Synthesizer or Remote Programmable Synthesizer, or to the Buffer Amplifier (for option 1).

Output Frequency Synthesis

1-2.5

Option 1 uses a Buffer Amplifier to provide a 50.255055 Mhz non-programmable sinewave output. This version is for systems that have their own synthesis capabilities.

For options 03 through 07, standard output frequencies of 2.048, 5, 10.23, 13 and 15 Mhz are provided by the Direct Digital Synthesizer (DDS) within the Synthesizer. Corresponding standard output frequencies and options are as follows:

Option	Standard Frequency (MHz)
03	5
04	15
05	13
06	2.048
07	10.23

Option 08 is reserved for customer specified output frequencies between 1 Hz and 20 MHz with a setting resolution of 0.012 Hz.

Option 09 produces a TTL wave output between 1 Hz and 10 MHz at a duty cycle of 50% \pm %.

Options 2 output is RS-232 remote-controllable with a frequency range of 2×10^{-7} at a resolution of 3×10^{-12} . Option 11 allows wideband digital tuning for the selection of any frequency between 1 Hz and 20 MHz in steps of 2×10^{-12} Hz. The output frequencies are stepped approximations of sine waves.

The basic functional blocks of the Direct Digital Synthesizer consist of a Phase Accumulator (which is clocked and tunable). A Look-Up Table (part of a ROM), a Digital-to-Analog Converter (DAC) and Alias Filter. The Phase Accumulator contains a BCD counter which accumulates changes in phase for each incoming clock cycle and then generates a linear progression of digital number (words) corresponding to phase of the desired output waveform. These words are then fed to the ROM Look-Up Table. In the Look-Up Table, each discrete phase point corresponds to a discrete amplitude value representing sampled converter. The digital words from the Look-Up Table drive the Digital-to-Analog Converter (DAC) which approximates the ideal amplitude value for a given clock cycles. The output of the DAC is a staircase waveform whose individual steps correspond to clock cycle. The output of the DAC is further filtered via an alias filter. The resultant signal from the DDS is amplified, passed through a crystal filter, and further amplified to produce standard output frequency waveforms with exceptional spectral purity including very low spurious, harmonic, and phase noise content.

Section 2. OPERATION AND USE

INSTALLTION

2-1

Site Selection

2-1.1

The selected installation site should be within standard ambient temperature and ranges as specified in Table 3, and should be free from strong surrounding magnetic fields.

Cabling Data

2-1.2

Use Table 4 to configure cabling for the **RFS**.

TABLE 4. CABLING DATA

DESIGNATION	UNIT CONNECTOR	MATING CONNECTOR
J1	DE9PU	DE9S
J2	SMA Female	SMA Male

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TURN-ON PROCEDURE

2-2

Perform the following steps to verify the **RFS** is operating properly. If the unit does not meet all requirements refer to **REPAIR** section of this manual.

- a. Connect power to the power connector (J1) of Rubidium Frequency Standard (**RFS**) under test.
- b. For all options except Options 20 & 25: Connect pin 1 to a DC Power Supply capable of supplying +15 Vdc at a peak current of 1.7A. Connect pin 4 to a DC Power Supply capable of supplying +5 Vdc at a current of 150 mA.
For Option 20: Connect pin 1 to a DC Power Supply capable of supplying +15 Vdc at a peak current of 1.8.
For Option 25: Connect pin 1 to a DC Power Supply capable of supplying +22 to 32 Vdc at a peak current of 1.25A.
- c. Connect pins 2 (all options) and 5 (all options except 20 & 25) labeled **return** to the DC Power Supply Return.
- d. Turn on power and allow the **RFS** to warm up for 4 minutes.
- e. Measure the **LOOP LOCKED** Indicator Voltage (pin 3) and verify it is less than 1 Vdc.
- f. Measure frequency at SMA connector J2. (Note:frequency accuracy of the FE-5650A is better than most counters).

FREQUENCY ADJUSTMENT PROCEDURE

Perform the following steps to adjust the output frequency of the **RFS**.

- a. Refer to Figure 1. Locate the “C”-Field adjustment potentiometer which is accessible from the bottom cover of the **RFS**. Adjust the potentiometer fully counterclockwise.
- b. Remove five pan head screws from the cover of the **RFS**, four from the sides and one from the top. Remove the cover.
- c. Apply power to the **RFS** and allow 10 minutes for the unit to stabilize.
- d. Monitor the 10 MHz output with a frequency counter (HP 5335A or equivalent).

NOTE: The frequency counter should be referenced to a known good “primary” standard.

- e. Locate the Direct Digital Synthesizer (DDS) printed circuit board which is at the side of the **RFS** to the far left of the “C”-Field potentiometer. Referring to Figure 5. Locate the 8-position dip switch in the upper left-hand corner of the DDS PCB assembly. Use S401 on the Standard DDS, the circuit board with one dip switch (Figure 5a). Use S404 on the Universal DDS, the circuit board with four dip switches (Figure 5b).

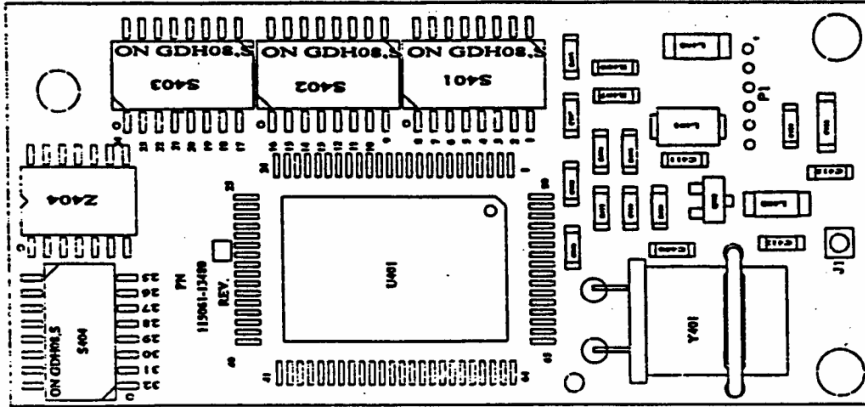
NOTE: Do not adjust any other dip switches (S401-403) on the Universal DDS circuit board. This will cause the frequency to move outside of the bandwidth of the crystal filter

- f. Set the frequency to 9,999,999,99 Hz (-1×10^{-9}) by adjusting the DDS dip switch. Start at position 1, MSB (most significant bit) and continue to position 8, LSB (least significant bit). The LSB moves the frequency approximately 1×10^{-9} . Placing a switch at the “ON” setting decreases the frequency.

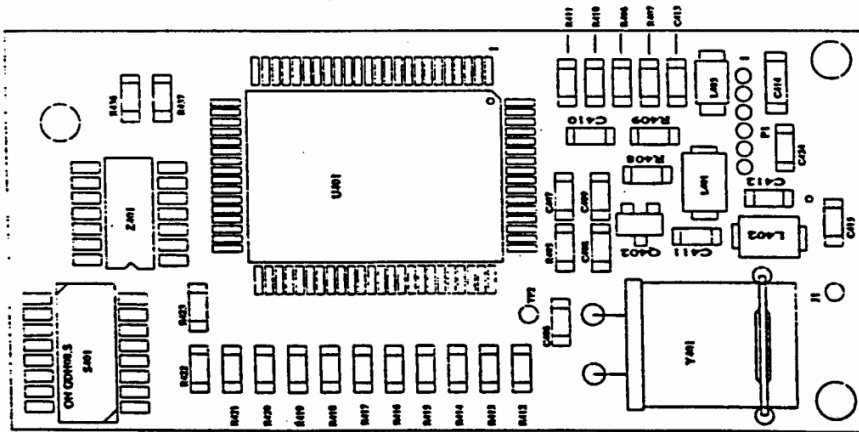
NOTE: If the RFS is equipped with Analog Tuning (Option 12), apply 2.5 Vdc between the analog tuning input (pin 8 of J1) and the analog

- g. Adjust the “C”-Field potentiometer so that the frequency is 10,000,000,000 Hz.
- h. Remove power from the **RFS**.
- i. Replace the cover and 5 screws removed in step b.

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b. Universal DDS



a. Standard DDS

FIGURE 5. DIRECT DIGITAL SYNTHESIZER (DDS) PC ASSEMBLY COMPONENT LOCATIONS

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GENERAL**3-1**

The Rubidium Frequency Standard (RFS) is not field repairable. All units that need repair should be shipped to the address given below. Prior to returning any units, contact the Marketing Department at extension 5030 to obtain an RMA number.

Frequency Electronics, Inc.
55 Charles Lindbergh Blvd.
Mitchel Field, NY 11553
Tel (516) 794-4500
Fax (516) 794-4340

RUBIDIUM FREQUENCY STANDARD MODEL FE-5650, ADDENDUM

Effective with serial number 07576 and higher, all units will operate on a single +15Vdc supply and the frequency adjustment procedure has been amended. Refer to Option 20 in manual for specifications and details on the single supply. The amended procedure is as follows:

FREQUENCY ADJUSTMENT PROCEDURE (SECTION 2-3)

- e. Locate the Direct Digital Synthesizer (DDS) printed circuit board which is at the side of the **RFS** to the far left of the "C"-Field potentiometer. Referring to Figure 5.1 (attached), locate the two push-button switches, S401 and S402.

- f. Set the frequency to 9,999,999.985 Hz (-1.5×10^{-9}) by pressing S401 to increase frequency or S402 to decrease the frequency. Each time a button is pressed, the frequency will move approximately 1.0×10^{-9} .

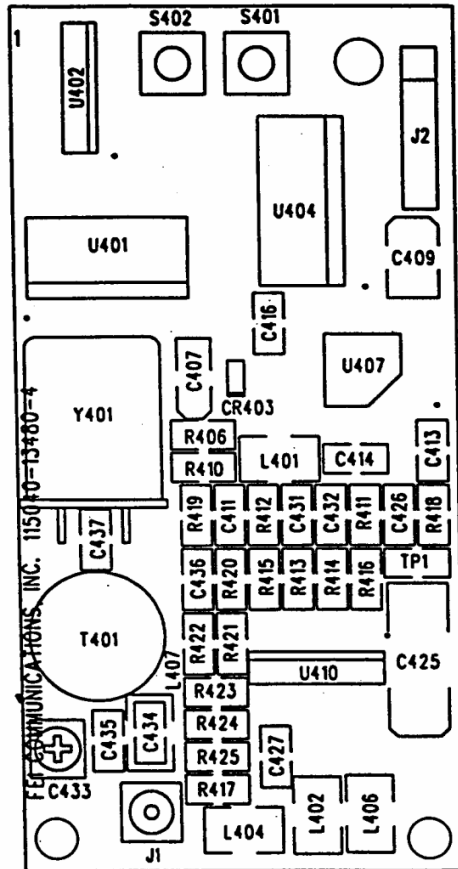


FIGURE 5.1. DIRECT DIGITAL SYNTHESIZER (DDS) PC ASSEMBLY COMPONENT LOCATIONS