University of Hawai'i at Mānoa
School of Ocean and Earth Science and Technology
Radio Oceanography Laboratory

Generic High Frequency Doppler Radar Synthesizer-Transmitter Unit Model MK3-PW-PA-TX Operational Description

April 2022
v. 10

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Marine Sciences Building
1000 Pope road
Honolulu Hawai'i 96822

FCC Supplier’s Declaration of Conformity

University of Hawai'i Generic High Frequency Doppler Radar Synthesizer-Transmitter Unit, model *MK3-PW-PA-TX.*

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) this device may not cause harmful interference, and

(2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by University of Hawai'i could void the user's authority to operate the equipment.

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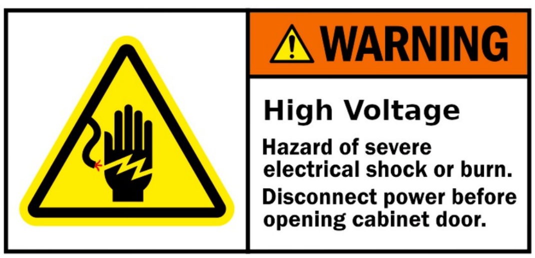
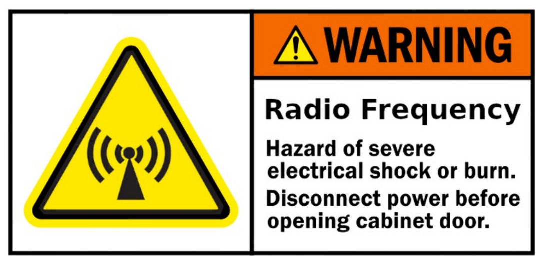
Warnings





This device contains potentially dangerous high voltages and high frequency radiation. Operation and servicing is restricted to properly trained and certified personnel.

Maximum output power is 50 W (+0.5dB) for frequencies 8 MHz and below and 30 W (+0.5dB) for frequencies 12 MHz and above.

The user’s authority to operate this device if connected to any radiating antenna or structure in the United States is contingent on applying for and being awarded a valid license through the FCC Universal Licensing System before transmitting. This device may not be powered up for testing unless connected to a non-radiating resistive load.

Table of Contents

Generic High Frequency Doppler Radar (G-HFDR)

1. Physical principles

The G-HFDR is an Oceanographic High Frequency Doppler radar designed with bare minimum features to ensure low production cost, low power requirement, and easy maintenance.

The operation of the G-HFDR consists of transmitting frequency-modulated continuous radio waves that are channeled along the surface of the conducting ocean as ground waves, in the wavelength range of 10 to 100 m (frequency 3 to 30 MHz).

These radio waves are coherently back-scattered by the ocean's surface gravity waves at half the radio wavelength (5 to 50 m), and captured by an array of receive antennas. The back-scattered radio waves are shifted in frequency by the Doppler effect due to the sum of the surface wave velocities and the surface current. The velocity of the radial currents in the direction of the G-HFDR is estimated from this Doppler shift.

For "Region 2", the Americas, the International Telecommunication Union (ITU) has recommended and the Federal Communication Commission has allocated dedicated secondary frequency bands for operating High Frequency Doppler radars (Table 1).

Table 1. Allocation for Oceanographic High Frequency Doppler radars in Region 2.

Center	*Occupied bandwidth*
(MHz)	*(kHz)*
4.463	50
5.2625	25
13.500	100
16.150	100
24.550	200
26.310	220

The G-HFDR consists of two units or subsystems: the Synthesizer-Transmitter Unit, and an optional Receiver-Digitizer Unit.

The Synthesizer-Transmitter Unit is based on commercial off-the-shelf modules and contains: (i) an ultra-low phase noise reference oscillator (OCXO), (ii) direct digital signal synthesizers (DDS-FPGA), (iii) a power amplifier (PA), (iv) an anti-harmonic filter (LPF), (v) power supplies (PS) and power line filters (RFI). This unit is the subject of the present technical document.

The optional Receiver-Digitizer Unit is based on schematics and engineering drawings published by the Radio Oceanography Laboratory and released in the public domain as Open Design/Open Source. It is a passive homodyne quadrature demodulator to baseband and does not contain any oscillator, frequency synthesizer or RF power amplifier. This unit is the subject of a separate technical document.

The units exchange information with the outside world through ethernet links. Absolute timing, if required, can be provided by the precision network time protocol (*ptp*), encompassing master network-based GPS clocks or atomic clocks.

2. System description and schematics

The following modules are integrated to form the Synthesizer-Transmitter Unit (Figure 1):

1. an ultra-low phase noise oven-controlled crystal oscillator (OCXO) fitted with a thermal-inertia bell, providing the clock signal to the digital synthesizer. Features: 100 MHz frequency, single side-band phase noise -148dBc/Hz. Manufacturer: Bliley (United States), model N79A-optA. The technical specification are found in appendix 1.

2. a clock-remapping direct digital synthesizer (DDS-C) to correct for frequency offset, aging and drift of the OCXO with a precision of 1 mHz, based on initial factory-calibration against a rubidium clock or optional real-time calibration against network clocks.

3. a two-channel quadrature (I, Q) direct digital synthesizer (DDS-A/B) providing frequency-modulated (chirped) signals. Features: internal frequency 300MHz after base clock multiplication, 48-bit phase register yielding 1 µHz tunability, 12-bit digital-to-analog converter, 80 dB SFDR, 27MHz analog low-pass filters resulting in an operating frequency extending to 27MHz. Both the clock-remapping DDS-C and the chirping DDS-A/B are based on Analog Devices' model AD9854 CMOS DDS, integrated by D-Tacq Solutions (Scotland/UK), model RAD-CELF. The technical specifications of this triple DDS radar controller are found in appendix 2 and its schematics are shown in Figure 2 and 3.

4. an embedded processor, combining on the same integrated circuit, a programmable logic gate array (FPGA) and a dual-core sequential processor operating under Linux (ARM Cortex-A9) based on Xilinx' model Zynq-7000. Mother-board integrated by D-Tacq Solutions (Scotland/UK), model ACQ-1001Q.

5. a solid state Class AB MOSFET RF power amplifier (PA) operated in continuous mode (CW). Features: input signal level -10dBm, Maximum output power is 50 W (+0.5dB) for frequencies 8 MHz and below and 30 W (+0.5dB) for frequencies 12 MHz and above. Stable operating range from 0.5 to 150 MHz. Manufacturer: Tomco Technologies (Australia), Model BTM00250-AlphaSA. The technical specifications are found in appendix 3.

6. a 9th order Butterworth power low-pass filter to cancel spurious signal harmonics and aliases. Manufacturer: DLW associates (Missouri, USA). The low-pass filter is built to the specific operating frequency and factory-fit at time of manufacture. The technical specifications are found in appendix 4.

7. switching power supplies manufactured by Traco, including 12V model for the digital electronics (TSP-070-112) and 26V model for the RF power amplifier (TSP-360-124 coupled with TSP–BCM24 battery controller module). The Traco power supplies are rated for an input voltage range 85V to 260V. They feature oscillator dithering to reduce spurious radiated peaks. The technical specifications are found in appendix 5. AC and DC power line filters (RFI) are inserted to mitigate spurious radiated emissions. Standard circuit breakers are added for protection.

8. a custom-built enclosure rated IP65 in white lacquered aluminum 20x60x75 cm protecting all electronic modules from weather and electromagnetic interference, including 6-point grounding harness for the door. The Synthesizer-Transmitter Unit operates without an active cooling device over an ambient temperature range of -30C to +50C.

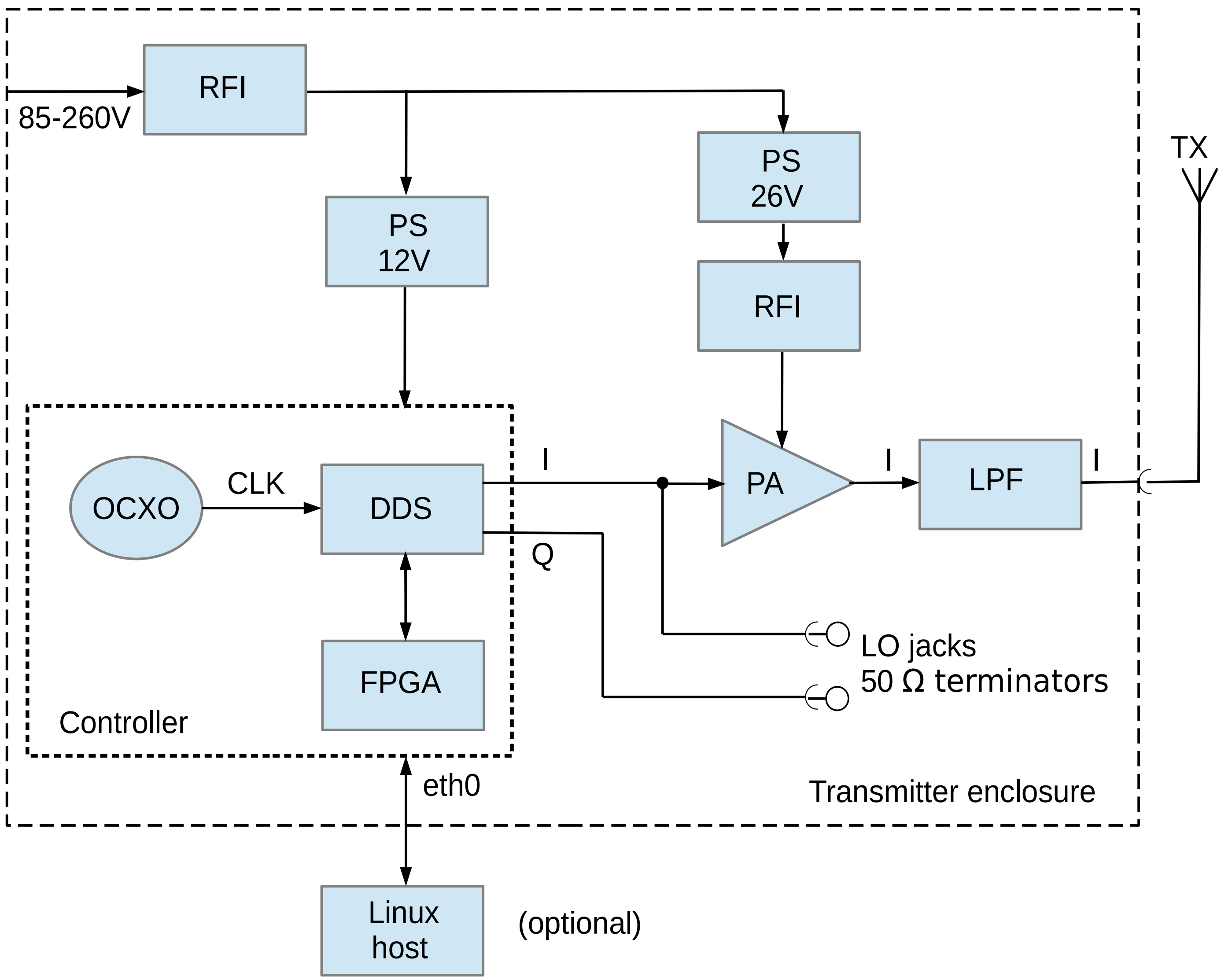


Figure 1. Schematics of the Synthesizer-Transmitter Unit.
See Table 2 for list of components and references.

Table 2. List of commercial modules incorporated in the Synthesizer-Transmitter Unit

Tag	*Description*	*Reference*	*Manufacturer*
OCXO	Oven-controlled crystal oscillator, 100 MHz	N79A-optA	Bliley Technologies Inc. 2545 W Grandview Blvd, Erie PA 16506 USA
FPGA	Carrier with embedded FPGA&ARM processors	ACQ1001	D-TACQ Solutions Ltd., International House Stanley Blvd, Blantyre G72 0BN Scotland UK
DDS	Triple DDS Radar Controller	RAD-CELF	*id.*
PA	Radio-frequency power amplifier	BTM00250-AlphaSA	Tomco Technologies 38 Payneham Rd, Stepney, Australia 5069
LPF	Power low-pass filter	FLxxMLP-HFDR	DLW Associates 6 Woodford place, St. Charles MO 63301 USA
PS12V	Industrial power supply	TSP-070–112	Traco Electronic AG Sihlbruggstrasse 111, CH-6340 Baar
PS26V	Industrial power supply	TSP-360–124	*id.*
RFI-DC	EMI Filter with High Attenuation Performance	FN2030M-Z-20-06	Schaffner Holding AG Nordstrasse 11, CH-4542 Luterbach
RFI-AC	EMI Filter with High Attenuation Performance	FN9266-10-06	*id.*

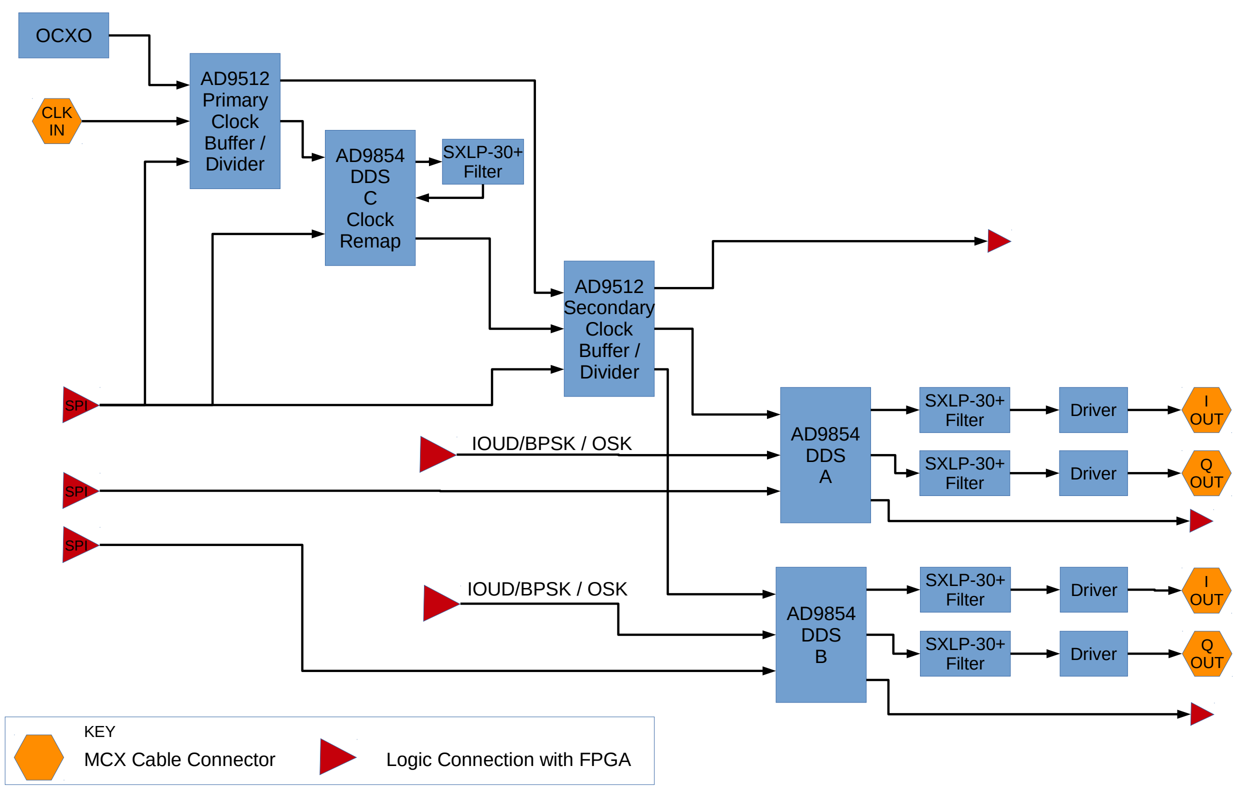


Figure 2. Schematics of the Triple DDS Radar Controller.
See Table 3 for list of components and references.

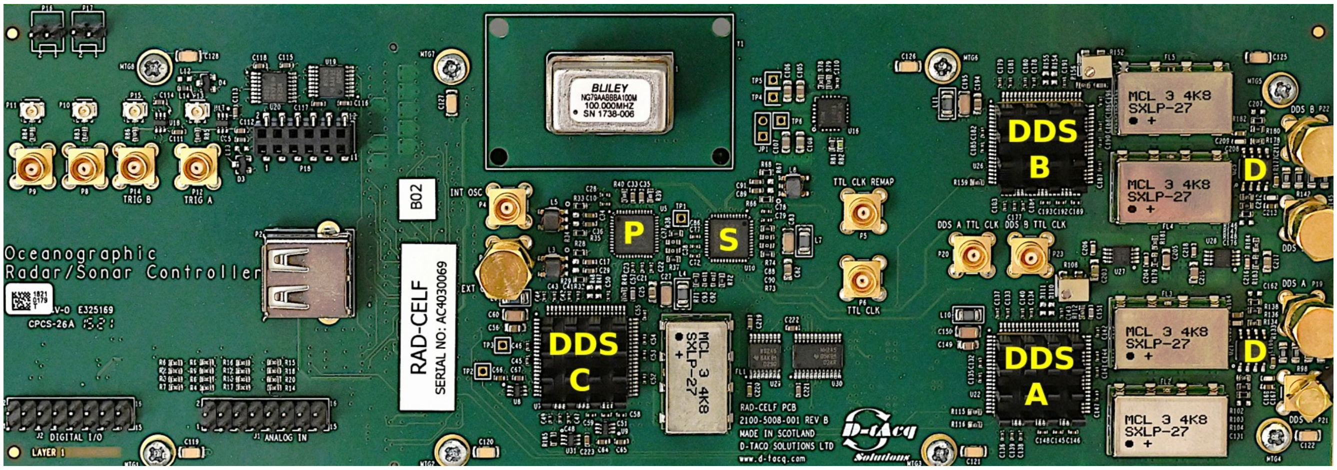


Figure 3a. Photo of the Triple DDS Radar Controller board (top face).

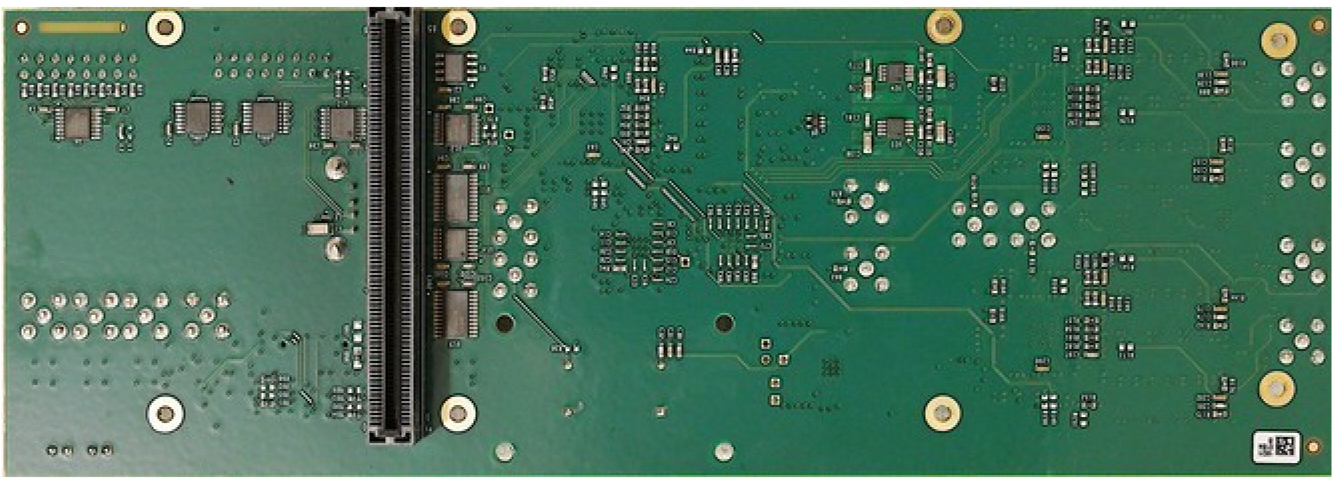


Figure 3b. Photo of the Triple DDS Radar Controller board (bottom face).

Figure 3c. Photo of the carrier board with FPGA (top face; bottom face not accessible).

Table 3. List of functional integrated circuits used in the Triple DDS Radar Controller

Tag	*Description*	*Reference*	*Manufacturer*
Primary	Clock/buffer divider	AD9512BCPZ	Analog Devices One Analog Way, Wilmington MA 01887 USA
Secondary	Clock/buffer divider	AD9512BCPZ	*id.*
DDS-A	Direct digital synthesizer	AD9854ASVZ	*id.*
DDS-B	Direct digital synthesizer	AD9854ASVZ	*id.*
DDS-C	Direct digital synthesizer	AD9854ASVZ	*id.*
Filter	Lumped LC low-pass filter	**SXLP-27**+	Mini-Ciruits 13 Neptune Ave, Brooklyn NY 11235 USA
Driver	Operational amplifier	OPA2694D	Texas Instruments 12500 TI Blvd., Dallas TX 75243 USA

Note: commodity components (inductors, capacitors, resistors, regulators) used on the Radar controller board have passive functions and do not contribute to the signal generation.

3. Summary of specifications

Signal characteristics:	FMCW linear sweep (chirp)
Emission designation:	F1N
Design operating frequencies:	3 MHz to 27 MHz
Modulation bandwidth:	Max. 2% of operating frequency
Restricted operating frequencies/bandwidth:	firmware-restricted to FCC/ITU allocations
Sweep (chirp) rate, radar mode:	1-5 Hz
Sweep (chirp) rate, call-sign mode:	1 kHz
Master reference clock:	OCXO 100 MHz SC-cut
Single side-band phase noise:	148 dBc/Hz @ 1 kHz or better
Clock frequency stability:	300 ppb or better (1-year, full temp. range)
Conducted output power < 10 MHz:	50 W
Conducted output power > 10 MHz:	30 W
Harmonics at rated power:	2*$f0$ < -70 dB; 3*$f0$ < -80 dB
Supply voltage range:	85 V to 260 V AC, 50-60 Hz
Supply power:	250 W AC
Operating temperature range:	-30°C to +50°C

4. Tune-up procedure

This device has no adjustments to tune output power and reference frequency because these are digitally programmed during the manufacture of the system and drifts are non-existent within the precision of measurements.

Programming the unit is password-protected and reserved to factory-authorized personnel. There are no user-accessible controls to modify the programming of the unit.

5. Configuration and operation

The unit is programmed to emit a repetition of frequency sweeps (chirps), typically at a rate of 1Hz to 4Hz and an occupied bandwidth of 25 to 220kHz determined by the ITU frequency allocation (see Table 1), resulting in a frequency-modulated continuous wave (FMCW mode, emission designation F1N).

The unit is factory-programmed to start transmitting automatically upon power up at the ITU frequency for which a low-pass filter is factory-fitted. To avoid any erroneous operation that could damage the power amplifier and/or the low-pass filter, or result in unlicensed transmissions, all frequencies are factory-disabled, except the ITU frequency for which a low-pass filter is actually factory-fitted to the unit. Programming the unit to other frequencies is password-protected and reserved to factory-authorized personnel.

If a FCC call sign has been provided at the time of factory-configuration, a full-bandwidth broadcast of the call sign is automatically scheduled every 20 min. Chirps at a rate of 1 kHz are transmitted over the same occupied bandwidth, for short periods corresponding to the dots and dashes of the Morse code, resulting in a similar frequency-modulated continuous wave (emission designation F1N).

The unit can be powered-up in two modes of operation: (a) a test mode, for which the output is connected to a 50Ω non-radiating resistive load, or (b), a live mode, for which the output is connected to a radiating antenna or structure. The user’s authority to operate this device in the live mode (b) from a location within the United States is contingent on being awarded a license through the FCC Universal Licensing System. In the absence of a valid FCC license, the device may only be operated in the test mode (a).

The firmware allows programming all operations of the digital synthesizer, including chirping, calibration tones and full-bandwidth call-sign broadcast, using a single ethernet web server interface, configured through the Dynamic Host Configuration Protocol (DHCP; Figure 4). The actual settings of the digital synthesizers are continuously read back from the DDS registers and displayed on a separate diagnostic web page (Figure 5).

5.1. Start-up procedure

The following steps must be performed in the order given:

1. open enclosure and verify that the frequency of the low-pass unit fitted (figure 9) corresponds to the factory-configured frequency marked on the label (figure 8).
2. verify that all breakers are off in the down positions (figure 9).
3. for mode (a), connect a power attenuator such as a a Bird 100-SA-FFN-30 to the N-type RF output of the unit (figure 12).
4. for mode (b), connect the cable to the TX antenna, with a minimum attenuation of 5 dB (figure 12).
5. connect a CAT-6e cable from a local network to the RJ45 jack of the unit (figure 12);
6. connect a grounded power cable to the IEC-C13/C14 power inlet (figure 12) and plug into a 120 or 240V outlet (the unit auto-detects the voltage).
7. connect the power adapter of the heat-exchanger shown in figure 5 into a 120 or 240V outlet (the unit auto-detects the voltage).
8. power up the unit and the heat exchanger.

9. enable the power surge suppressor by flipping its breaker to the up position (lower DIN rail, figure 9).
10. enable the power supplies by flipping all remaining breakers in sequence from right to left to the up position (middle DIN rails, figure 9).
11. tie the 6 grounding connections of the door and close the enclosure.
12. verify that the network router has provided an IP address through DHCP (waiting 2-3 minutes may be necessary to let the boot sequence complete).
13. open browser on this IP address, verify that a screen similar to figure 4 is obtained.
14. click on “Status”, verify that a popup screen similar to figure 5 is obtained and that the entry shown for ---DDS-A--- under /FREQ displays the expected factory-configured frequency.

The unit is now operating and transmitting the required signal.

5.2. Toggling between signal types

Two signal types are allowed: standard frequency-modulated continuous wave chirp for normal radar operation, and continuous tones for calibration. Continuous tones can be programmed at three distinct frequencies: at the lower limit of the allocated bandwidth *f0-bw/2*, at the center frequency *f0* and at the upper limit of the allocated bandwidth *f0+bw/2.*

To toggle between signal types:

1. open a browser on the unit’s IP address, obtain a screen similar to figure 4.
2. to change between signal types, click on the appropriate button.
3. wait 15 sec for the command to execute.
4. verify with the “Status” screen that the frequency has been updated.

The unit is now transmitting the required signal.

5.3. Power-down procedure

The following steps must be performed in the order given:

1. open a browser on the unit’s IP address, obtain a screen similar to figure 4.
2. click on the “Stop” button.
3. wait 15 sec for the command to execute.
4. verify with the “Status” screen that the frequency has been updated to 0.
5. open enclosure.
6. disable the power supplies by flipping all breakers in sequence from left to right to the down position (middle DIN rails, figure 9).
7. power down the unit and the heat exchanger.
8. close enclosure and stow unit.

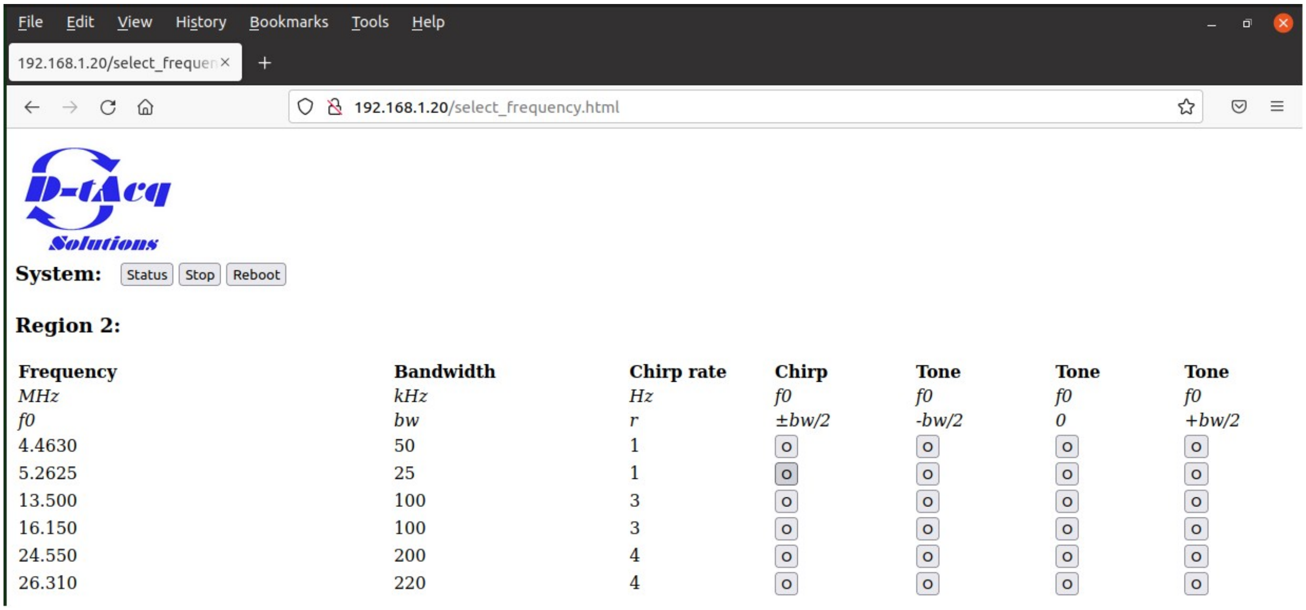


Figure 4. Web interface for programming the synthesizer/transmitter.

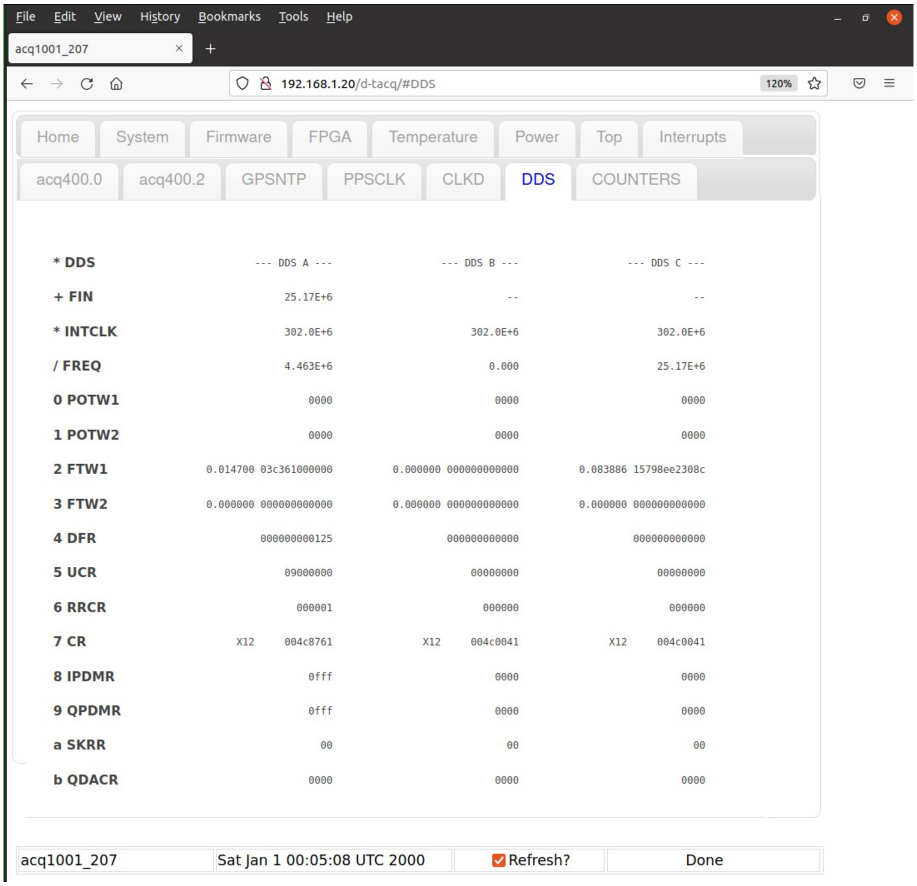


Figure 5. Diagnostic page with DDS registers read-back.

6. Antenna design

The transmit antennas are normal-mode helical monopoles (Kraus, J.D., “The Helical Antenna”, *Proc. I.R.E.* 1949 pp. 263-272). They consist of an AWG-16 vertical wire of length λ/4 wound over a mast of height λ/8 and diameter λ/300, a 3-loop tuning air-coil, and a network of 4 underground radials of length λ/4 (λ is the electromagnetic wavelength). The air-coil diameter is adjusted to achieve resonance using a standard commercial VSWR meter.

The customer-provided mast may be built of any non-conductive material, such as fiberglass, PVC, bamboo, wood. The typical gain of a normal-mode helical monopole is approximately 2 dBi.

Figure 6. Normal-mode helical monopole with air-coil on a fiberglass mast (8 MHz).

Figure 7. Normal-mode helical monopole with air-coil on a PVC mast (16 MHz).

Table 5. Dimensions of the antenna components as function of ITU frequency (metric)

F	*Wavelength*	*Vertical wire*	*Radial wires*	*Pole height*	*Diameter*
(MHz)	*(m)*	*(m)*	*(m)*	*(m)*	*(cm)*
4.4630	67.22	16.80	16.80	8.40	22.4
5.2625	56.01	14.00	14.00	7.00	18.7
13.500	22.22	5.55	5.55	2.78	7.4
16.150	18.58	4.64	4.64	2.32	6.2
24.550	12.22	3.05	3.05	1.53	4.1
26.310	11.40	2.85	2.85	1.43	3.8

The coaxial cable connecting the synthesizer/transmitter unit in the shack to the remote antenna, preferably deployed at the water edge, is specified as standard RG-213U, with a typical attenuation of at least 5 dB, depending on the frequency.

To comply with FCC RF exposure requirements, the antennas must be installed to ensure a minimum separation distance from persons while operating:

Table 6. Minimum separation distance to comply with FCC RF exposure requirements

Operating Frequency	*Minimum Separation Distance*
(MHz)	*(m)*
4.463	10.66
5.2625	10.66
13.500	3.55
16.150	3.55
24.550	2.30
26.310	2.30

7. Photos of unit

Figure 8. Above: Synthesizer-Transmitter Unit model MK3-PW-PA-TX, serial 3-003 (March 2022), door closed. Below: device identification label, affixed to the top right of the enclosure door. The factory-programmed operating frequency and output power are marked, here 16.150 MHz/30W.

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Generic High Frequency Doppler Radar
Synthesizer-Transmitter Unit

Model: MK3-PW-PA-TX	Serial number: 3-003
Input voltage: 85-260 V	Input power: 250 W AC
FCC ID: 2A562-MK3-PW-PA-TX	Modulation: FMCW mode F1N

Operating frequency / Bandwidth / RF power:

☐ 4.4630 MHz / 50 kHz / 50 W	☐ 5.6250 MHz / 25 kHz / 50 W
☐ 13.500 MHz / 100 kHz / 30 W	■ 16.150 MHz / 100 kHz / 30 W
☐ 24.550 MHz / 200 kHz / 30 W	☐ 26.310 MHz / 220 kHz / 30 W

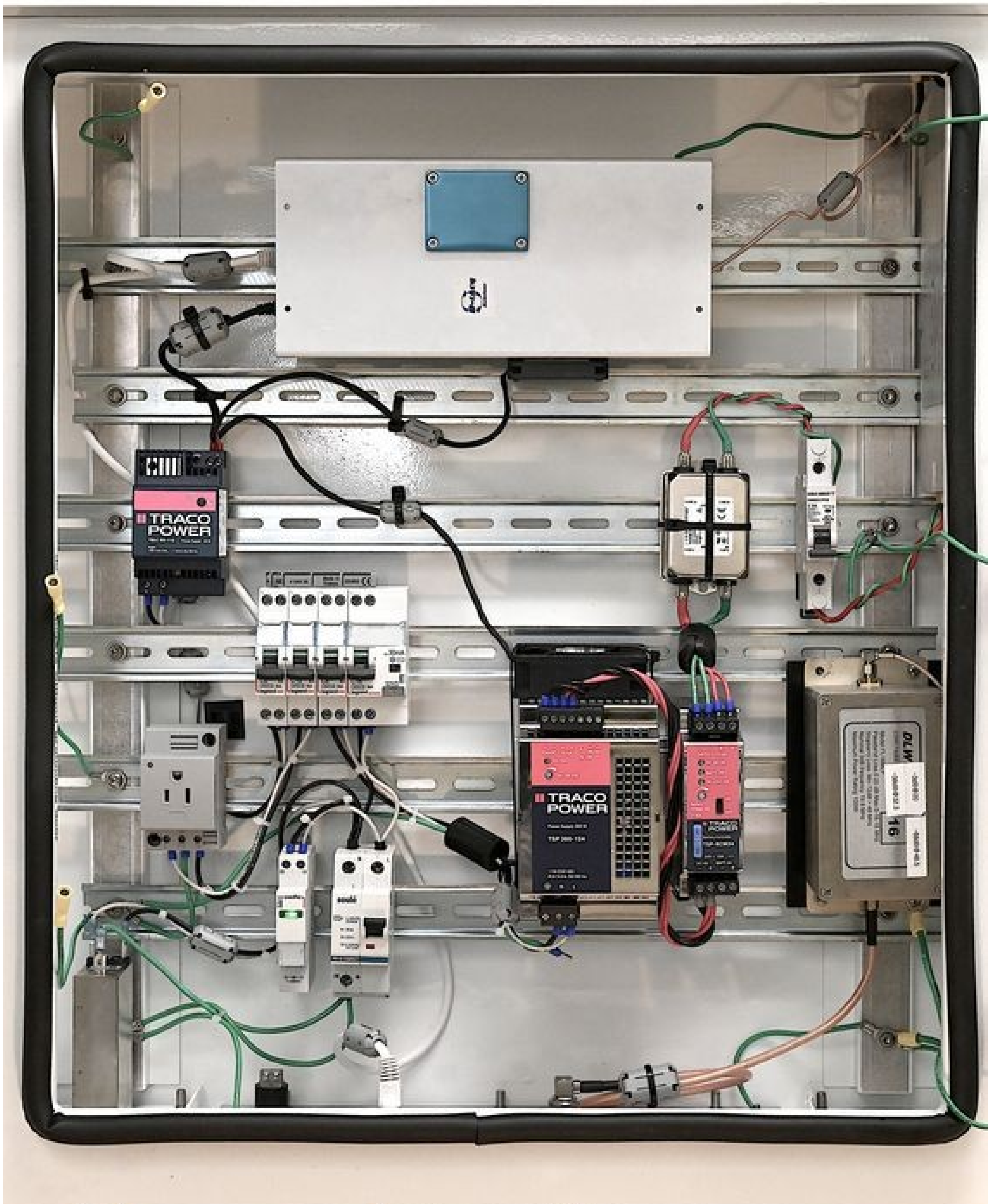

Figure 9. Synthesizer-Transmitter Unit, door open.
Bottom rails: power supplies with circuit breakers.
Upper rail: digital synthesizer and controller with blue thermal bell.
On the right wall: the power amplifier module and the low-pass filter.

Figure 10. Synthesizer-Transmitter Unit, door open, slanted view. The power amplifier module (top) and the low-pass filter (bottom) are seen on the right inner wall.

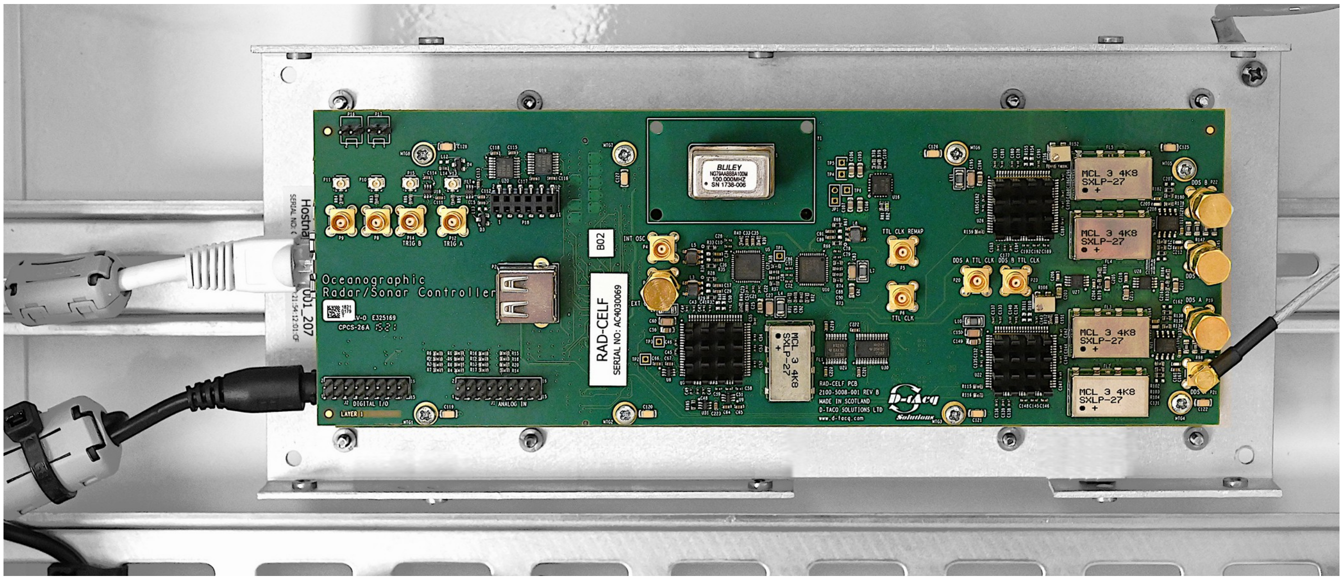

Figure 11. Upper rail enlarged from Figure 9 and 10, after removal of the aluminum lid and thermal bell, showing the Triple DDS Radar Controller board.

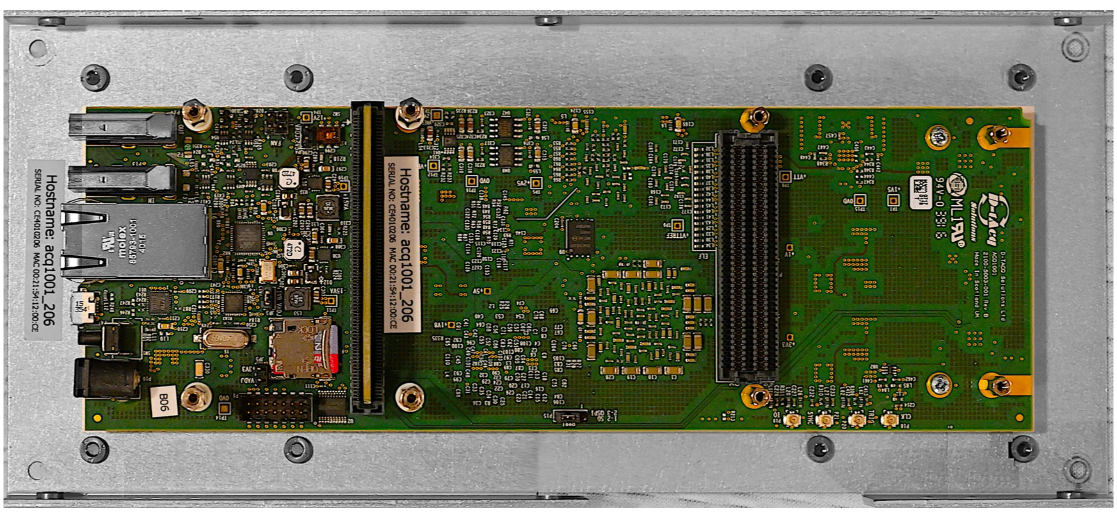

Figure 12. Carrier board with FPGA, after removal of the Triple DDS Radar Controller board (top face; bottom face not accessible).

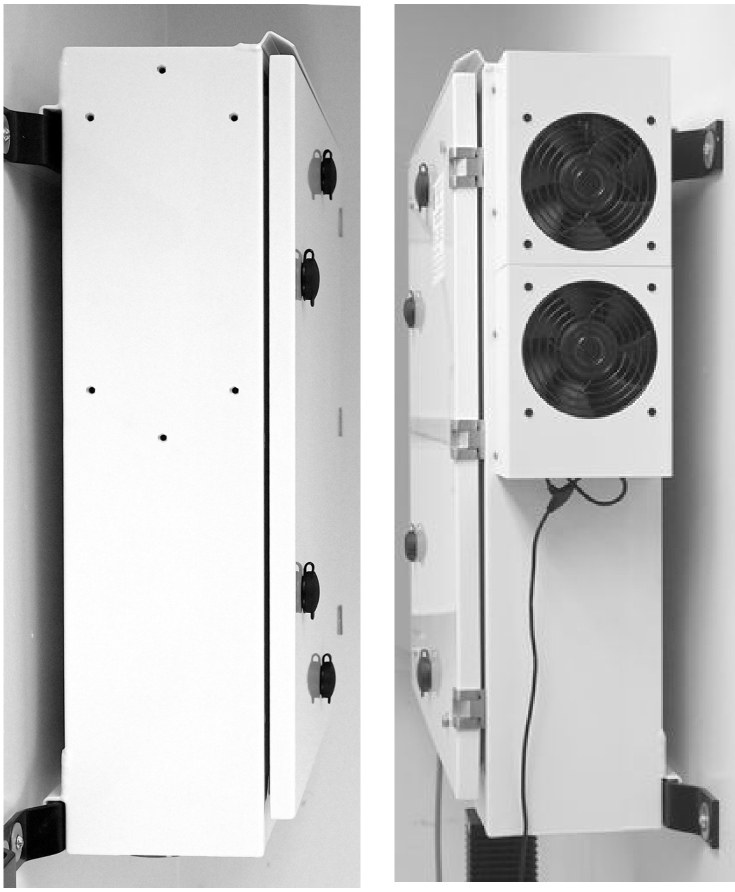

Figure 13. Synthesizer-Transmitter Unit, left and right side views.
The twin-fan forced air flow heat exchanger unit is seen on the right side.

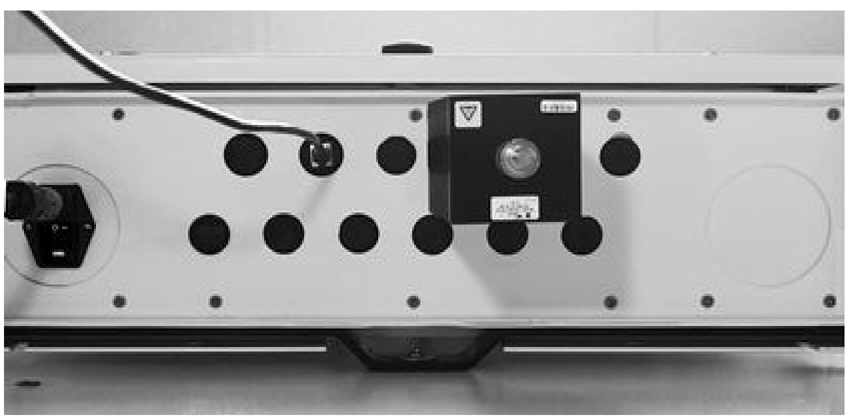

Figure 14. Synthesizer-Transmitter Unit, bottom view.
Connector plate with IEC-C13/C14 power inlet, RJ45 jack for CAT6 Ethernet, N-type bulkhead adapter for cable to antenna (a Bird 100-SA-FFN-30 power attenuator is attached).

Fig. 14. Synthesizer-Transmitter Unit, top view.
The twin-fan forced air flow heat exchanger unit is seen on the right side.

Fig. 15. Synthesizer-Transmitter Unit, back view
(after removing unit from wall supports).