ERS1380NB Theory of Operation

WULFSBERG ELECTRONICS, INC.

RT-138

SECTION 3

THEORY OF OPERATION

3.1 GENERAL

The RT-138 operational theory is presented in two sections. The first section is a basic presentation of module functions, while the second portion is a more detailed description of the operation of each module.

The radio is designed to provide multiple channel capability for VHF-FM communications in the 138.0000 to 173.9975 MHz band. The Transceiver is capable of being channeled to any 2.5 kHz increment in this band; 14,400 channels in all. An optional Guard Receiver allows monitoring a guard frequency while the Main Receiver is channeled to another frequency.

For pin assignment and other operational information on some of the integrated circuits used in the RT-138, see Section 7.3 of this manual.

3.2 COMPLETE OPERATIONAL BLOCK DIAGRAM

The RT-138, as shown in the block diagram (Figure 3.2-1), consists of five basic modules. These five modules are: Synthesizer Assembly, R/T Assembly, Audio Board, Guard Receiver Assembly, and a Power Supply. These modules plug into the Chassis Assembly which contains the interconnect wiring plus two voltage regulators that provide the +15 VDC for the radio.

The Synthesizer Module (A9) provides the first local oscillator injection for the Main Receiver and drive for the transmitter. All output channel frequencies are derived from a temperature controlled crystal reference oscillator that provides excellent stability. The Synthesizer contains an out-of-lock detection circuit that disables the transmitter power output if an unlocked condition exists. The Synthesizer is programmed by negative BCD codes applied to the tuning inputs and provides on-frequency operation for the transmitter or a 20 MHz offset for receiver L.O. injection, depending on the state of the PTT line.

The R/T Module (A7) contains the Main Receiver as well as a 10 watt transmitter. The T/R Relay switches the antenna between receive and transmit. Receive energy is divided equally between Main and Guard by a power splitter. The R/T Module contains RF, IF and detector circuits of the Main Receiver. Transmitter power stages are also located in the R/T Assembly.

3.2 COMPLETE OPERATIONAL BLOCK DIAGRAM (cont.)

The Audio Board (A3) contains the interfacing circuitry required to make the Main R/T and Synthesizer perform as a transceiver. The PTT control of the antenna relay, sidetone audio and modulation signal is provided by the Audio Board. Mic audio processing is performed by the Audio Board. The audio level control and squelch circuitry are also located on the Audio Board.

The Guard Receiver (A8) is optional. It is a single channel receiver without an audio power amplifier. The channel is crystal-controlled and the crystal frequency is tripled for low side local oscillator injection. The multiplier and preselector are aligned for a user specified channel. Any channel in the frequency band can be used. Noise squelch detection is incorporated in the module. Low level guard audio is fed to the Audio Board for further processing.

The Power Supply (A2) and the Regulator Assembly supply various DC voltages required by the RT-138. Primary voltage for the unit (15V) is distributed by two 15V dissipative regulators. Peripheral voltages needed in the system are generated by the FLEXCOMM Power Supply. Using 27.5V aircraft power as its input, the FLEXCOMM Power Supply delivers +5V, +28V and -28V used throughout the system.

3.3 SYNTHESIZER BLOCK DIAGRAM AND CIRCUIT THEORY

The Synthesizer Module consists of three sub-assemblies contained in an RF shielded box. See Figure 3.3-1 for the Synthesizer block diagram. The circuit blocks of the Synthesizer are:

Logic Board (A10)
Modulator Board (A11)
VCO Assembly (A12)

These three boards interconnect through the Chassis wiring to form a highly stable phase-locked RF generating system. Using one crystal (12.8 MHz) as a frequency reference, the Synthesizer is capable of tuning all 14,400 frequencies.

The Synthesizer is a plug-in module that generates outputs required for both receive and transmit modes of operation. For receive, the module functions are:

1. Synthesize the correct frequency and injection level for the R/T Assembly L.O. drive.
2. Generate the DC tuning voltage for the preselector.

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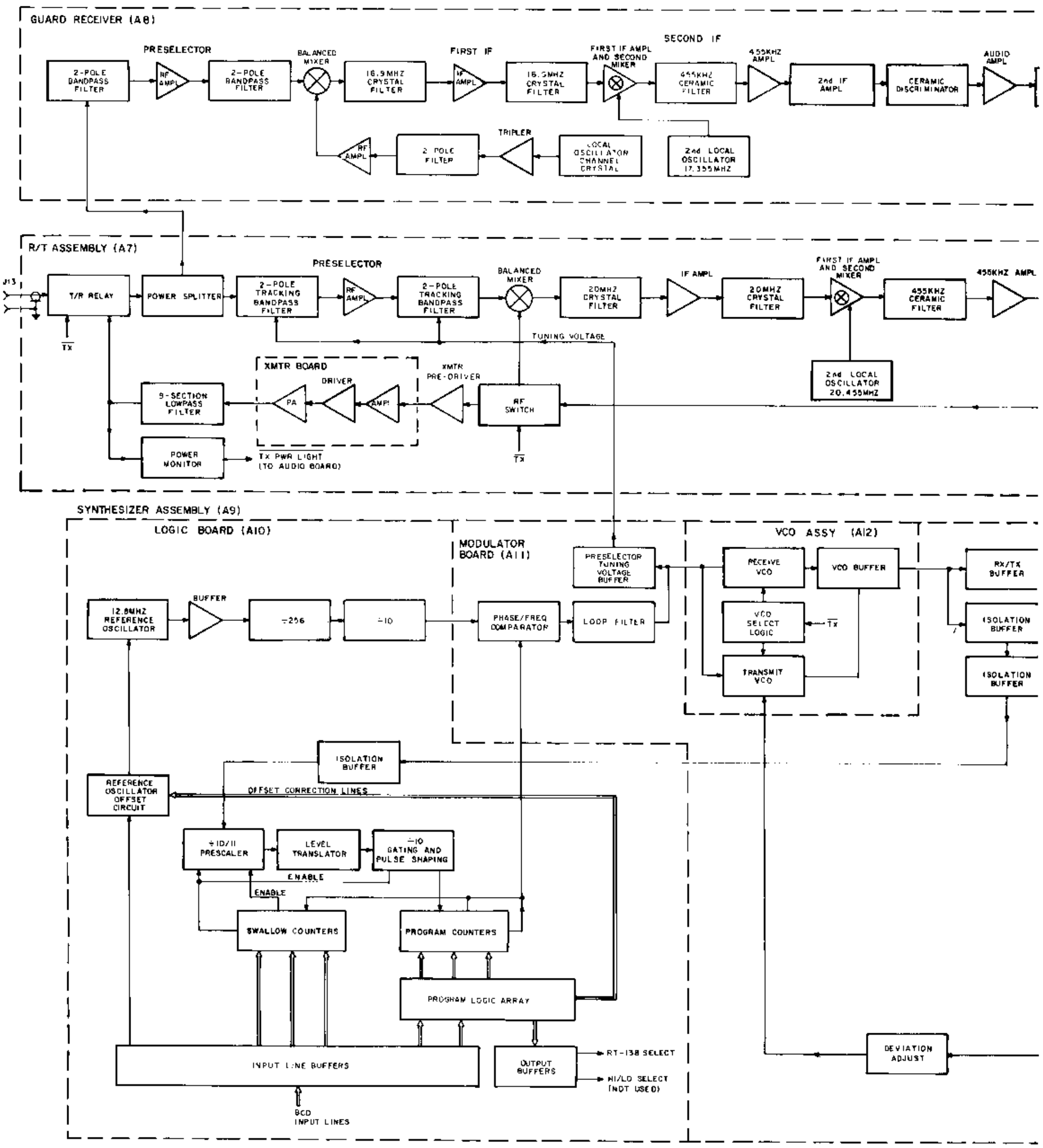
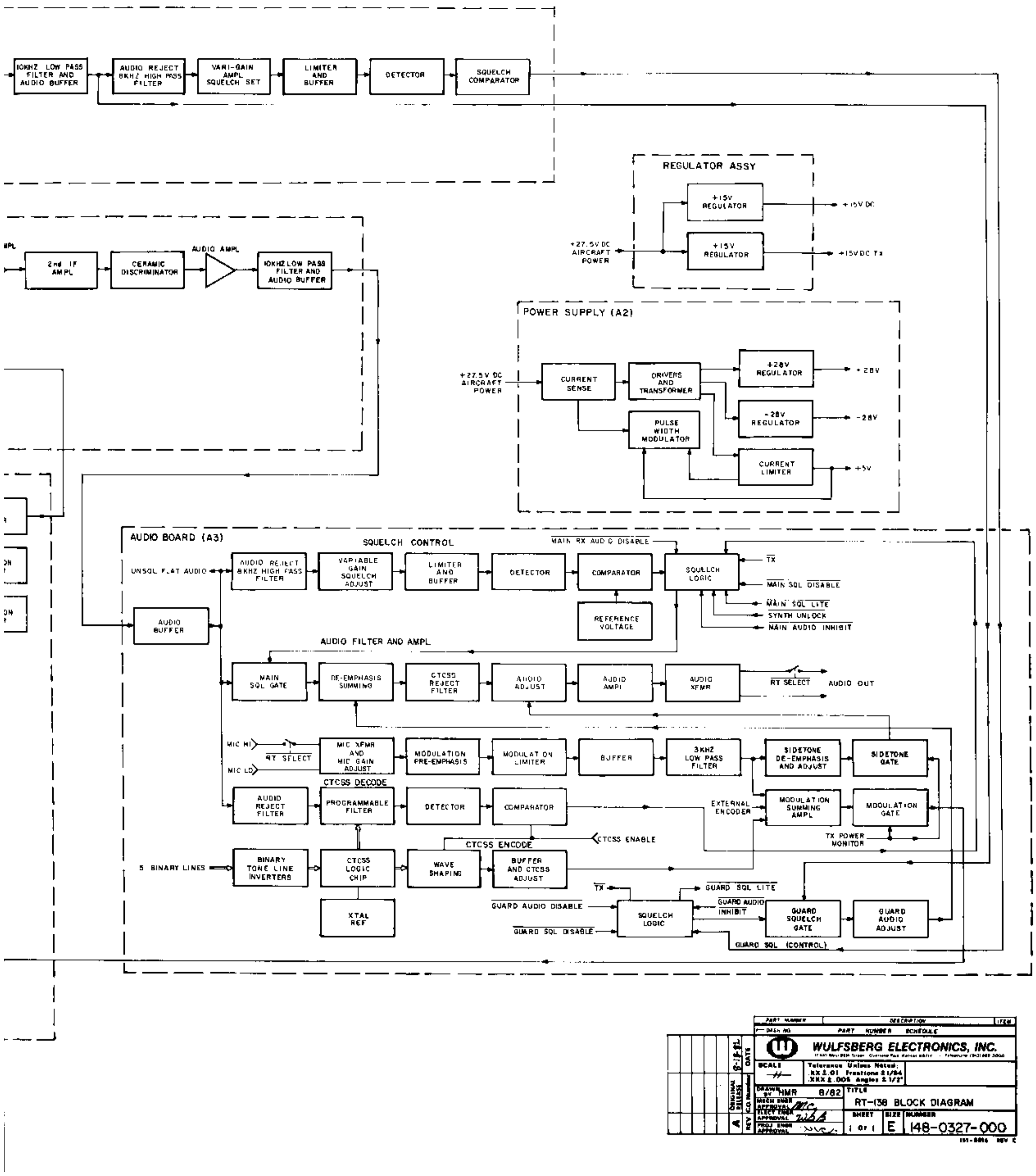


RT-138 BLOCK DIAGRAM
FIGURE 3.2-1

3-3/4



10KHZ LOW PASS FILTER AND AUDIO BUFFER
AUDIO REJECT 8KHZ HIGH PASS FILTER
VARI-GAIN AMPL SQUELCH SET
LIMITER AND BUFFER
DETECTOR
SQUELCH COMPARATOR
REGULATOR ASSY
+15V REGULATOR
+15V DC
+27.5V DC AIRCRAFT POWER
+15V REGULATOR
+15VDC Tx
2nd IF AMPL
CERAMIC DISCRIMINATOR
AUDIO AMPL
10KHZ LOW PASS FILTER AND AUDIO BUFFER
POWER SUPPLY (A2)
+27.5V DC AIRCRAFT POWER
CURRENT SENSE
DRIVERS AND TRANSFORMER
+28V REGULATOR
+28V
-28V REGULATOR
-28V
PULSE WIDTH MODULATOR
CURRENT LIMITER
+5V
AUDIO BOARD (A3)
SQUELCH CONTROL
MAIN RX AUDIO DISABLE
UNSQL FLAT AUDIO
AUDIO REJECT 8KHZ HIGH PASS FILTER
VARIABLE GAIN SQUELCH ADJUST
LIMITER AND BUFFER
DETECTOR
COMPARATOR
SQUELCH LOGIC
TX
MAIN SQL DISABLE
REFERENCE VOLTAGE
MAIN SQL LITE
SYNTH UNLOCK
MAIN AUDIO INHIBIT
AUDIO BUFFER
AUDIO FILTER AND AMPL
MAIN SQL GATE
DE-EMPHASIS SUMMING
CTCSS REJECT FILTER
AUDIO ADJUST
AUDIO AMPL
AUDIO XFMR
RT SELECT
AUDIO OUT
MIC HI
MIC LO
RT SELECT
MIC XFMR AND MIC GAIN ADJUST
MODULATION PRE-EMPHASIS
MODULATION LIMITER
BUFFER
3KHZ LOW PASS FILTER
SIDETONE DE-EMPHASIS AND ADJUST
SIDETONE GATE
CTCSS DECODE
AUDIO REJECT FILTER
PROGRAMMABLE FILTER
DETECTOR
COMPARATOR
EXTERNAL ENCODER
MODULATION SUMMING AMPL
MODULATION GATE
CTCSS ENABLE
TX POWER MONITOR
CTCSS ENCODE
5 BINARY LINES
BINARY TONE LINE INVERTERS
CTCSS LOGIC CHIP
WAVE SHAPING
BUFFER AND CTCSS ADJUST
TX
GUARD SQL LITE
GUARD AUDIO DISABLE
GUARD AUDIO INHIBIT
SQUELCH LOGIC
GUARD SQUELCH GATE
GUARD AUDIO ADJUST
GUARD SQL DISABLE
GUARD SQL (CONTROL)
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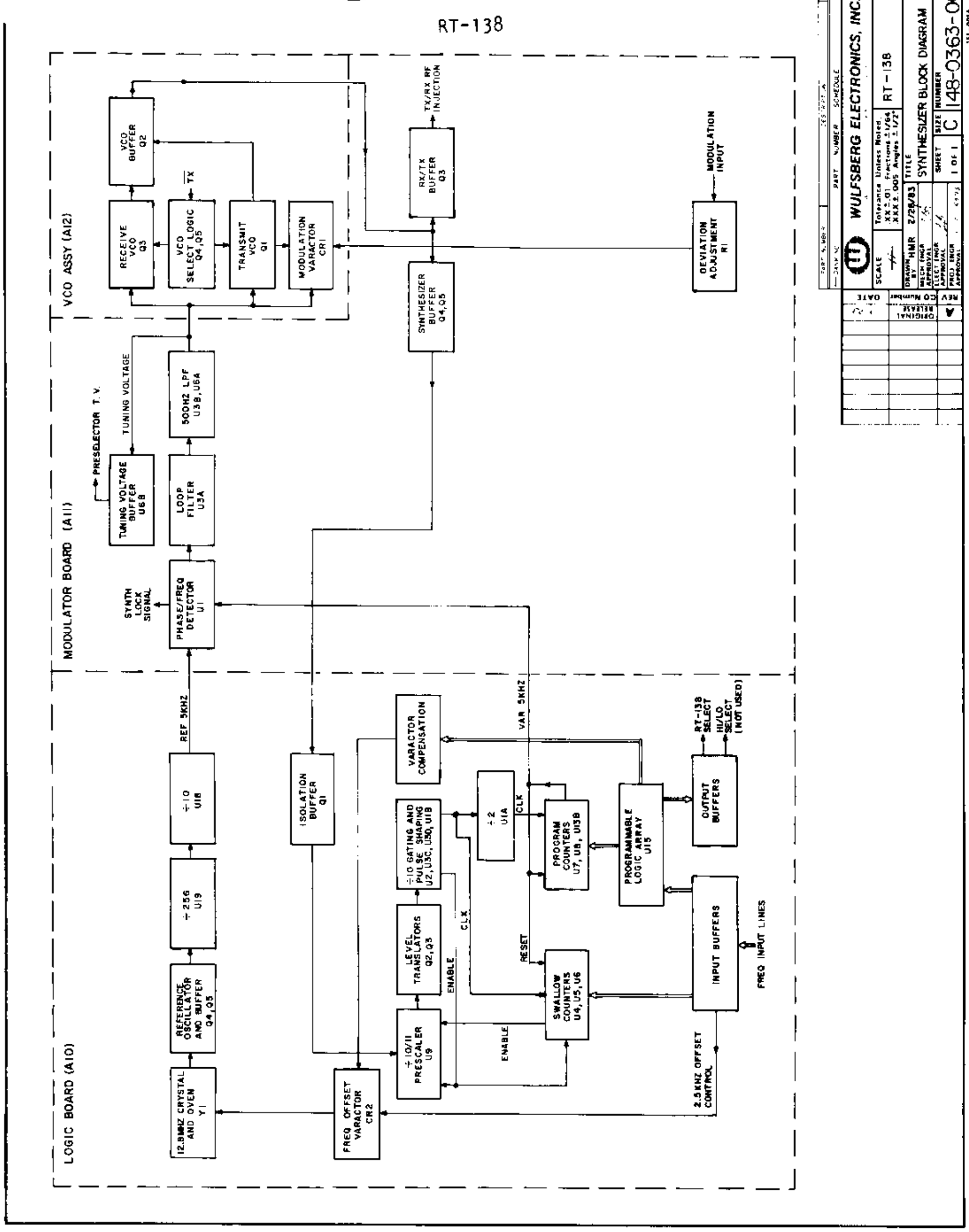

RT-138 SYNTHESIZER BLOCK DIAGRAM
FIGURE 3.3-1

3.3 SYNTHESIZER BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

For transmit the functions are:

1. Synthesize the correct frequency RF injection level for the R/T Assembly transmitter.
2. Frequency modulate the RF injection.
3. Control the FM sensitivity across the frequency range of the system.

3.3.1 VOLTAGE CONTROLLED OSCILLATOR (A12)

This assembly features a rigid-mounted printed circuit contained in a shielded box. To prevent frequency instabilities caused by component vibration, the completed assembly is filled with an epoxy encapsulation material. Only variable tuning adjustments remain accessible.

There are two independent oscillators plus a common buffer (A15Q2) housed within the VCO package. Only one VCO is functional at a time. Switch transistors (A12Q4 and A12Q5) select the desired oscillator. The VCO's and their frequency ranges are as tabulated.

VCO	F MIN	F MAX
TRANSMIT Q1	138.000 MHz	173.9975 MHz
RECEIVE Q3	118.000 MHz	153.9975 MHz

VCO frequencies are voltage controlled by varactor tuning of the oscillator LC circuits. A common tuning line from the Synthesizer Modulator controls both oscillators. Representative frequency versus voltage curves are shown in Figure 3.3.1-1.

3.3 SYNTHESIZER BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.3.1.1 RECEIVE VCO

In receive, A12Q3 is the selected oscillator. A high $\overline{TX}$ line turns on switch transistor (A12Q4) to activate the RECEIVE VCO. JFET A12Q3 is a self-biased device in a modified Colpitts configuration. Capacitors A12C26, A12C27 and A12C28 are the feedback control elements. These capacitors, along with variable padder A12C25 and varactor A12CR3, resonate with A12L8 to determine the oscillator frequency. Transmit and receive VCO's share a common drain network and a common buffer output (A12Q2).

3.3.1.2 TRANSMIT VCO

Transistor A12Q1 is selected for transmit operation by the VCO SELECT transistors. The TRANSMIT VCO design is similar to the receive except for modulation capability. The primary tuning varactor is A12CR2 and the modulation varactor is A12CR1. Corrected modulation bias voltage at A12C6 capacitor node is a combination of the main tuning voltage and an input from the fixed +10V supply. This summation of DC voltages maintains uniform modulation characteristics over the RT-138 frequency range.

3.3.1.3 VCO BUFFERED OUTPUT

The oscillator output is coupled through A12C19 to the base of output buffer stage A12Q2. Output from the buffer leaves the VCO Assembly at A12J15 pin 13.

3.3.2 SYNTHESIZER MODULATOR BOARD (A11)

In addition to the modulation adjustment, this board contains essential portions of the Synthesizer phase-lock loop. These are the RF buffers, the phase detection circuit and the loop filter circuit.

3.3.2.1 RF BUFFERS

The RF BUFFERS are part of the Modulator Board. The components are shielded by means of an RF fence with a removable top cover. Transistor A11Q3 is the RX-TX buffer which supplies RF energy to the R/T Assembly. Cascaded buffer transistors A11Q4 and A11Q5 complete the link between the VCO and the Logic Board prescaler.

3.3 SYNTHESIZER BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.3.3.4 PULSE SWALLOWING PRESCALER

The prescaler is the circuitry between the RF injection input and the prescaled output at A10U1B pin 8. This circuitry consists of buffer A10Q1, variable modulus (÷ 10 or ÷ 11) ECL counter A10U9, level translators A10Q2 and A10Q3, flip-flops A10U2 and A10U1B, and the programmed swallow counters. The number of counts "swallowed" or gated out of the VCO pulse train is determined by the BCD code on the load inputs of the swallow counters.

3.4 MAIN R/T ASSEMBLY BLOCK DIAGRAM AND CIRCUIT THEORY

The R/T detailed block diagram is shown in Figure 3.4-1. In receive, the RF signal is passed through the Transmit/Receive Relay and Power Splitter to the Main Receiver preselector. The preselector features four-pole selectivity with an RF amplifier isolating two tuned pairs. The preselector output drives a double conversion superhetrodyne circuit with IF's of 20.0 MHz and 455 kHz. FM detection is accomplished by a 455 kHz ceramic discriminator.

The transmitter is a broadband design with a nominal output of 10 watts switched by the T/R Relay. The transmitter has an RF amplifier, a Class "C" driver, a Class "C" final P.A. and a filter to minimize harmonic content.

3.4.1 PRESELECTOR OPERATION

The primary function of the preselector is image rejection. Double-tuned resonant circuits are employed at the input and output of RF amplifier A7Q1. These circuits are broadly tuned to accept the desired frequency but highly attenuate the image at any selected channel. Tuning is accomplished by hyperabrupt varactor diodes with the DC tuning supplied by the Synthesizer.

A bipolar transistor (A7Q1) with excellent intermodulation characteristics, in conjunction with the input resonator, determines the overall receiver sensitivity. After amplification by A7Q1, the preselector output is fed to the receiver mixer for frequency conversion.

3.4.2 IF STRIP

The Main Receiver has a dual-conversion IF. The first IF is 20 MHz and the second IF is 455 kHz. Low side injection is applied to the first mixer through an RF switch diode. The second L.O. is 20.455 MHz to provide the 455 kHz second IF.

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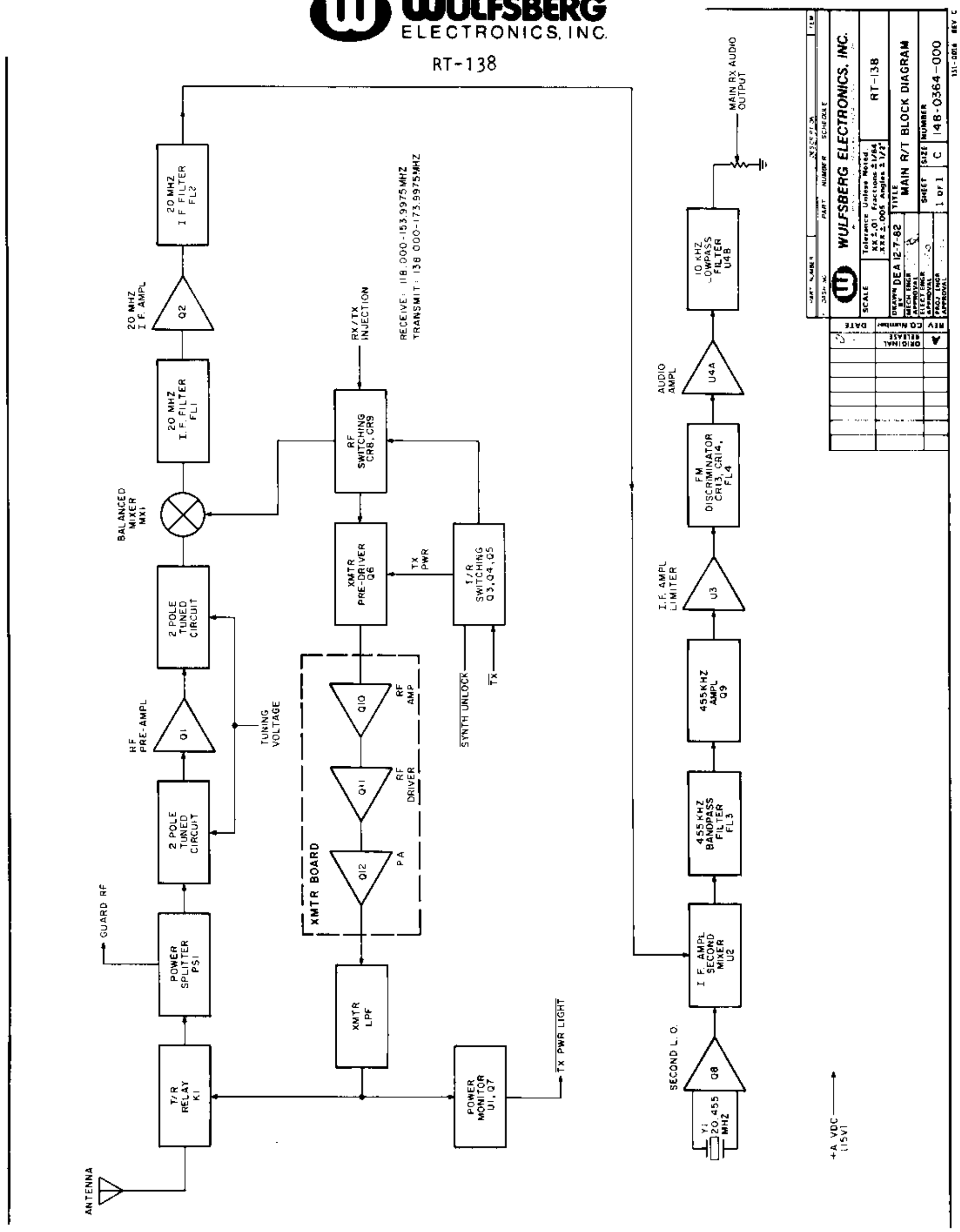

RT-138 R/T MODULE BLOCK DIAGRAM
FIGURE 3.4-1

3.4 MAIN R/T ASSEMBLY BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.4.2.1 FIRST IF AND MIXER (20.0 MHz)

The first mixer (A7MX1) is a doubly-balanced type whose output is primarily the sum and difference frequencies of the mixing process. The difference frequency is coupled through A7C33 to the input of A7FL1. Components A7C33, A7L15 and A7C34 match the mixer output impedance (typically 75 ohms) to the filter input impedance of 1.5 kohm.

Monolithic crystal filters A7FL1 and A7FL2 provide the 20 MHz selectivity of the IF strip. Each filter package provides four poles of IF selectivity. Input and output design impedances of this filter type are 1.5 kohms.

The 20 MHz filter output is AC coupled to Gate 1 of IF amplifier A7Q2. A voltage divider biases the gates to obtain maximum amplifier gain. Reactive components A7C35, A7C36, A7L16 and A7C38 tune the output of A7FL1. The drain circuit of A7Q2 is tuned by A7C43 providing the proper impedance for A7FL2.

This filter (A7FL2) is identical to the first filter and provides an additional four poles of 20.0 MHz selectivity. An "L" type step-down matching network matches the 1.5 kohm filter output to 220 ohms. The "L" is formed by A7L18 and A7C48. A fine adjust for the network is provided by A7C47.

3.4.2.2 IF AMP INTEGRATED CIRCUIT

A brief description of A7U2 (a multi-purpose integrated circuit designed for FM applications) follows. It has a three-stage limiting amplifier which is internally connected to a balanced product detector. The output of the product detector is emitter-follower buffered and appears at pin 1 of A7U4. Pin 9 of A7U4, monitored by a test point, is an attenuated version of the limiting amplifier output. It is attenuated 20 dB and terminated internally with 50 ohms.

The signal input of A7U2 is terminated by A7R44 and pin 6 is AC grounded by A7C70. The 20.0 MHz bandpassed signal input is amplified by the limiting amplifier and coupled to the product detector. The product detector serves as the second mixer of the IF.

3.4 MAIN R/T ASSEMBLY BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.4.2.3 SECOND LOCAL OSCILLATOR AND MIXER

A crystal-controlled Pierce oscillator (A7Q8) generates the Second L.O. frequency. The 20.455 MHz L.O. signal is coupled to the mixer input, pin 12 of A7U4. The 455 kHz difference is taken from A7U4 pin 1.

3.4.2.4 455 kHz IF AND FM DISCRIMINATOR

The mixer output of A7U2 is fed to A7FL3, a multi-element 455 kHz ceramic filter with equal input-output impedances of 1.0 kohm. This filter provides some adjacent channel selectivity plus spurious rejection.

The filter output is amplified by A7Q9 and then coupled to pin 4 of A7U3. Limited output from A7U3 drives a ceramic piezoelectric discriminator circuit through A7R55.

The discriminator circuit consists of A7FL4, hot-carrier diodes (A7CR13 and A7CR14) plus associated filter components. This combination of piezoelectric filtering and diode detectors produces the familiar "S" curve associated with FM detection. The curve is extremely linear for normal system deviation of ± 5 kHz.

3.4.3 RECEIVER AUDIO OUTPUT

Recovered discriminator audio is typically 100 mV peak-to-peak, and therefore, the primary function of A7U4A is audio amplification. The high impedance plus (+) input of A7U4A and A7R59 provides minimal discriminator loading. Voltage gain of A7U4A equals 16 which is controlled by A7R60 and A7R61. The low output impedance of A7U4A drives receiver output stage A7U4B.

The final opamp stage (A7U4B) is a low pass design whose response extends to 10 kHz before a frequency rolloff of 12 dB per octave occurs. The cascaded audio amplifiers reduce the 455 kHz component to an acceptable level before the audio leaves the R/T Assembly. Normalized audio from the R/T Assembly is adjusted to 0.50 VRMS by A7R68.

3.4.4 TRANSMIT/RECEIVER RF SWITCHING

Pin diodes A7CR8 and A7CR9 switch the TX/RX RF INJECTION to the MIXER or to the XMTR PREDRIVER input.

3.4 MAIN R/T ASSEMBLY BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.4.4 TRANSMIT/RECEIVER RF SWITCHING (cont.)

Within MX1, pins 7-8 are transformer primary connections which complete a DC path for the RX SWITCH diode. In receive, A7Q4 is off and the emitter follower output of A7Q3 goes to nearly 14 volts. Current flows through A7R21 and the mixer winding to turn on the RX SWITCH diode. The voltage drop across A7R20 is sufficient to keep the TX SWITCH back-biased during receive.

During transmit, the TX SWITCH diode becomes active. $\overline{TX}$ (A7P7 pin 14) is pulled low to energize the T/R relay; it also turns on A7Q4 and A7Q5 if the synthesizer loop is locked. The switched collector of A7Q5 closes the TX SWITCH and supplies power to the XMTR PRE-DRIVER (A7Q6). RF is amplified by A7Q6 to supply +12 dBm to the transmitter input.

3.4.5 TRANSMITTER SECTION

The transmitter chain is a three-transistor lineup located on the XMTR Board. It is a broadbanded VHF design providing 10 watts of saturated RF power. Active devices are A7Q10, A7Q11 and A7Q12.

3.4.5.1 XMTR BOARD

DC power is applied to all XMTR Board stages through Chassis mounted resistors. Remote mounted resistors distribute heat uniformly throughout the unit and also help stabilize Class "C" RF power stages by providing degenerate DC feedback.

The RF input is impedance transformed from 50 ohms (4:1 stepdown) by balun A7T2. Transistor A7Q10 is a Class "AB" RF stage whose temperature stability is maintained by A7CR16 and voltage feedback from the collector. Amplified power output is approximately one-half watt.

The base of A7Q11 is driven by a double-tuned interchange. Capacitor A7C98 is the mutual coupling element common with the A7Q10/A7Q11 tuned circuits. Bandpass characteristics are controlled by the mutual capacitance value.

The driver (A7Q11) is an intermediate level power device, capable of 2 to 3 watts of RF power operating Class "C". The interchange between the driver and the final is also double tuned with A7C105 being the mutual coupling element. The low impedance final output is matched to 50 ohms by output balun A7T3. A section of 50 ohm transmission line is tuned to resonance by A7C110 to couple the XMTR Board output to the LPF (Low Pass Filter).

3.4 MAIN R/T ASSEMBLY BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.4.5.2 LOW PASS FILTER (LPF)

The LPF is a nine-section elliptic filter design with ripples in both the pass and stop band responses. It is designed to pass transmit frequencies with low attenuation and to provide a large amount of harmonic suppression.

3.4.5.3 TRANSMIT POWER SENSOR AND MONITOR

Presence of RF is sensed by a detector consisting of diodes A7CR2 and A7CR3. When detected RF approaches the fixed voltage of comparator A7U1A pin 2, the comparator "trips" to turn on A7Q7 providing the TX PWR LIGHT function.

3.5 AUDIO BOARD BLOCK DIAGRAM AND CIRCUIT THEORY

The Audio Board is identical and interchangeable in all transceivers of the FLEXCOMM System. Only one transceiver of a FLEXCOMM system wired for multiple transceivers is actively used at a time. Control Unit tuning data indirectly controls MIC audio input and audio output switching of the desired transceiver. When the RT-138 is the only system transceiver, the MIC input-audio output switching is enabled for all valid RT-138 frequencies.

A block diagram of the audio circuitry is shown in Figure 3.5-1. Audio switching, audio response tailoring, Main Receiver squelch and Main Receiver tone encoding-decoding are the main functions of this board.

The circuitry blocks of the Audio Board are:

1. RT Select
2. Squelch logic and switching
3. Main Receiver squelch detection
4. Receiver audio processing
5. Transmit audio processing and switching
6. CTCSS tone encoding and decoding.

An understanding of these circuits will be aided by referencing the audio block diagram, the schematic diagram (Figure 5.1-7) and the following text.

3.5 AUDIO BOARD BLOCK DIAGRAM AND CIRCUIT THEORY (cont.)

3.5.1 RT SELECT CIRCUIT

$\overline{\text{RT SELECT}}$ is an active low input when the RT-138 Synthesizer recognizes the tuning wire inputs as a valid frequency. For other FLEXCOMM Transceivers, operated from the same Control Unit, $\overline{\text{RT SELECT}}$ will be high. Loading, due to paralleled input-output connections, is eliminated in a system hookup.

With $\overline{\text{RT SELECT}}$ low, emitter-follower A3Q11 is turned on and A3K1 is energized. One set of A3K1 contacts completes the MIC audio input circuit to A3T2 and another set of contacts completes the audio output circuit to A3T1.

3.5.2 MAIN RECEIVER SQUELCH LOGIC AND SWITCHING

Figure 3.5.2-1 is a simplified diagram of the Main Receiver squelch logic components. It is used to explain squelch operation.

Main Receiver squelch logic has two outputs. One (A3Q1) is an open-collector transistor whose output turns on the main squelch LED. The other output is the controlling line of the Main Receiver squelch switch.

Unless the Control Unit SQ TEST switch is activated (low), squelch test transistor A3Q2 is turned off. With A3Q2 off, its collector acts as an open circuit and has no effect on the squelch logic. Squelch test operation is described in Section 3.5.2.4.

3.5.2.1 MAIN AUDIO GATE SQUELCH CONTROL

To close switch A3U16C, 10V DC is applied to pin 6 through a resistor string consisting of A3R34, A3R35 and A3R36. With no signal applied, rectified noise will cause A3U3B pin 7 output to be low. This low, or inhibit, effectively grounds the junction of A3R34 and A3R35. This causes A3R35 and A3R36 to act as a pull-down resistance on the control line, blocking the receiver audio signal. The same low from noise comparator A3U3B keeps A3Q1 turned off so that the main squelch LED is off.