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PERSONAL VHF/UHF TRANSCEIVER

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FORWARD

The Personal VHF/UHF Transceiver Program was performed under Contract F33657-71-C-0832 by Martin Marietta Aerospace, Orlando Division, Orlando, Florida. This report is issued as Martin Marietta Report OR 12,787 and covers work performed from 22 April 1971 to 30 August 1973. The Air Force Program Monitor is Lt. Harold Engler, AFSC. This report was submitted in September, 1973, as data item A/B014.

The following is a list of the data items submitted on the contract:

A002/A003	Part I and Part II Configuration Item Development Specification for Personal VHF/UHF Transceiver
B002/B003	Part I and Part II Configuration Item Development Specification for Personal VHF Transceiver
A005	Drawings, Category "A" UHF/VHF
B005	Drawings, Category "A" VHF
B006	Technical Manual for Personal VHF Transceiver
A/B009	Reliability Program Plan
A/B010	Maintainability Program Plan
A/B011	Final Reliability and Maintainability Analysis Report
A/B012	CI Subsystem Design Analysis Report
B013	Electromagnetic Compatibility Plan
A/B015	System Design Trade Study Report
A/B016	Electromagnetic Compatibility (Non-systems) Test Plan for Personal Transceiver
A/B017 and A/B018	Equipment Test Plan (Non-systems)
A/B019	Acceptance Test Procedures

A020	Equipment Test Report for U.S. Air Force Prototype Personal Transceiver
B020	Equipment Test Report for Department of Justice Prototype Personal Transceiver
B020	EMC Test Report for Prototype Personal Transceiver
A021	Acceptance Test Report for Prototype Personal Transceiver
B021	Acceptance Test Report for Prototype Personal Transceiver

ABSTRACT

This report describes the personal VHF/UHF transceiver prototype development effort and the five different versions of the transceiver that were produced during the program. The program involved the development of state-of-the-art microelectronic modules, miniature parts, and modular packaging techniques to meet the design objects of a small, lightweight easy-to-maintain personal transceiver to satisfy requirements for municipal law enforcement agencies and Air Force Security Police. The requirements were met by using a combination of thick-film hybrid substrate modules, miniature discrete component modules, and custom development of miniature electrical parts and mechanical hardware.

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SECTION I

INTRODUCTION

1.0 OBJECTIVE

The objective of this effort was to develop and deliver prototype models of state-of-the-art personal VHF/UHF transceiver designed specifically to meet the needs of municipal law enforcement agencies and a personal VHF transceiver to satisfy world-wide requirements of the Air Force Security Police. This contract consists of Phase I of a two-phase effort to provide commercially available transceivers to satisfy the stated requirements.

Specifically, six prototypes of a VHF transceiver were to be built for the U.S. Air Force, six prototypes of variations of VHF and UHF transceivers were to be built for the U.S. Department of Justice, and associated test data and reports were to be provided.

2.0 APPROACH

Electrical design analysis, human factors tests, components evaluations, and packaging concepts led to tradeoffs being conducted to establish an overall design concept conducive to meeting the objectives of small size, lightweight, ruggedness, electrical performance, and ease of repair. The tradeoffs resulted in the selection of microelectronic hybrid substrate modules as the basic packaging concept. Human Factors tests were instrumented in finalizing a mechanical configuration and physical shape factor that equally satisfies both shoulder mount and handheld usage. The electrical and mechanical designs were directed toward a maximum of commonality among the different transceiver versions to minimize later requirements for test equipment and spares inventories.

3.0 RESULTS

Compact, lightweight versions of VHF, UHF, and crossband FM transceivers were developed and delivered in the quantities stipulated with the required data items. The transceivers feature RF power outputs of 4 watts and receiver sensitivities of 0.35 microvolts (VHF) and 0.5 microvolts (UHF). Each transceiver consists of a quick disconnect, tiltable antenna, an electronics unit containing all circuits and operating controls, and a detachable, self-contained, rechargeable battery assembly. The design provides for the interconnection of the three subassemblies to form an integral handheld unit. Furthermore, the antenna/electronics unit can be mounted on the user's shoulder while the battery is remoted by an extender cable for attachment (in a holster) to the user's belt. The operator controls are positioned for ease of use and are limited to ON-OFF/Volume, Squelch, Channel Selector and Press-to-Talk for simplified operation.

SECTION II

GENERAL DESCRIPTION

The VHF/UHF Personal Transceiver is a fully solid-state, four-channel, frequency-modulated transceiver, designed to be worn as an integral part of a police officer's uniform and to be used in handheld operation. The radio set (Figure 1) consists of the three separate sections of battery, electronics section, and antenna. The Air Force transceivers weigh 20.8 ounces and has a 19.6 cubic inch volume while the DOJ transceiver weighs 18.7 ounces with a 17.1 cubic inch volume.

The battery for both the Air Force (AF) and Department of Justice (DOJ) transceiver is made up of a series of seven 2-volt nickel-cadium cells capable of being recharged for a minimum of 360 cycles. The total ampere-hour requirement for the two services differs, however, necessitating two separate configurations. An extender battery cable is supplied with the AF equipment so that the battery can be carried in an inside pocket of the operator's clothing during extremely cold operating conditions (below 0°C).

The electronics section consists, for the most part, of several micro-circuit modules that plug into a single motherboard, allowing for ease of maintenance. Five different versions of the electronics section were built. All AF units are identical and can be tuned to operate in a 5-MHz band from 138 to 174 MHz (VHF). The DOJ transceivers are required to operate in a 7-MHz band with tone squelch over the frequencies given in Table I.

TABLE I

Department of Justice Transceivers

Type	Transmit Frequency (MHz)	Receive Frequency (MHz)
UHF/UHF	450 - 470 (UHF)	450 - 470 (UHF)
VHF/VHF	150 - 160 (VHF)	150 - 160 (VHF)
VHF/UHF	150 - 160 (VHF)	450 - 470 (UHF)
UHF/VHF	450 - 470 (UHF)	150 - 160 (VHF)

The antenna is a standard off-the-shelf item with a special plug-in connector. This fitting allows the antenna to separate from the electronics section when pulled, thereby preventing an assailant from grabbing the transceiver by the antenna and using it as a weapon on the user. Two types of antennas are used: one for the VHF and one for the UHF transceiver. In the case of the DOJ crossband radios, the transmitter frequency band determines the type of antenna that is used.

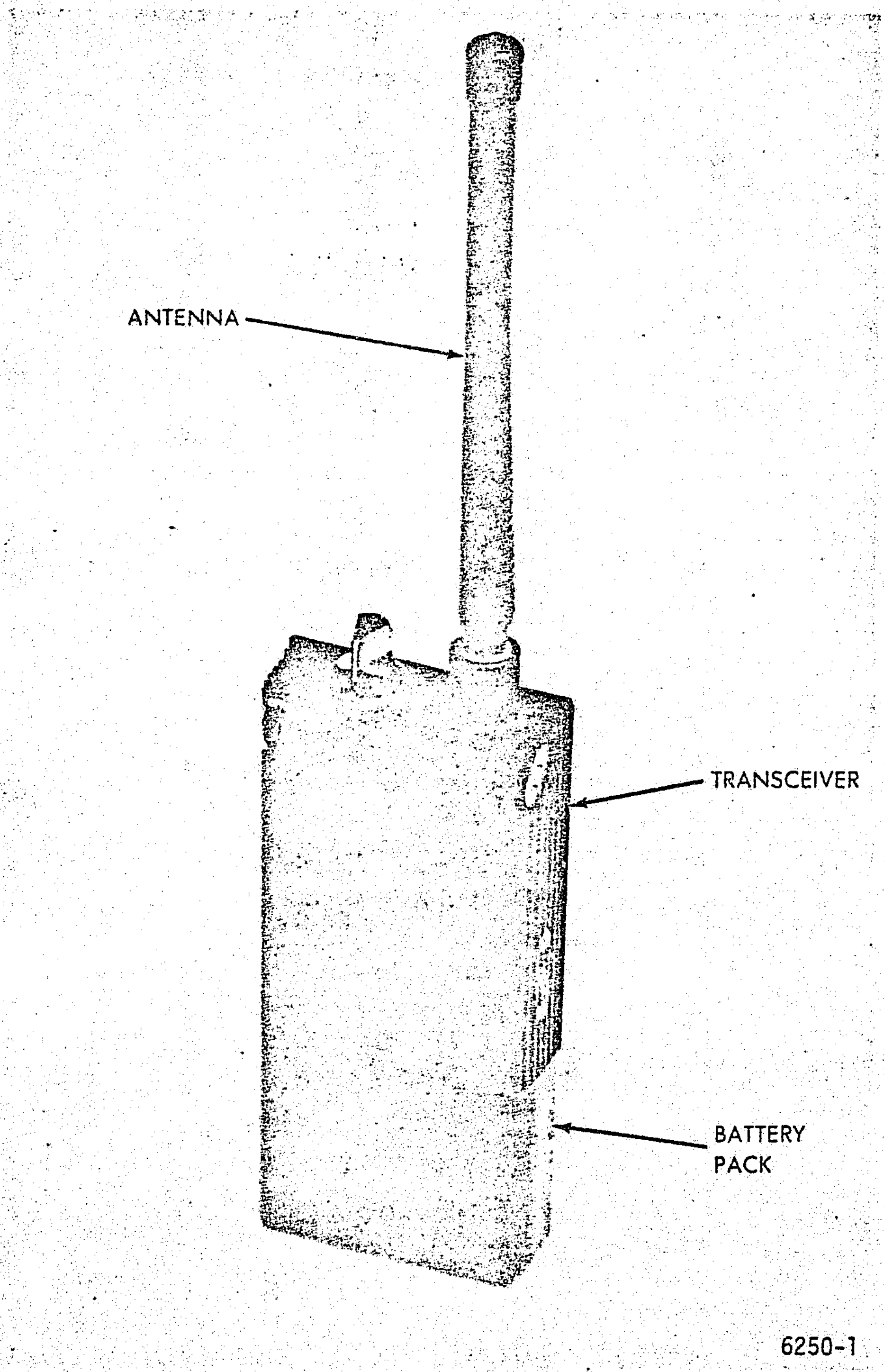

Figure 1. Personal Transceiver

The specifications and measurements taken for the DOJ transceivers are shown in Table II. The measurements and specifications for the AF transceivers are shown in Table III. The differences between the specifications and measured data are attributed to the small size requirement, limited battery power, and difficulty in obtaining performance and making changes when using microcircuits.

Four conveniently located operating controls allow the transceiver to be operated in the dark or under a garment. Figure 2 shows the operating controls. Transceiver operation is simple and straightforward. The desired channel is selected by using the select control. The squelch control is then adjusted to its minimal position (fully counterclockwise) and the OFF/VOL switch turned to the ON position. The OFF/VOL control is then adjusted to provide to a comfortable listening level and the squelch control adjusted to reject noise and receive the desired signals. To transmit, it is only necessary to touch the press-to-talk pressure plate and speak into the microphone. A brief description of the controls and operation of the transceiver is outlined as follows:

1. OFF/VOL Switch - This switch performs two functions: power is applied to the radio as the switch is turned clockwise; then, as the control is advanced further in this direction, the volume of the speaker increases. To turn the radio off, the control is turned counterclockwise until the stop is reached.

2. Squelch Control - As this control is moved clockwise, bias is applied to the squelch circuit, which removes power from the audio amplifier. This, in turn, inhibits the low-level random noise fed to the speaker in the absence of an RF signal. When a signal is present, power is again applied to the audio amplifier, allowing the amplified voice signal to pass on to the speaker.

3. Channel Select Switch - This switch selects any one of the four channels on which the transceiver operates. The switch has two-poles in order to simultaneously switch both the receive and transmit crystals into the oscillator module.

4. Press-to-Talk Switch - The transceiver, when on, is normally in the receive mode. To transmit any message, the press-to-talk switch must be depressed. This switch enables regulator module H113 to transfer power, both +9V and +6V, between the receive and transmit circuits.

TABLE II.

Summary of DOJ Transceiver Performance Specifications

Parameter	Contract Specification Limit	Measured Performance Data
Receiver, Spurious Response	85 dB	49 dB
IM Spurious Attenuation	65 dB	55 dB
Dynamic Range	80 dB	70 dB
Selectivity	80 dB	70 dB
Mod Acceptance Bandwidth	±7.5 kHz, minimum	±7.5 kHz
Sensitivity	0.35 μv	0.5 μv
LO Frequency Stability	±0.0005%	±0.0005%, -20°C to +50°C
Acoustic SPL	105 dB, minimum	90 dB, minimum
Audio Output Power	80 mW, maximum	80 mW, minimum
Audio Distortion/Noise	5% maximum/50 dB, minimum	5% maximum/50 dB, minimum
Receiver, Audio Response	+1, -3 dB	+3, -8 dB; 600 to 3000 Hz
Tone Squelch Sensitivity	<6 dB	<6 dB
Tone Squelch Turn-on Time	≤250 msec	≤250 msec
RF Front End Bandwidth	3 dB BW, 1.5-2.0 MHz (VHF) 4.5-5.0 MHz (UHF) -36 dB atten. @ 4xBW	3 dB BW, 1.5-3.0 MHz (VHF) 4.5-7.5 MHz (UHF) -16 dB atten. @ 4xBW
Tone Gen Stability	±0.5%	±0.5%
Tone Gen Turn-on Time	≤50 msec	≤50 msec
Transmitter Frequency Stability	±0.0005%	±0.0005%, -20°C to +50°C
Audio Distortion	5% maximum	5% maximum
Transmitter, Audio Response	+1, -3 dB	+3, -11.5 dB
FM Hum and Noise	40 dB, minimum	35 dB, minimum
Deviation Limiter	±5 kHz	±5 kHz
AM Hum and Noise	35 dB, minimum	35 dB, minimum
RF Power Output	4 watts ±1 dB	4 watts ±1 dB
RF Bandwidth and Tuning Range	7 MHz, minimum 150-160 MHz (VHF) 450-470 MHz (UHF)	7 MHz, minimum 150-160 MHz (VHF) 450-470 MHz (UHF)
Transmitter, Spurious Response	49 dB, minimum	40 dB

TABLE III.

Summary of Air Force Transceiver Performance Specifications

Parameter	Contract Specification Limit	Measured Performance Data
Spurious Response	85 dB	40 dB
IM Spurious Attenuation	65 dB	55 dB
Dynamic Range	80 dB	70 dB
Selectivity	80 dB	70 dB
Mod Acceptance Bandwidth	±7.5 kHz	±7.5 kHz
Sensitivity	0.35 μv	0.5 μv
LO Frequency Stability	±0.0005%	±0.0005%, -30°C to +50°C ±0.0010%, -40°C to -30°C
Acoustic SPL	105 dB, minimum	90 dB minimum
Audio Output Power	80 mW, maximum	80 mW, minimum
Audio Distortion/Noise	5% maximum/50 dB, minimum	5% maximum/50 dB, minimum
Receiver Audio Response	+1, -3 dB	+3, -10 dB, 600 to 3000 Hz
RF Front End Bandwidth	3 dB, BW 5 ±1 MHz 60 dB atten. @ 5xBW	3 dB BW, 5 ±1 MHz 50 dB atten. @ 5xBW
Transmitter Frequency Stability	±0.0005%	±0.0005%, -30°C to +50°C ±0.0010%, -40°C to -30°C
Audio Distortion	±5% maximum	±5% maximum
Transmitter Audio Response	+1, -3 dB	+3, -11.5 dB
FM Hum and Noise	40 dB, minimum	35 dB, minimum
Deviation Limiter	±5 kHz	±5 kHz
AM Hum and Noise	35 dB, minimum	35 dB, minimum
RF Power Output	4 watts ±1 dB	4 watts ±1 dB
RF Bandwidth and Tuning Range	5 MHz, minimum 138-174 MHz	5 MHz, minimum 138-174 MHz

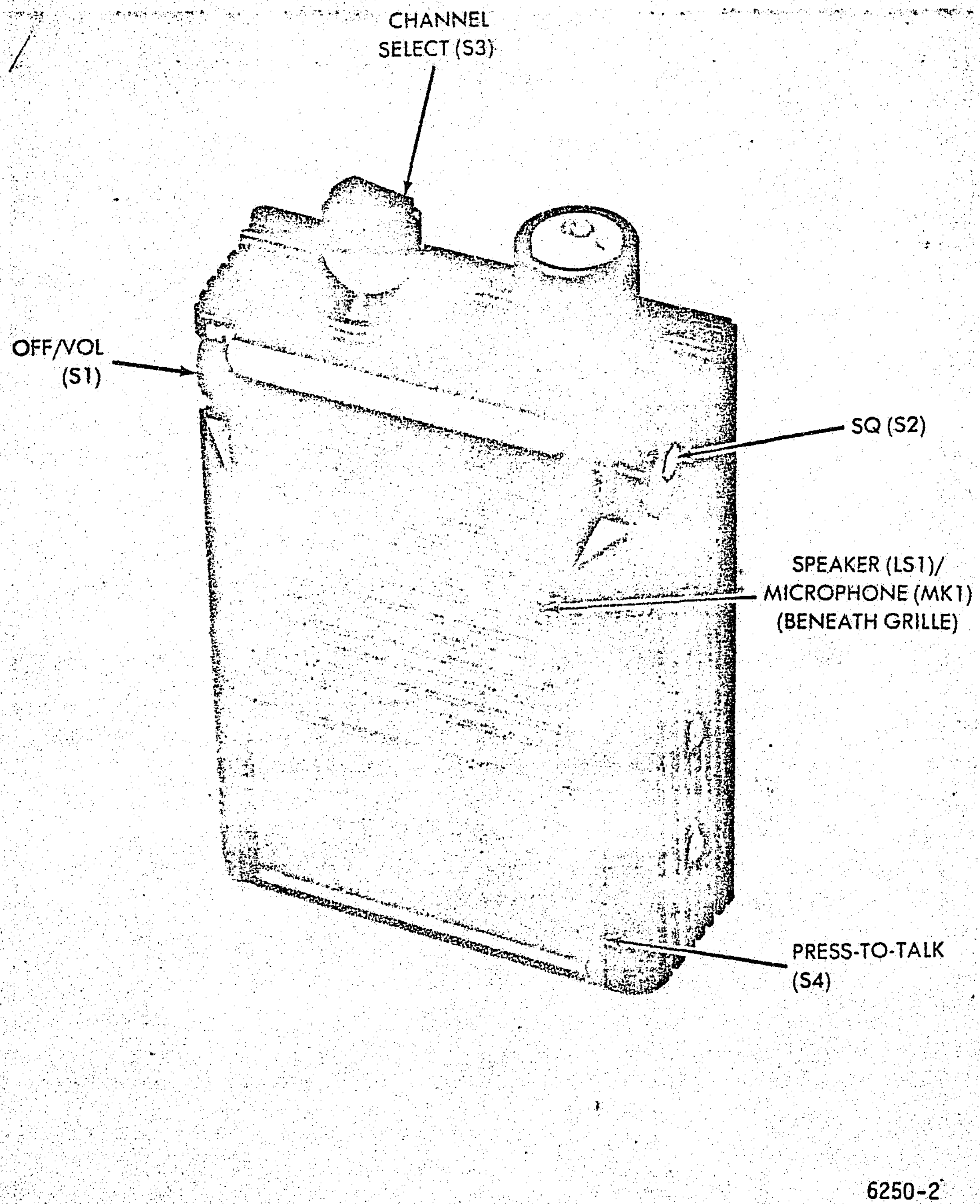

Figure 2. Operating Controls

SECTION III.

FUNCTIONAL DESCRIPTION

1.0 INTRODUCTION

The prototype Personal Transceiver is a fully solid-state, multi-channel, FM unit. The AF units transmit and receive on the 138- to 174-MHz VHF band. The DOJ units provide for operation in one (but only one) of the four combinations of frequency bands listed in Table IV.

TABLE IV.

Department of Justice Unit Frequency Bands

Type	Transmit (MHz)	Receive (MHz)
VHF/UHF	150 - 160	150 - 160
VHF/UHF	150 - 160	450 - 470
UHF/VHF	450 - 470	150 - 160
UHF/UHF	450 - 470	450 - 470

A block diagram of the basic transceiver subsystems is shown in Figure 3.

2.0 RECEIVE SUBSYSTEM

In the receive mode, the transceiver accepts electromagnetic energy in the desired band (150 MHz or 450 MHz), amplifies the energy, recovers the modulation information, and energizes a transducer with this information to produce the desired acoustic pressure level at the operator's ear.

The receiver frontend bandwidth is determined by an input bandpass filter and tuned RF amplifier. The received signal is passed through the antenna switch to the helical bandpass input filter assembly where most out-of-band signals are attenuated. This filter provides a substantial degree of the required receiver selectivity. The output of the helical filter is applied to the RF frontend module where it is amplified and then mixed with a local oscillator (LO) signal of the proper frequency to form a 21.4-MHz IF signal. The LO is derived by multiplying the output of the channel select oscillator module by an appropriate factor, depending on the receive frequency.

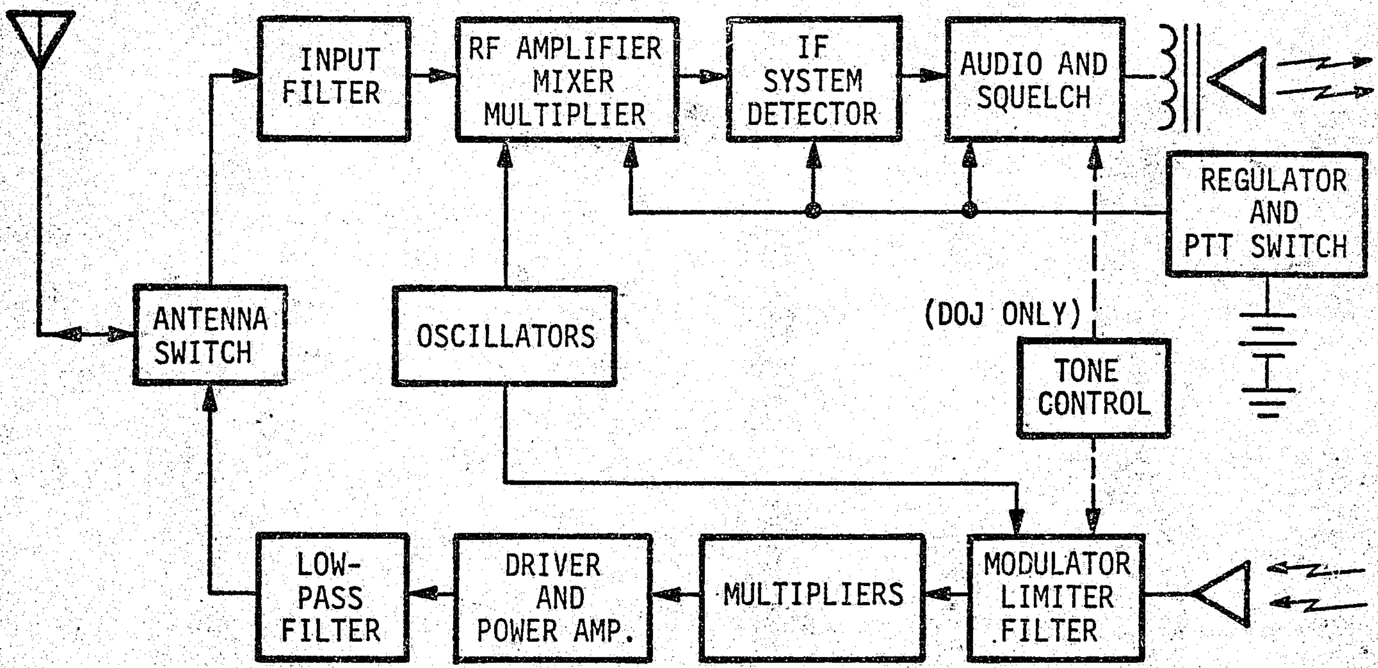

Figure 3. Transceiver Block Diagram

The major portion of the receiver gain is provided by the three IF amplifier modules, which are each capable of 50-dB voltage gains at the 21.4-MHz IF. Two four-pole crystal filters, each with 3-dB bandwidths set at ±7.5 kHz, provide the necessary IF selectivity.

The amplified and filtered output of the IF chain is applied to the discriminator module, which strips the audio information from the IF signal. The audio is amplified and applied to the speaker. A noise squelch circuit, which removes power from the audio amplifier when the input signal level is below some desired reference, is provided on all units. Audio gain and noise squelch threshold are both operator controls, allowing ease in selecting the weakest signal to be received and in setting the volume level of the received signal. In the DOJ units, a continuous tone squelch system is provided in addition to the noise squelch previously mentioned. The tone squelch module, in the receive mode, is sensitive to a particular preset subaudio tone. When the noise squelch indicates that a signal of desired magnitude is being received, the tone squelch circuit determines the presence of the particular tone of interest in the output signal from the discriminator. The presence of this tone activates the squelch mechanism, allowing the output audio amplifier to turn on.

3.0 TRANSMIT SUBSYSTEM

In the transmit mode, the transceiver accepts voice sound pressure through the microphone, which converts it to an electrical signal. This signal is impressed on an RF carrier in the form of phase modulation, and the resulting signal is multiplied up to the desired frequency band (UHF or VHF) and amplified to a level of 4 watts. It is then transmitted as electromagnetic energy by means of the antenna.

When the transceiver power is turned on and the press-to-talk switch is depressed, the transmit circuits are energized and the receive circuits are inhibited. With the transceiver in the transmit mode, the audio signal voltages from the microphone are amplified, filtered, and subjected to limiting (when the maximum audio signal level exceeds a predetermined reference) before they are applied to the modulator. Filtering the audio input signal ensures that only the bandwidth necessary for optimum intelligibility is applied to the modulator. The purpose of the limiting function is to control the maximum audio voltage level that can be used to modulate the carrier, thus controlling the maximum frequency deviation of the modulated output signal.

The RF carrier is generated by a crystal-controlled oscillator. The operating channel is selected by connecting the appropriate crystal to the oscillator circuit with the channel select switch. The DOJ transceivers incorporate a continuous tone squelch system, which generates (during transmit mode) the required subaudio tone. This tone is summed with the voice audio, thus modulating the RF carrier with both signals.

The oscillator output is divided into two signals having a quadrature phase relationship. The signals are selectively attenuated by the processed audio signal and then recombined, resulting in a phase modulated carrier. Since a phase modulator is used, no pre-emphasis is required for the audio input signal. The output of the modulator is multiplied by an appropriate factor (8 for VHF or 24 for UHF) and then applied to the RF power amplifier. The power amplifier module amplifies the modulated carrier so that the output power from the transceiver is approximately 4 watts. The amplified RF signal is then filtered and applied to the antenna. The lowpass filter removes higher order harmonics and helps assure that only the desired carrier frequency is transmitted.

SECTION IV

PHYSICAL DESCRIPTION

Three main assemblies of the personal transceiver are the antenna, the electronics section, and the battery assembly. Figure 4 illustrates the completely assembled Air Force Personal Transceiver. Accessories available for use with the transceiver are an extender cable for remotely locating the battery, a transceiver shoulder mount kit, a belt-mounted battery carrying case, and a battery charger.

Physical characteristics of the transceivers (with battery pack as viewed in Figure 5) are:

	DOJ	AF
Height	6.5 inches[1]	7.1 inches[2]
Width	2.6 inches	2.6 inches
Depth	1.3 inches	1.3 inches
Weight (with antenna and battery pack)	18.7 ounces	20.8 ounces
Volume (Archemedian)	17.1 cubic inches	19.6 cubic inches

The electronics section is the basic component of the personal transceiver equipment and contains the transmitter, receiver, and operating controls. The transceiver electronic enclosure is a rugged aluminum housing, finned on each side to maximize power dissipation. The channel-select knob is located on top with the squelch and VOL/OFF switch mounted on the sides. The press-to-talk is located on the front of the housing below the speaker grill. All controls are easily accessible whether attached to a uniform or hand-held. The controls and external hardware are either recessed, flush, or otherwise protected to prevent damage during high impact or shock situations, to prevent inadvertant movement of the controls, and for the comfort of the user.

The battery is a completely separate rechargeable nickel-cadmium type sealed assembly that attaches to the bottom of the transceiver with a quarter-turn quick-attach electromechanical connector (Figure 6). The battery has been designed for ease of replacement in the dark; it cannot be attached backwards or inadvertently removed. Furthermore, during battery replacement, none of the electronics in the electronics unit is exposed.

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1. 5.95 inches excluding connector protrusions.
2. 6.53 inches excluding connector protrusion.

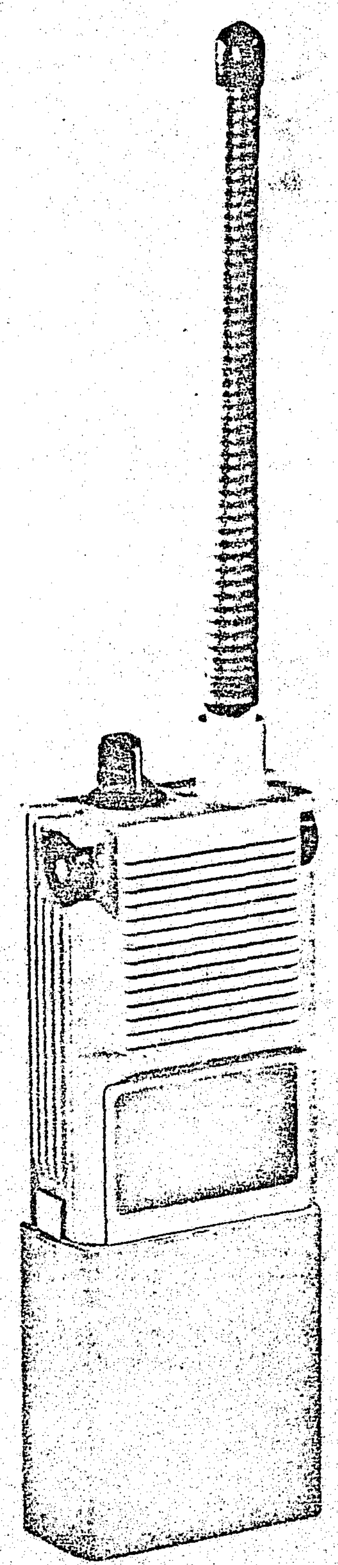


Figure 4. Air Force Personal Transceiver

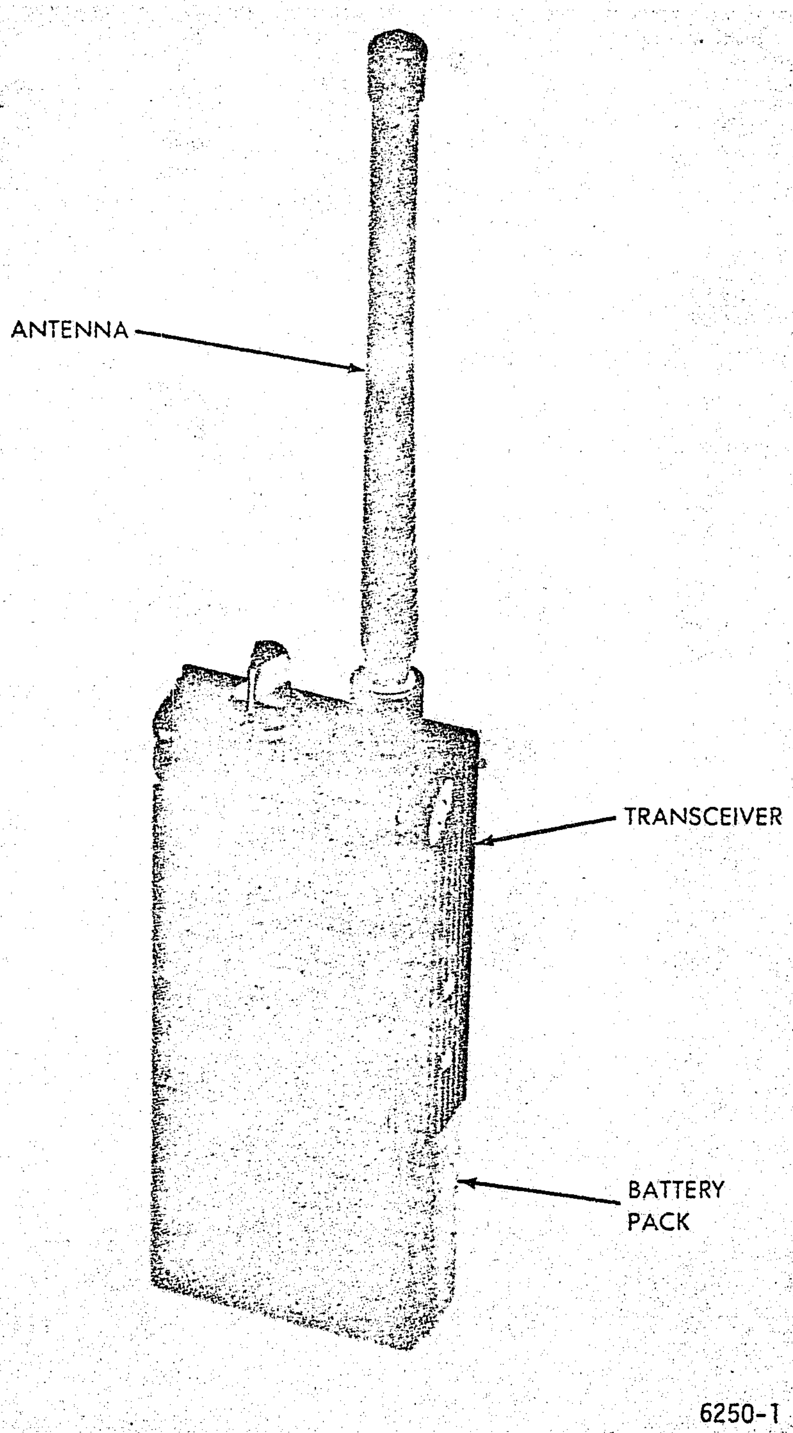


Figure 5. Personal Transceiver

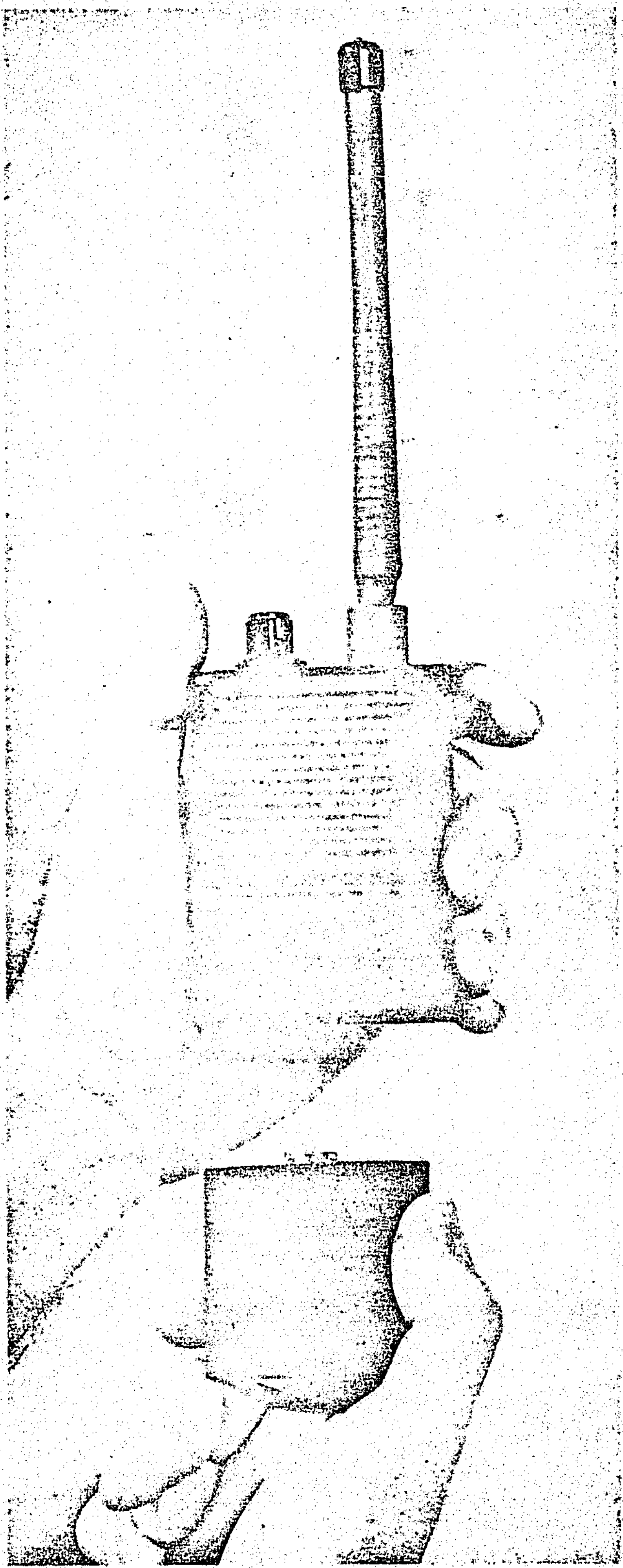


Figure 6. Personal Transceiver, Showing Detachable Battery

The antenna is connected to the top of the transceiver with a plug-in type connector so that the antenna cannot be used as a hand-hold for an assailant. The antenna is easily dismounted from the transceiver without damage to the unit and can be tilted as far as 20 degrees from the vertical position to allow for optimum location with respect to the users body or head. The unit consists of a flexible metal element with a soft neoprene or polyurethane cover.

The electronics unit contains a single common motherboard onto which is mounted all electronic circuits. Essentially all active circuit elements are contained on plug-in modules that are positioned into logical, functional subassemblies for ease of maintenance and repair. Removal of the electronics unit rear cover exposes the electronics hardware as shown in Figure 7. In all transceiver configurations, the receiver circuits are contained on the right-hand side of the electronic unit while the transmitter circuits are housed on the left-hand side, when observed from the rear of the unit as shown in Figure 7. Details of the part numbers and locations of all modules and other subassemblies are given in later sections.

The plug-in modules are catagorized into two types; the thick-film hybrid substrate configuration and the miniature discrete component configuration. Shown in Figure 8 is the DOJ VHF frontend module (discrete component) and the AF VHF frontend module (substrate). Both types use 0.22-inch diameter pins and plug into the motherboard on edge. The microcircuit modules use 0.040-inch thick ceramic substrates with circuit components mounted on one side and a ground plane plated on the other side. The substrates are covered with 0.005-inch thick insulated copper foil strips for protection against physical damage and for RFI. The discrete modules consist of miniature discrete components mounted on 1/32-inch thick printed-circuit boards.

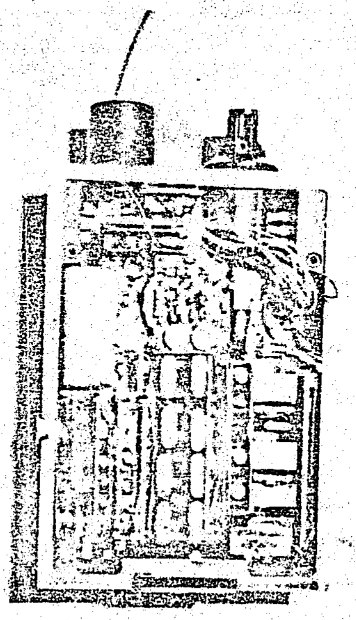


Figure 7. Internal View of
Transceiver Electronics Section

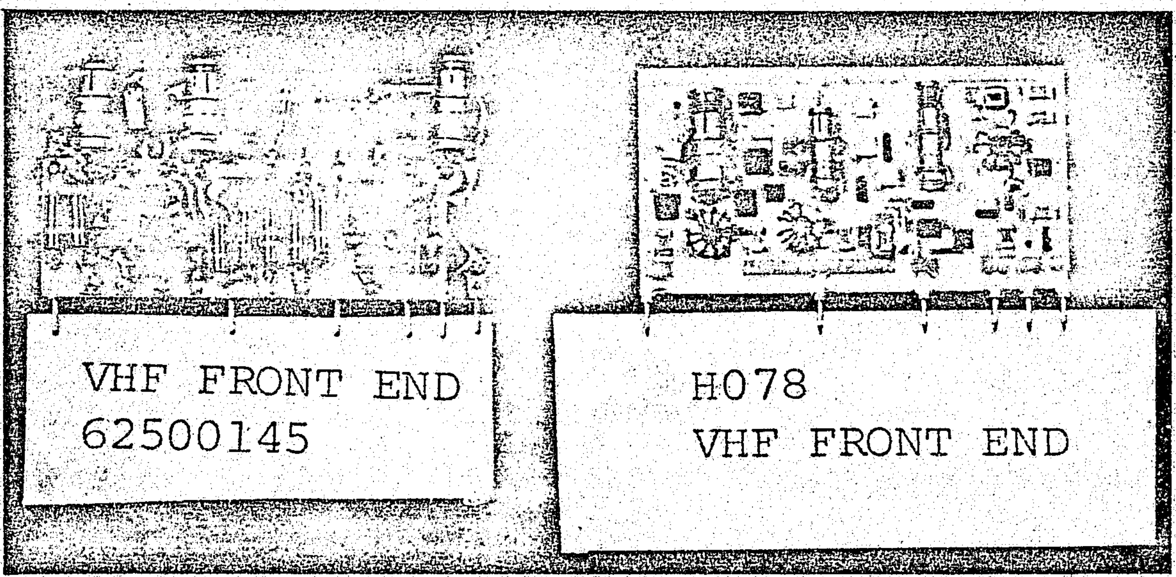


Figure 8. Internal View of DOJ and AF Frontend Modules

SECTION V.

ELECTRICAL DESCRIPTION

1.0 INTRODUCTION

This section contains a description of the electrical configurations and operation of the various Air Force and Department of Justice versions of the personal transceiver. These descriptions are followed by a detailed circuit description of each transceiver module and functional subassembly.

2.0 AF VHF TRANSCEIVER

The Air Force Personal Transceiver is a fully solid-state, portable, battery powered, multichannel unit that transmits and receives in the 138- to 174-MHz VHF band. The device may be divided into the following three functional areas:

1 Receive subsystem.

2 Transmit subsystem.

3 Common functions.

The schematic for this Air Force transceiver is shown in Figure 9.

2.1 COMMON FUNCTIONS

The transceiver press-to-talk (PTT) switch/regulator module supplies power to whichever subsystem (transmit or receive) is in use. When OFF/VOL switch S1A is placed in the ON position, the +9-volt battery output is applied to pin 6 on PTT switch/regulator module H113. Module H113 generates a regulated +6V output at pin 1 and a +9V output at pin 8 that activates the receive circuits; the transmitting circuits are automatically inhibited. When press-to-talk switch S4 is depressed, a ground signal is applied through thermostat S3 in the VHF power amplifier module to pin 7 on switch-regulator module H113. The ground signal applied to pin 7 causes circuits in the module to remove the +6V and +9V at pins 1 and 8 and to apply the voltages to pins 2 and 5, respectively. This condition inhibits the circuits in the receiving function and enables the circuits in the transmitting function. The circuits remain in this state as long as press-to-talk switch S4 is held depressed. When the switch is released, the circuits reverse, the receiving function is again enabled, and the transmitting function is inhibited.

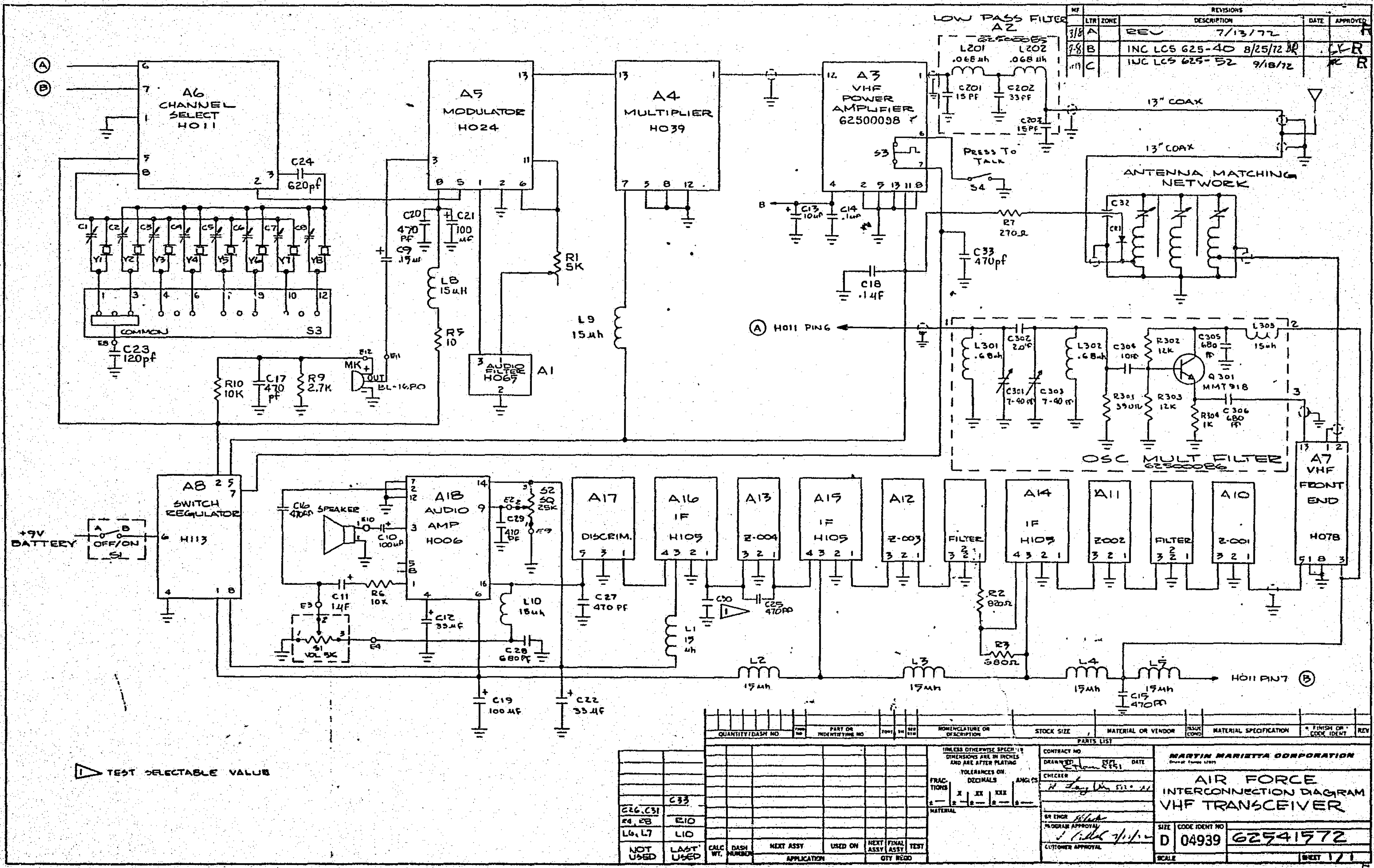


Figure 9. AF Transceiver Schematic Diagram.

2.2 RECEIVE SUBSYSTEM

In the receive mode, regulated +6V is applied to pin 7 of channel select module H011, which activates the receive oscillator circuit and produces a constant RF signal from pin 6 that is applied to the oscillator-multiplier-filter circuit. The frequency of the RF signal is controlled by crystal Y1, Y3, Y5, or Y7. The controlling crystal is selected when channel select switch S3 is placed to one of the four channel positions. The crystal frequencies for the four channels are selected so that they occur within a 0.625-MHz segment of the allotted 14.6- to 19-MHz frequency range. Trimmer capacitors C1, C3, C5, and C7 provide for fine tuning of the associated receiver channel frequency. The capacitors are adjusted both at the factory and at the time the channel frequency (crystal) is changed.

The RF signals from module H011 are applied to a narrow bandpass filter in the oscillator-multiplier-filter circuit, with a bandwidth of approximately 0.5 to 1.0 MHz. The bandpass filter is tuned with variable capacitors C301 and C303, so that the fundamental signal frequencies are filtered out and the second harmonic signal frequencies at approximately 33 MHz are passed unattenuated. The frequency-doubled RF signals from the oscillator-multiplier-filter are applied as a local oscillator signal input to pin 13 on the VHF frontend module H078. This signal is multiplied by four to produce the local oscillator signal, which is 21.4 MHz below the center frequency of the RF input signal for the selected channel that is received via the antenna.

The RF input signal is accepted by the antenna and filtered by the antenna matching network before it is applied to pin 2 of the VHF front-end module. The antenna matching network contains a 3-pole helical band-pass filter centered at the RF input frequency that attenuates out-of-band RF signals.

In module H078, the RF input signal is mixed with the local oscillator signal to develop a desired intermediate frequency (IF) signal of 21.4 MHz. The 21.4 MHz IF signal is applied through pin 5 and impedance matching network Z001 to filter FL1.

Filter FL1 is a bandpass filter that removes undesired signals falling outside a 15-kHz band centered about 21.4 MHz. The 21.4-MHz IF signal is applied through impedance matching network Z002 to IF amplifier Number 1 (module H105). Module H105 is a wideband amplifier that has a gain of approximately 50 dB at the IF. The 21.4-MHz signal output from module H105 is further filtered and amplified through filter FL2, impedance network Z003, IF amplifier Number 2 (module H105), impedance network Z004, and IF amplifier Number 3 (module H105), and is then applied to the discriminator module.

In the discriminator module, the IF signal is demodulated to develop the desired audio signal voltages. The audio signal voltages are applied through pin 5 to OFF/VOL potentiometer/switch S1B and to pin 16 on audio amplifier module H006.

Potentiometer/switch S1B (OFF/VOL) is an operator control that controls the amplitude of the audio signal voltages applied to audio amplifier module H006. The positioning of OFF/VOL potentiometer/switch S1B controls the amplitude of the demodulated and amplified audio output signal voltage applied through pin 3 to speaker LS1. Squelch potentiometer S2 is connected to a squelch circuit in module H006. This control is an operator adjustment that effectively biases the squelch circuit so that low-level random noise voltages are inhibited from generating an output signal to the speaker, yet the stronger, desired audio signals are amplified through module H006 and applied to the speaker.

2.3 TRANSMIT SUBSYSTEM

When the press-to-talk switch S4 is depressed, +6V is applied to pin 5 on channel select module H011, thus activating the transmit oscillator, which produces a constant RF output signal from pin 2. The frequency of the RF output signal is controlled by crystal Y2, Y4, Y6, or Y8. The controlling crystal is selected when channel select switch S3 is placed in one of the four channel positions. The crystal frequencies for the four channels are selected so that they occur approximately within a 0.6-MHz segment of the alloted 17.2- to 21.75-MHz frequency range. Trimmer capacitors C2, C4, C6, and C8 provide for fine tuning of the four channel frequencies. The capacitors are adjusted both at the factory and at the time the channel frequency (crystal) is changed.

The audio signal voltages from microphone MK1 are applied to pin 3, and the RF signals from channel select module H011 are applied to pin 5 of modulator module H024. In H024, the audio signals are amplified and subjected to limiting (when the maximum audio signal exceeds a predetermined level). The purpose of the limiting function is to control the maximum audio voltage level that can be used to modulate the carrier. This limiting action is a direct factor in controlling the maximum frequency deviation of the modulated output signal. The audio signal is routed through pin 1 to pin 3 on audio filter module H065. The filtered audio signal is applied from pin 1 on the module through potentiometer R1 to pins 6 and 11 on module H024. Potentiometer R1 is adjusted at the factory to control the maximum amount of modulation present in the output from module H024 by controlling the amplitude of the signal voltages applied to the module. The factory adjustment is set so that the maximum amount of frequency deviation of the final modulated transmitter output is less than 5 kHz. In module H024, the audio voltage applied from module H065 modulates the RF signal applied from channel select module H011. The phase-modulated signal output from the module is routed through pin 13 to pin 13 on multiplier module H039.

The modulated signal applied to multiplier module H039 is multiplied by a factor of 8; this is accomplished by developing and amplifying the eighth harmonic of the applied signal. The signal from module H039 is applied through output pin 1 to pin 12 on the VHF power amplifier module.

The VHF power amplifier module amplifies the modulated RF signal by approximately 36 dB so that the output power from the transceiver will be 4 watts ±1 dB. The modulated RF signals are applied through output pin 1 and a lowpass filter to the antenna. The lowpass filter removes the second and higher harmonics from the RF signal that is centered at one of the four prescribed channel frequencies. A thermostat is mounted in the VHF power amplifier to protect the transmitting circuits from overheating caused by a high VSWR condition such as removal of the antenna while transmitting. When the temperature of the transmitting circuits exceeds 200° ±8°F, the thermostat opens and removes the ground signal being applied to switch-regulator module H113. This action causes the transmitting circuits to be inhibited and the receiving circuits to be enabled. Once the ambient temperature drops 20°F below the temperature at which the thermostat opened, the thermostat closes, the ground signal to switch regulator module H113 is again applied from switch S4 (assuming the operator is still depressing the pressure plate), and the transmitting circuits are enabled.

3.0 DOJ VHF TRANSCEIVER

The Department of Justice (DOJ) VHF transceiver is very similar electrically to the Air Force (AF) transceiver discussed in Section 3.0. The primary differences consist of the addition of tone squelch circuits, changes in the antenna matching network, and a change in the battery size (Figure 10).

The DOJ units incorporate a tone squelch system in addition to the noise squelch described in the previous section. In the transmit mode, the tone squelch module generates a subaudio tone that is common for all channels. The tone frequency is preselected and factory set. The output tone from pin 2 is applied to summing amplifier A1 along with the processed audio from pin 1 of module H065. The summing amplifier combines the correct proportions of the two signal streams and applies them to pin 11 of modulator module H024. The subaudio tone is then transmitted as a component of the RF output signal, with a frequency deviation between 300 and 700 Hz.

In the receive mode, the tone squelch module functions as a narrowband tone decoder. It monitors the discriminator output and detects the presence of the desired tone. Only when the proper tone is continuously present does the tone module allow audio amplifier module H006 to function.

Antenna matching network 62500042 contains a two-pole helical bandpass filter, which rejects out-of-band RF signals. The out-of-band attenuation characteristics are approximately those predicted for a two-pole Butterworth response.

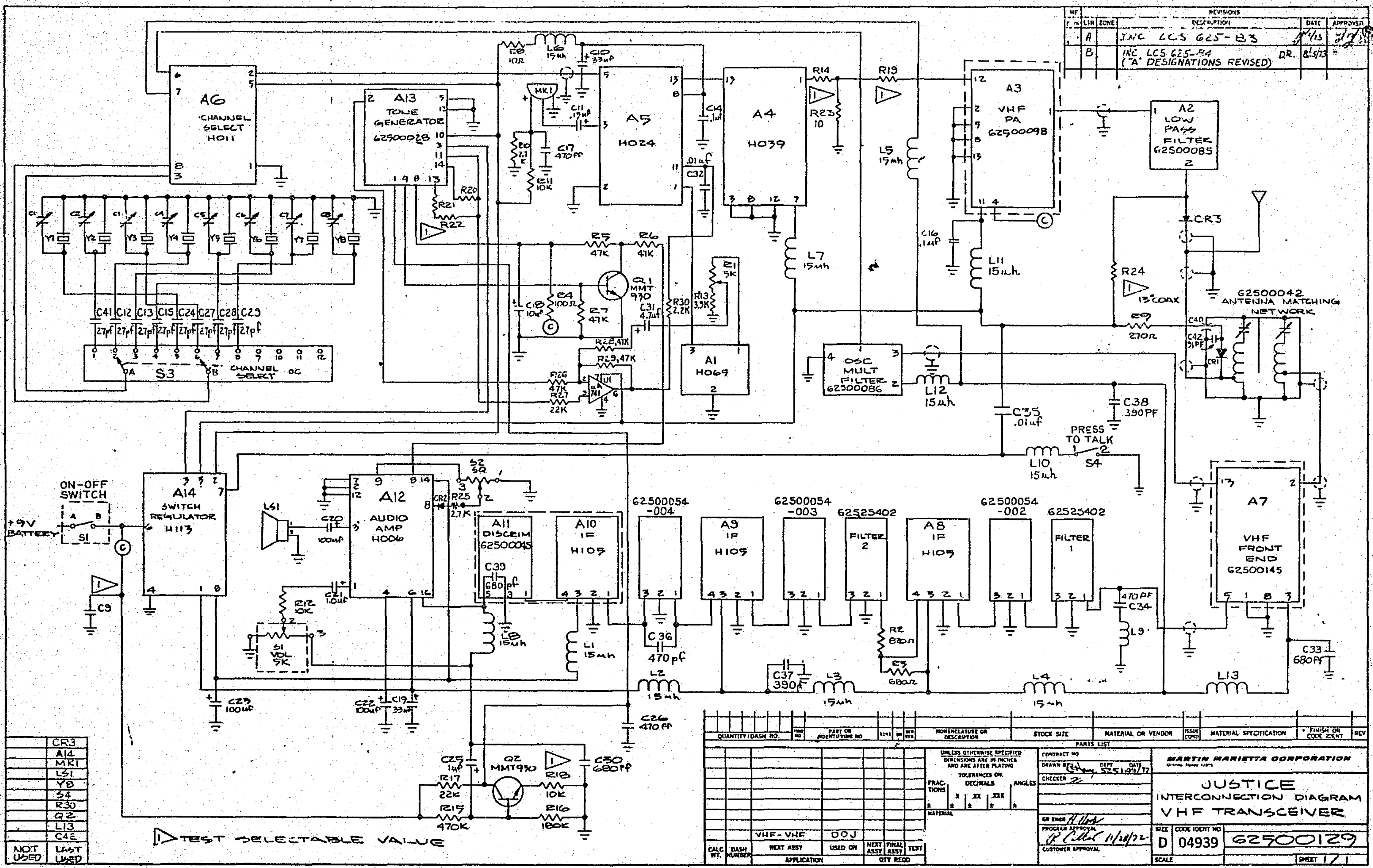


Figure 10. DOJ VHF Transceiver Schematic Diagram

4.0 DOJ UHF TRANSCEIVER

The DOJ UHF transceivers are electrically similar to the DOJ VHF units. The only significant differences occur in the RF processing and multiplier modules (Figure 11). The DOJ UHF units translate the RF signal by 24 times the crystal frequency, as opposed to a translation of 8 times in the VHF transceivers.

In the receive mode, the output of channel select oscillator module H011, pin 6, is applied to pin 1 of UHF oscillator-multiplier-filter 62500087. The module generates and filters the third harmonic of the crystal frequency at approximately 54 MHz. The frequency-tripled output from pin 3 of the oscillator-multiplier-filter is applied to pin 10 of UHF frontend module 62500107. A series of three frequency doublers in the UHF frontend module multiply the input signal (approximately 54 MHz) by a factor of 8, up to the 440-MHz region, which is 21.4 MHz below the RF input frequency. The RF input processing circuits consisting of the antenna, two-pole helical bandpass filter, antenna matching network, and RF front end amplifier, are tuned to the UHF input frequency. All processing and receive circuits following the RF mixer are identical to those in the DOJ VHF transceiver.

In the transmit mode, all circuits up to the output of multiplier module H039, pin 1, are the same as that in the DOJ VHF unit. The output of the multiplier module is applied to pin 3 of UHF tripler module H051, which multiplies the RF carrier up to the desired UHF frequency. The output of tripler H051, Pin 12, is applied to pin 12 of UHF power amplifier module 62500092, which amplifies the UHF signal to approximately a four-watt level. The power amplifier incorporates a lowpass filter within the module, which attenuates higher order harmonics of the desired transmit frequency. The output of the UHF power amplifier, pin 1, is then transmitted via the antenna.

5.0 DOJ CROSSBAND TRANSCEIVERS

There are two crossband units with one containing a UHF Transmitter and a VHF Receiver (Figure 12) while the other contains a VHF Transmitter and a UHF Receiver (Figure 13). The UHF and VHF circuits in the crossband transceivers are identical to the corresponding UHF and VHF circuits in the DOJ all-UHF and all-VHF transceivers. The units are supplied with crystals identical to those supplied with the all-VHF and all-UHF transceivers. Therefore, the crossband units can intercommunicate by using the VHF band to transmit from the VHF/UHF unit to the UHF/VHF unit and the UHF band to transmit in the reverse direction. Furthermore, a transmission made on channel 1 from the UHF/VHF unit can be heard on channel 1 of the all-UHF transceivers, etc.

The antenna supplied with a specific crossband transceiver is matched to the same band as the transmitter band of that transceiver,

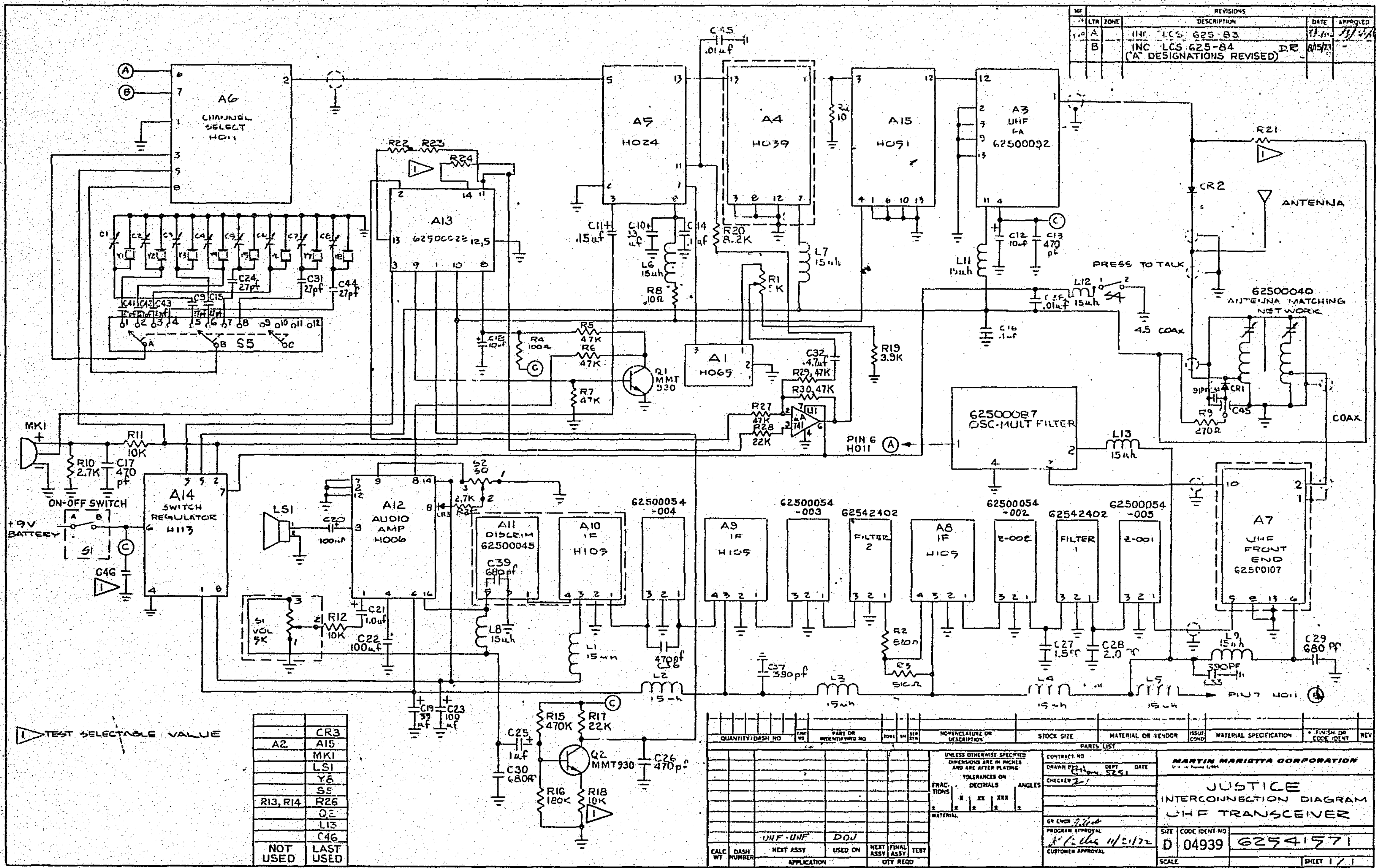


Figure 11. DOJ UHF Transceiver Schematic Diagram

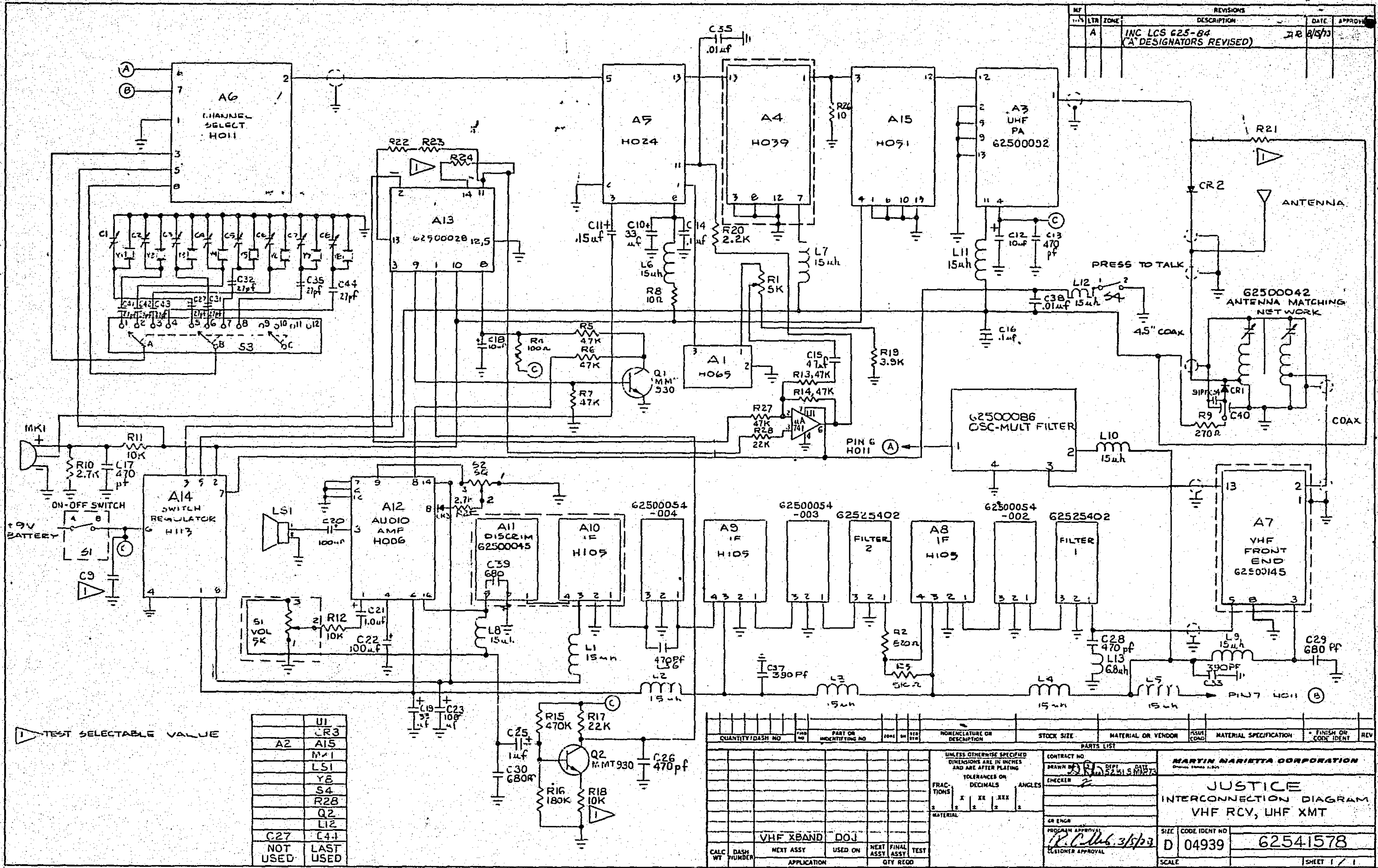


Figure 12. DOJ UHF/VHF Transceiver Schematic Diagram

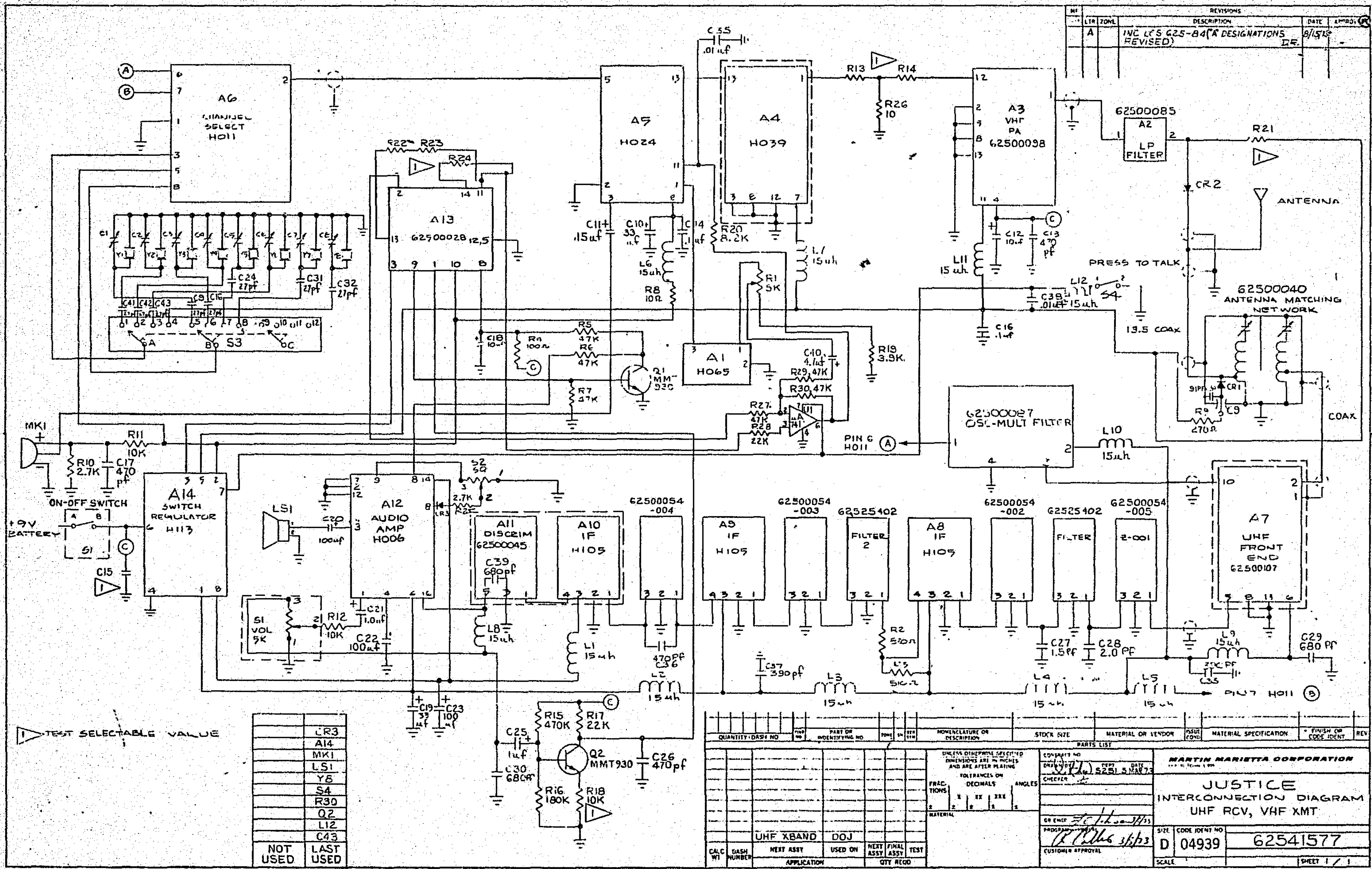


Figure 13. DOJ VHF/UHF Transceiver Schematic Diagram

(i.e., a UHF antenna is supplied with the UHF/VHF transceiver and a VHF antenna is provided with the VHF/UHF transceiver). The transceiver exhibits the best overall performance when the receiver is used with the "wrong" band antenna than when the transmitter is operated on the "wrong" band antenna.

6.0 MODULE DESCRIPTION

This subsection contains a circuit description of each transceiver module. The following is a list of all modules, the corresponding part numbers, and the paragraph number in which each is described:

Para. No.	Part No.	Description
6.1	H006	Audio
6.2	H011	Oscillator
6.3	H024	Modulator
6.4	H039	Multiplier-Transmitter (8)
6.5	H051	UHF Tripler
6.6	H065	Filter-Audio
6.7	H105	Amplifier, IF
6.8	H113	Regulator, Switch
6.9	62500028	Generator, Tone
6.10	62500040, 41, 42	Filter, Receiver Antenna
6.11	62500045	Discriminator
6.12	62500085	Filter, Lowpass
6.13	62500155	Power Amplifier, UHF
6.14	62500107	Frontend, UHF
6.15	H078, 62500145	Frontend, AF-VHF DOJ-VHF
6.16	62500086	Oscillator Filter, VHF
6.17	62500087	Oscillator Filter, UHF
6.18	62500098	Power Amplifier, VHF
6.19	62500054	Network, Impedance Matching
6.20	62525402	Filter, Crystal Bandpass

6.1 AUDIO AMPLIFIER MODULE H006

The audio amplifier module (Figure 14) is composed of an audio amplifier and noise squelch circuit. The audio recovered from the discriminator is fed simultaneously to both the audio amplifier and squelch circuits. The squelch circuit input consists of a four-pole active filter network, to sense noise present in the 4- to 7-kHz audio spectrum when a carrier is not quieting the receiver.

Pin 16 is the audio input from the discriminator to the squelch portion of the module. In the absence of signal, the audio consists of random noise in the range of 0- to 7-kHz at a 10-mv level. Amplifiers A1 and A2 are configured as highpass filters with a cutoff frequency of 8 kHz.

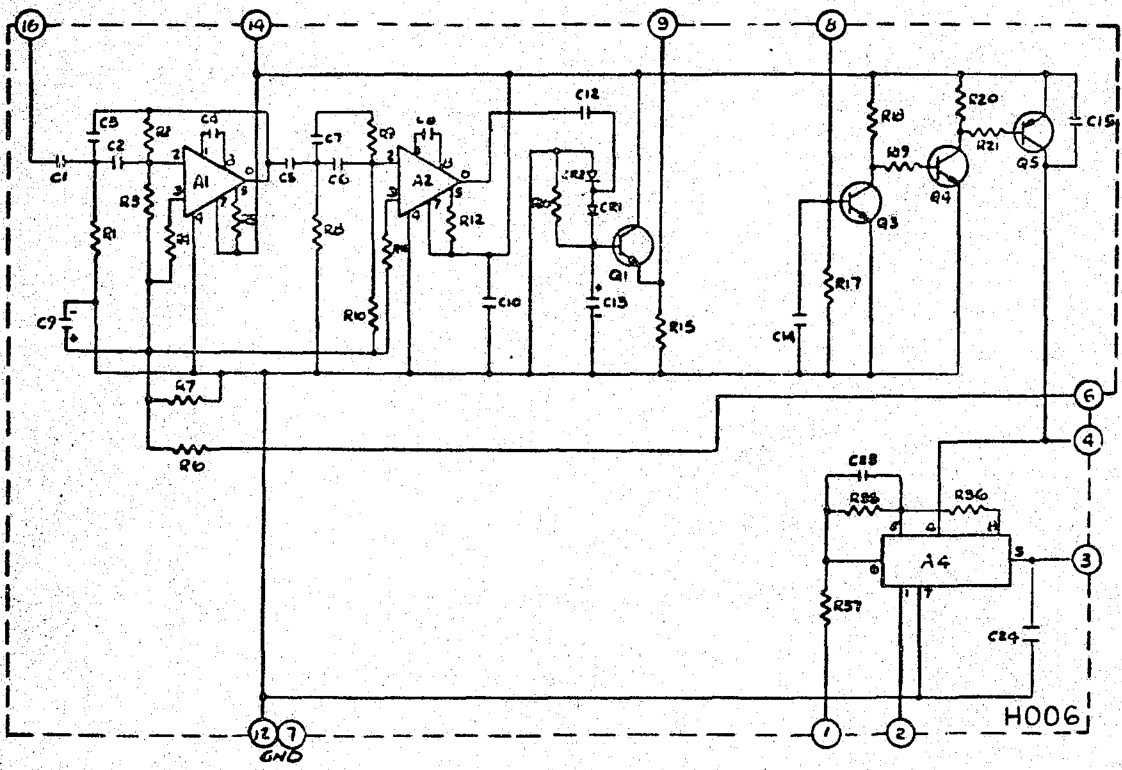


Figure 14. Audio Amplifier Module H006 Schematic Diagram

Together, they give a 24-dB/octave rejection of signal to high-frequency noise. The output of A2 is rectified by CR1 and CR2 in a voltage doubler configuration, resulting in a DC indication across C13 that is proportional to noise in the passband and inversely proportional to received signal strength. Emitter follower Q1 converts the high-impedance output of the doubler to a low-impedance driving point.

The output of Q1 is applied across the squelch threshold potentiometer. The variable arm of the potentiometer picks off a proportion of the voltage developed by the noise. This smaller voltage is applied to the base of Q3, along with the control voltage from the tone decoder (in DOJ units only). A voltage of 0.7V or greater at the base of Q3 effectively switches Q3 into conduction and Q4 out of conduction, thereby opening switch Q5, which is in series with the 9V line to the audio output stage.

When the receiver is quieted to the desired threshold, as described above, power is applied to A4. Amplifier A4 consists of an audio preamplifier stage and a power amplifier stage with a total audio gain of approximately 55 dB. The amplifier will provide 0.25W output power into an 8-ohm load.

6.2 CHANNEL SELECT MODULE H011

The channel select module (Figure 15) contains two separate but identical oscillator circuits. One circuit is used in the receive mode, the other in the transmit mode. The switch-regulator module supplies power to the appropriate oscillator in the desired mode. Each oscillator is a temperature-compensated, crystal-controlled Clap oscillator. The crystals, each with their compensating networks and series capacitors are external to the channel select module. The desired crystal (with its associated networks) is connected to the channel select module by the channel select switch. The switch is an operator control that allows the selection of the desired channel crystal and switches the hot side of both the transmit and receive crystals simultaneously, connecting them between the inputs of the channel select module (pins 3 and 8) and ground (pin 1). The crystal compensating networks and series capacitors are individually tailored for each crystal. Each oscillator will maintain a stability of 5 ppm from -30°C to +50°C and develop an output level of approximately 0 dBm at pin 2 (transmit) or pin 6 (receive). The module requires a nominal current of 3 to 5 milliamperes at 6 volts for proper operation.

6.3 MODULATOR H024

The modulator module (Figure 16) consists of a modulator section and an audio amplifier section. The audio circuit consists of an operational amplifier (A1), designed as a high-gain linear amplifier. The audio signal from the microphone is accepted at pin 3, amplified approximately 60 dB, and applied through pin 1 to audio filter module H065.

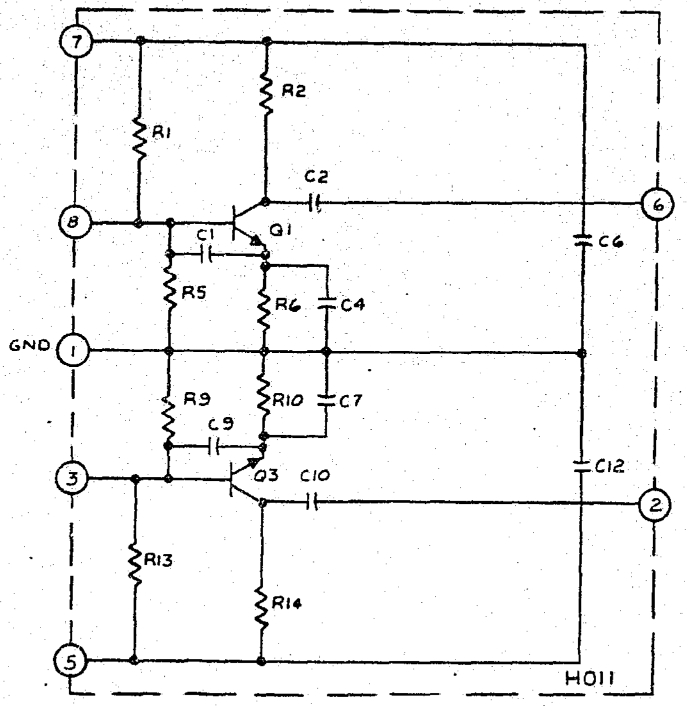


Figure 15. Channel Select Module
H011 Schematic Diagram

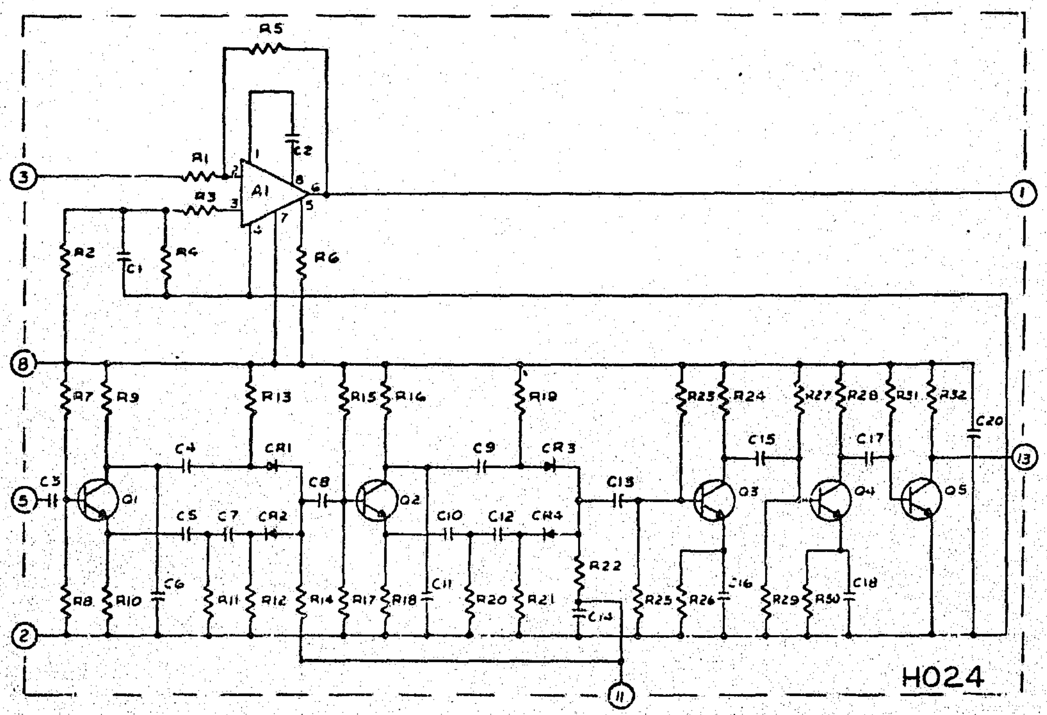


Figure 16. Modulator H024 Schematic Diagram

Since a regulated voltage supplies A1, the output is "limited" between +6V and ground regardless of the input, thus limiting the total FM deviation.

The identical phase modulator circuits (Q1 and Q2) are linked to provide a total linear modulation of ±80°. The channel select crystal oscillator output is applied to pin 5 at a 0-dBm level. The audio modulating signal is supplied to both modulator circuits through pin 11 at a level of approximately 1.5 volts, peak-to-peak. Referring to the first modulator stage, transistor Q1 and its related phase-shift circuits produce oscillator signals at the anode of CR1 and cathode of CR2 with a quadrature phase relationship. The audio input signal, applied through R14, varies the bias applied across diodes CR1 and CR2, thus causing the desired modulation. The second modulator stage is identical to the first, and each has an approximate loss of 10 dB. This modulator is a broadband device and requires no tuning for any of the input crystal frequencies.

The phase-modulated signal is amplified approximately 30 dB in the three limiter stages (Q3, Q4, and Q5). The output signal, which is roughly 4 volts peak-to-peak, is available at pin 13. The modulator modules use 16 milliamperes at 6 volts.

6.4 MULTIPLIER H039

The multiplier module (Figure 17) accepts the 19-MHz, 0-dBm signal output from the modulator module at pin 13, and buffers, multiplies, filters, and amplifies it to a +3-dBm, 150-MHz output signal applied to pin 1. Amplifier stage Q1 buffers and amplifies the input signal to increase the harmonic content presented to the filter. A three-pole, 1-dB-ripple Tschebycheff bandpass filter is tuned to the eighth harmonic of the input signal. The filter has a 3-dB bandwidth of approximately 7 MHz and skirt characteristics such that adjacent spurious responses are attenuated by at least 35 dB. Capacitors C8, C11, and C14 are utilized to tune the filter. Transistor stages Q2 and Q3 amplify the output of the filter by approximately 10 dB each, presenting a +3-dBm, 150-MHz signal with an output impedance of 50 ohms at pin 1. The module requires 23 milliamperes at +9 volts for proper operation.

6.5 UHF TRIPLER H051

The UHF tripler module (Figure 18) provides an additional X3 frequency multiplication to the output of the X8 multiplier module for UHF transmission. It accepts the 150-MHz, +3-dBm signal from the multiplier module at pin 3. Amplifier stage Q1 buffers and amplifies the input signal. Thermistor RT1 compensates the module by regulating the gain of the input amplifier to maintain a constant output over temperature. Transistor stage Q2 provides the proper matching network and filter characteristics to pass the third harmonic (450 MHz) of the input frequency.

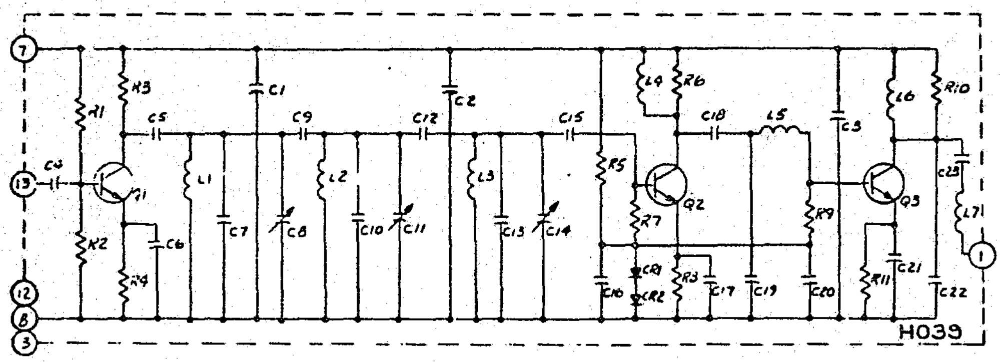


Figure 17. Multiplier H039 Schematic Diagram

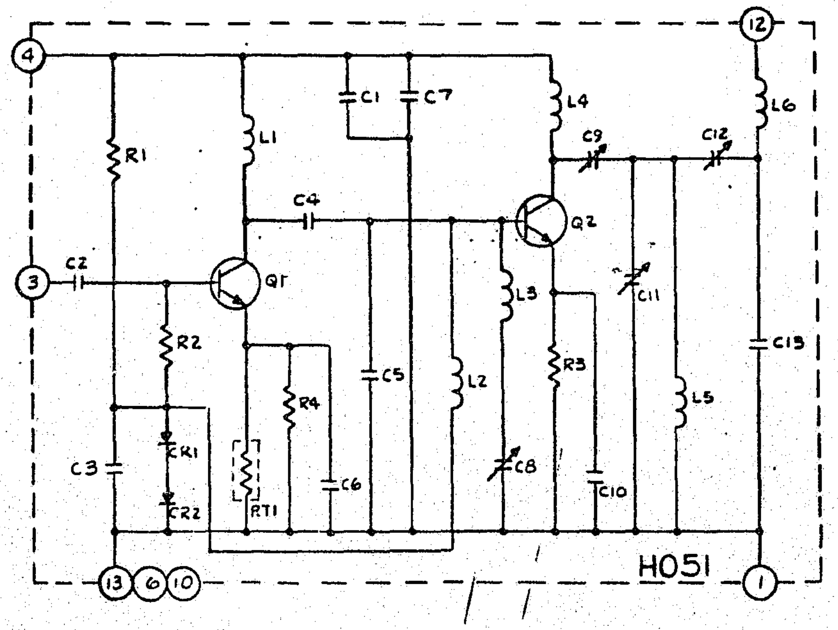


Figure 18. UHF Tripler H051 Schematic Diagram

Capacitors C8, C9, C11, and C12 are adjusted to maximize the presence of the third harmonic at the output and present a 50-ohm output impedance to the power amplifier. The UHF tripler module utilizes 50 to 60 milliamperes at 6 volts for normal operation.

6.6 AUDIO FILTER MODULE H065

The audio filter (Figure 19) is a three-section, resistor-capacitor (RC) lowpass filter. Its purpose is to substantially reduce the high-frequency products of the limiting action caused by the audio amplifier in order to control the total amount of deviation of the phase modulator.

6.7 IF AMPLIFIER H105

The IF amplifier module (Figure 20) is a three-stage, wideband amplifier exhibiting gain from 1 MHz to greater than 50 MHz. It is capable of 50-dB voltage gain at 21.4 MHz. The bandwidth of the module is determined by the filters external to the module. The entire IF response is a 15-kHz segment centered on 21.4 MHz. The amplifier is arranged to draw only one milliampere of current by connecting all active devices in a series DC circuit with equipotential drops across Q1, Q2, and Q3. Power consumption is 6 milliwatts at +6 volts.

6.8 VOLTAGE REGULATOR AND SWITCH MODULE H113

The voltage regulator and switch module (Figure 21) regulates the +9-volt battery to provide a stable +6-volt supply and switches power appropriately to the transmit or receive circuits. In the receive mode, +9 and +6 volts are supplied to the receiver circuits. When the press-to-talk switch on the transceiver front panel is depressed, the module switches off the receiver voltages and switches on both +9 and +6 volts to the transmitter section. Transistor Q1 is the switch for the transmit +9V source. Grounding pin 7 biases Q1, thus causing +9 volts to appear at pin 5, diode CR1 to become forward biased, and the transmit +6V series transistor Q3 to turn on. Forward biasing diode CR1 forces diode CR2 to turn off, thus removing the forward bias from the receive +9V switch transistor Q2 to turn it off. The receive +6V series transistor Q4 is controlled by the output of switch transistor Q2, and is also turned off. Upgrounding pin 7 reverses the above process, forcing transmit transistors Q1 and Q3 to turn off and allowing receive transistors Q2 and Q4 to turn on.

Transistors Q6 and Q7 form a differential comparator, which regulates the output of Q5 to +6 volts. The regulator reference is obtained from Zener diode VR2, which biases Q6. The bias applied to Q7 is proportional to the regulated +6V output and is the feedback control mechanism of the regulator. For example, if the +6V output were low, the potential at the base of Q7 would be low compared to the bias level at the base of Q6. This voltage difference would cause the collector current in Q6 to to increase, thereby biasing Q5 further into conduction and increasing the regulated output level.

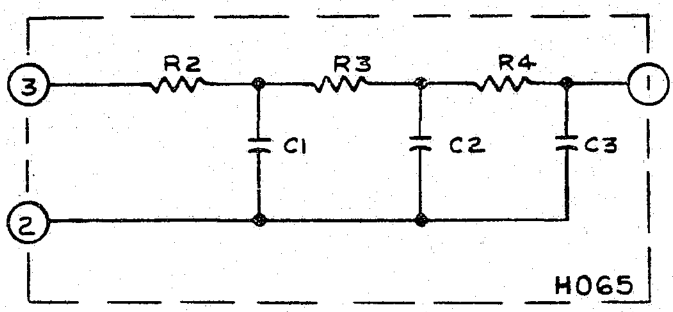


Figure 19. Audio Filter Module H065 Schematic Diagram

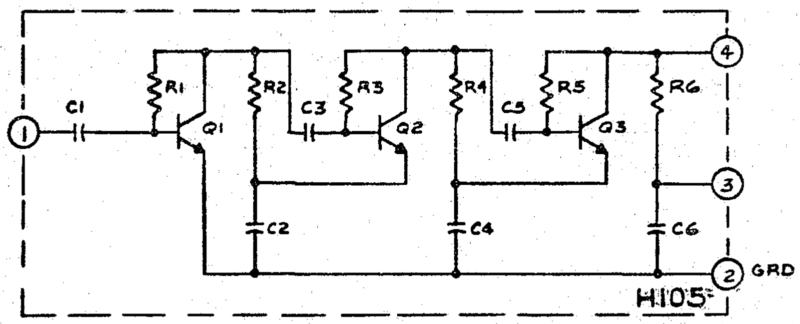


Figure 20. IF Amplifier H105 Schematic Diagram

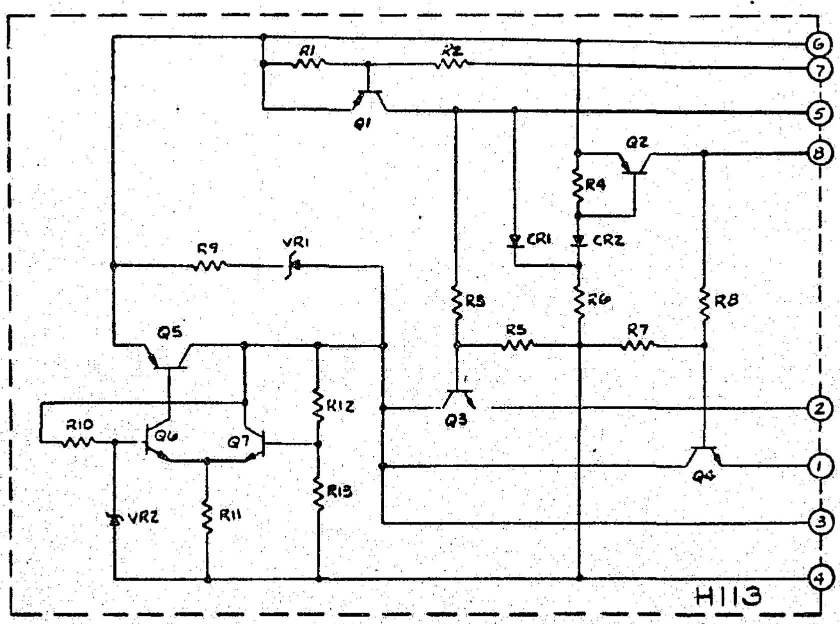
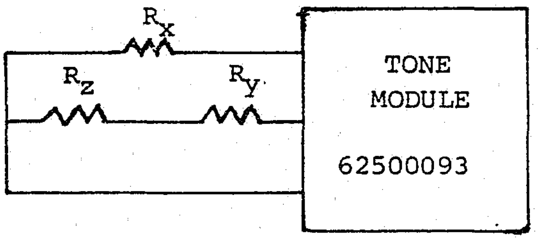


Figure 21. Voltage Regulator and Switch Module H113 Schematic Diagram

In the transmit (encoder) mode, the tone module is properly biased to function as a precision oscillator. The transmit +6 volts is applied through pin 10 of the tone module and turns on FET switches Q1 and Q2. With Q1 on, a portion of the filter output signal is applied through R11 to a filter input at pin 6 of the filter, thereby ensuring adequate positive feedback for oscillation. Turning on Q2 biases filter input pin 8 at a static potential, thus allowing the positive feedback to be the dominant factor in the filter operation. The generated tone is brought out at pin 2 of the tone module and combined with the transceiver audio input signal prior to modulation.

The tone frequency is changed by changing resistors R_x and R_y in the sketch shown below.



The tone frequency change is a factory adjustment and the tone determining resistors are 1-percent, low-temperature drift (± 50 ppm) components such as the RNC50 series. Thus, R_x and R_y can be selected to trim the tone frequency to 0.1 percent accuracy.

The values for the four tones tested during the prototype program are:

	Value	Frequency
$R_x = R_y$ =	28.3K Ohm	241.8 Hz
$R_x = R_y$ =	30.5K Ohm	250.3 Hz
$R_x = R_y$ =	4.28K Ohm	67.0 Hz
$R_x = R_y$ =	4.68K Ohm	71.9 Hz

The change is physically made on the rear side of the motherboard. The reference designators for R_x and R_y, as listed on the four DOJ interconnect diagrams, are:

Transceiver Configuration	R_x	R_y
UHF/UHF	R24	R22
VHF/VHF	R20	R21
VHF/UHF	R24	R22
UHF/VHF	R24	R22

At initial turn-on, transistor Q5 is turned off and the circuit is not functional. Resistor R9 and VR1 supply approximately 3 volts at initial turn-on time to activate the circuit. In transceivers with tone squelch capability, +6 volts is supplied continuously (from pin 3, H113) to the tone module: this voltage nominally approximates +6.3 volts. Being unregulated, the +9-volt supply can vary down to +7 volts as the battery condition deteriorates. The +6 supply volts remains at the level ±0.3 volts, however, as the battery varies.

6.9 CONTINUOUS TONE-CONTROLLED SQUELCH SYSTEM

Tone squelch is provided in all DOJ models of the radio. The tone squelch system is described in the block diagram of Figure 22 and top assembly drawing 62500028. The component parts of the tone squelch module module and all other circuits utilized in the operation of the continuous tone-controlled squelch system (CTCSS) is shown in Figure 23. The tone module consists of a KTI active filter, an H066 hybrid circuit, and additional discrete resistors and capacitors.

In the receive mode (decode), the tone module is utilized as a narrowband bandpass filter. During this condition, FET switches Q1 and Q2 are off to bias the active filter for bandpass operation. The audio signal from the discriminator module is amplified by a single transistor stage before being applied to the input of the active filter (pin 14). Resistors control the center frequency of the filter and are selected for the desired CTCSS frequency. The filter bandwidth (Q) is selected by adjusting resistor R18 for the desired bias at pin 8 of the filter. The filter output (pin 12) is applied to amplifier A1 on H066, which amplifies the detected tone to a usable level. The output of A1 is peak detected by CR1 and C6 and applied to one input of a differential amplifier composed of Q3 and Q4. When the peak-detected signal appearing at the base of Q3 reaches a preset level, the collector voltage of Q4 will exceed the Zener voltage of VR1 and cause transistor Q5 to switch, thus indicating the presence of a tone. This signal is applied to the squelch bias circuits contained within audio amplifier module H066 (pin 8).

The capability to override the tone squelch in the receive mode is provided to assure the operator that his radio is functional. Rotation of the squelch control to minimum position will allow infrequent noise bursts to be heard, demonstrating that the radio is working, and will also allow the proper setting of the volume control.

Further advance of the squelch control will stop the noise bursts. At this setting, the weakest usable signal will cause output from the radio. Full squelch requires a signal that is approximately 6 dB stronger than threshold to break squelch for noise-free reception. At no adjustment of the squelch control is it possible to lock out a signal of moderate amplitude.

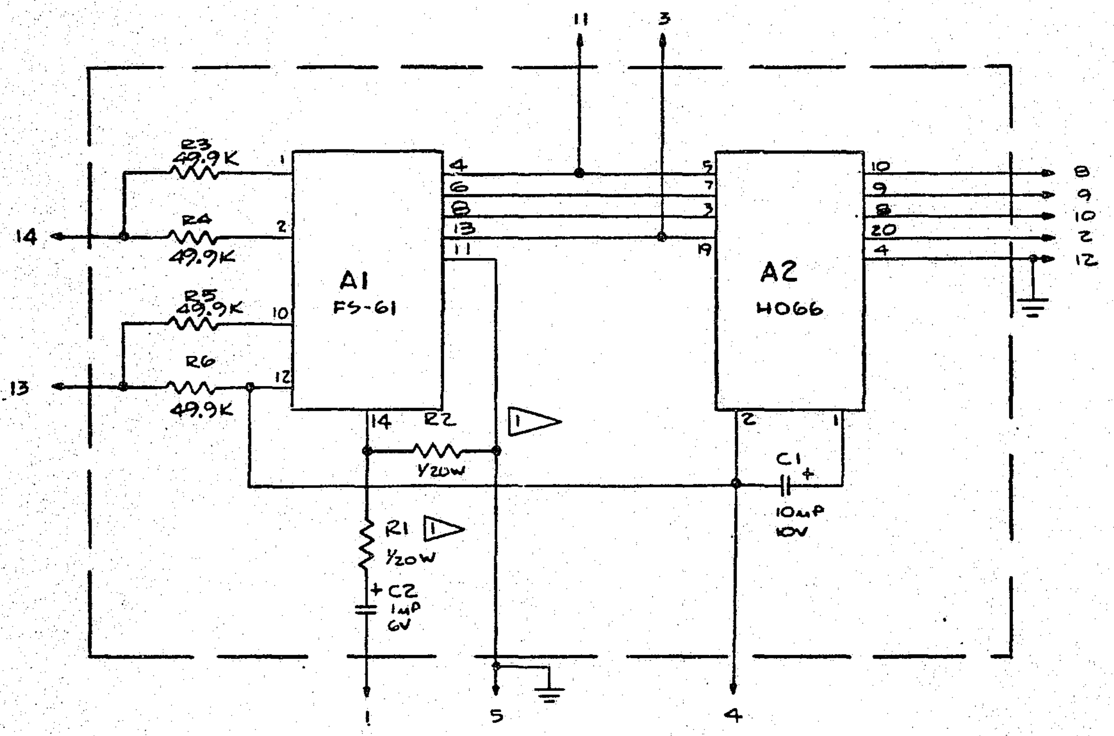


Figure 22. Continuous Tone-Controlled Squelch System Block Diagram

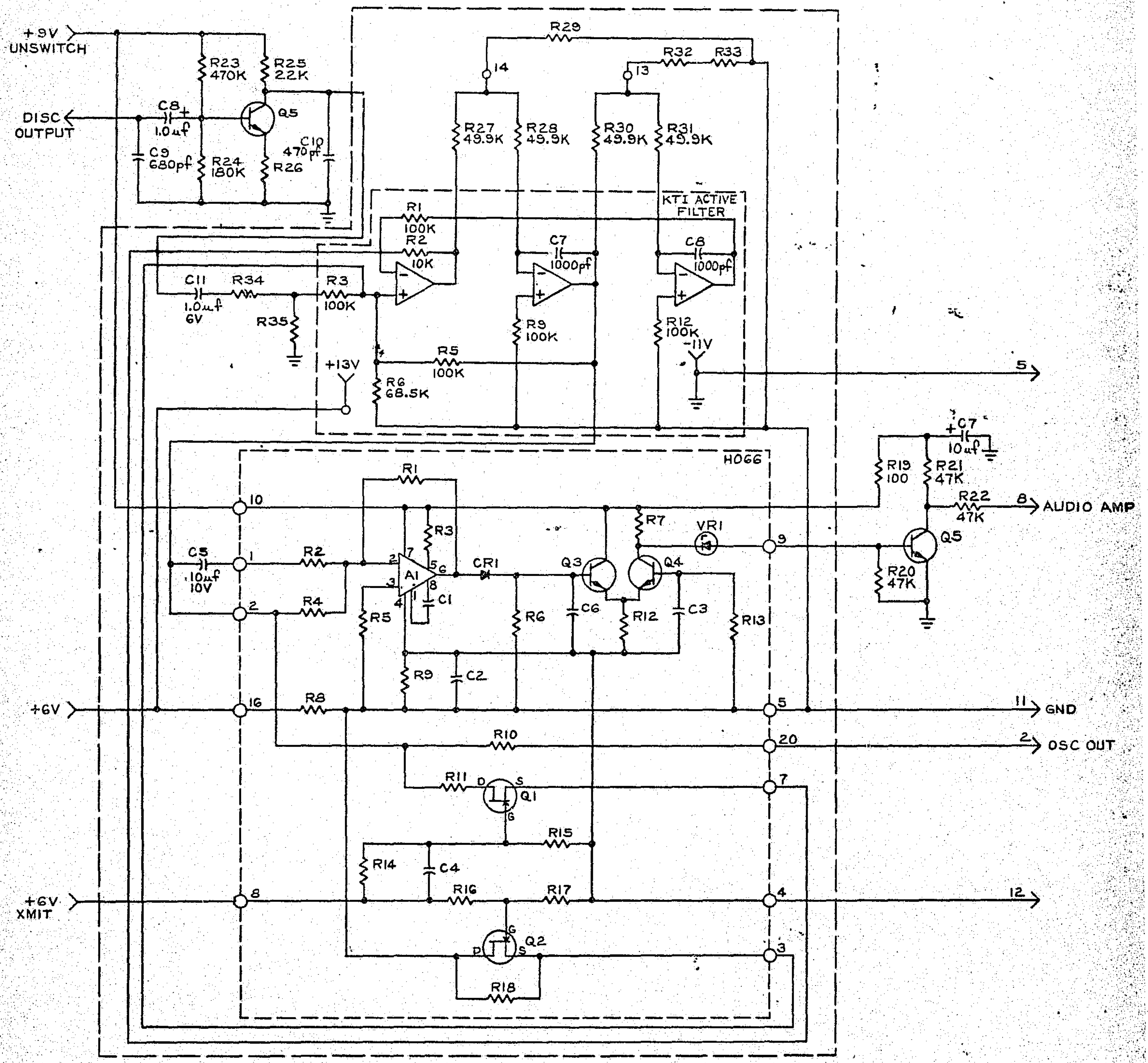


Figure 23. Continuous Tone-Controlled Squelch System Schematic Diagram

6.10 HELICAL FILTER MODULES

The two-pole helical bandpass filter module (62500042 for VHF receive and 62500040 for UHF receive) at the input of the receiver rejects out-of-band signals. The desired bandwidth of the filter is one percent of the center frequency, but due to physical constraints, the actual bandwidth is slightly wider. The filter bandwidth is related to the insertion loss and to the physical filter size. Since size was a controlling factor in packaging the transceivers, bandwidth was traded for insertion loss. With a bandwidth of 1.35 percent, the insertion loss is held to 2.5 dB in each set of filters. The out-of-band rejection is approximately that predicted for a two-pole Butterworth response.

The antenna port of each filter houses part of the antenna switch. The switch consists of a PIN diode bypassed to ground. It becomes a low-impedance circuit when power is applied to the diode (during transmit mode). The low impedance is transformed through a quarter wavelength transformer into a very high impedance at the antenna terminal, thus effectively opening the input to the receive circuits during transmit mode. When the voltage is removed (receive mode), the transformer appears as a conventional transmission line to pass the signal from the antenna to the helical filter.

The VHF Air Force version uses a three-pole helically constructed filter (62500041). It is similar to the DOJ units, except that the bandwidth is 3.5 percent, to allow signal reception in a 5-MHz band segment. Like the DOJ helical filters, it also houses antenna switching circuits.

6.11 DISCRIMINATOR MODULE

The discriminator module (62500045) consists of a passive, single-ended, crystal discriminator and IF module H105 (acting in its limiter mode), packaged inside a single shielded enclosure (Figure 24). Due to this shielded structure, all high-level IF signals are contained within the package, and the output of the module is only the detected audio. An input signal of approximately 10 mV at 21.4 MHz, with a 5-kHz FM deviation, produces an audio output signal of greater than 10 mV. The module requires +9 volts at one milliampere for normal operation.

6.12 VHF LOW-PASS FILTER

The VHF low-pass filter module (62500085) is designed to attenuate the undesired higher order harmonics of the transmit frequency (Figure 25). The amplified signal from the power amplifier module is fed into pin 1 of the filter. From pin 2, the filter output is applied to the antenna. The filter has a five-pole Butterworth response, with a 50-Ohm input and output impedance. The insertion loss is 0.4 dB, and the 3-dB breakpoint is set at approximately 200 MHz. The attenuation characteristics are such that adjacent harmonics are at least 30 dB below the fundamental.

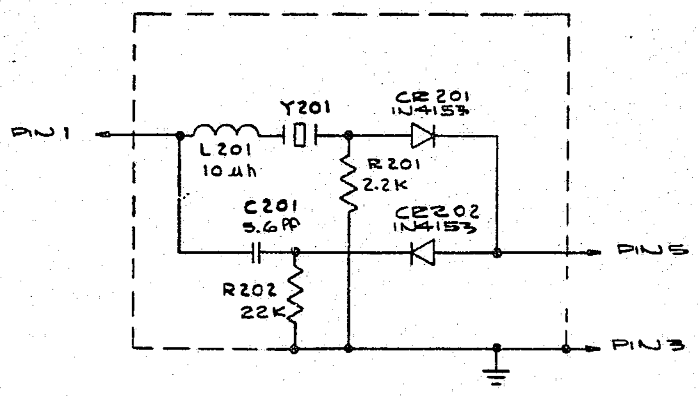
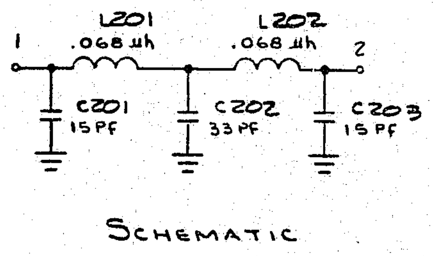


Figure 24. Discriminator Module Schematic Diagram



Fi ure 25. VHF Low-Pass Filter
Schematic Diagram

6.13 UHF POWER AMPLIFIER

The UHF power amplifier module (62500092) accepts the +10-dBm, 450-MHz signal from the UHF tripler module as its input at pin 12 (Figure 26). The signal is amplified in three stages, after which it leaves the module through pin 1 at a level of +36 dBm. Amplifier stages Q1, Q2, and Q3 provide 10 dB, 9 dB, and 7 dB of gain, respectively. The five-pole low-pass filter at the output of Q3 provides a 50-ohm output impedance for proper antenna matching and attenuation of higher frequency harmonics of the output signal. The filter breakpoint is set at approximately 500 MHz. The module bandwidth (±1 dB) is approximately 25 MHz and the presence of the second harmonic in the output signal is at least 50 dB below the level of the fundamental.

Switched +9 volts from the regulator module is applied at pin 11. This voltage provides bias for the first stage. Collector current to the three stages is applied from an unswitched +9V line connected at pin 4. An unswitched supply is used because of the large collector currents involved. Until the switched +9 volts is applied to pin 11 (unit in the transmit mode), the transistors are cut off, and thus draw only very low collector leakage currents (approximately 100 microamperes). During normal transmit operation, the module uses 1.1 amperes of current at a positive 9 volts.

6.14 UHF FRONT END MODULE

The UHF front end module (62500107) consists of an RF amplifier, mixer, and three multiplier stages (Figure 27). The multiplier stages (Q3, Q4, and Q5) receive the 54-MHz signal presented by the oscillator-filter at pin 10 and perform a doubling operation in each of the three stages. The result is a 432-MHz signal (the 24th harmonic of the crystal oscillator) at approximately 0 dBm. It is this injection signal that, when applied to the mixer and combined with the incoming signal, causes the incoming signal to be translated into the IF bandpass. Amplifier stage Q1 is a single-tuned, class A RF amplifier stage that is intended to reduce the noise figure of the mixer. It presents approximately 10-dB gain to the incoming signal to overcome the noise inherent in the mixer. Mixer stage Q2 utilizes emitter injection of the 432-MHz local oscillator, and provides approximately 4 dB conversion gain. A signal presented to the module input (pin 2) in the 450- to 470-MHz range will be translated downward in frequency by 24 times the oscillator frequency and simultaneously amplified by approximately 14 dB. The input impedance level is approximately 50 ohms and the output is approximately 180 ohms. Six volts (applied to pin 6) at 8 to 10 milliamperes are required to power this module.

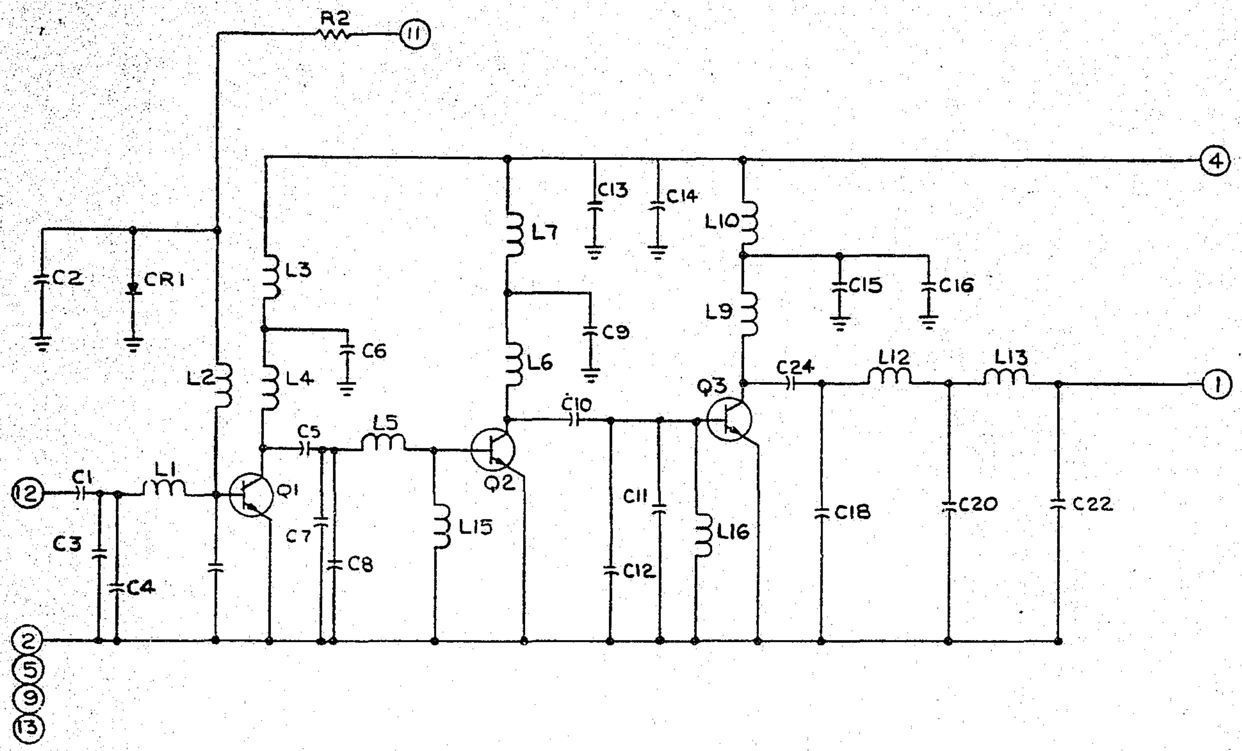


Figure 26. UHF Power Amplifier Schematic Diagram

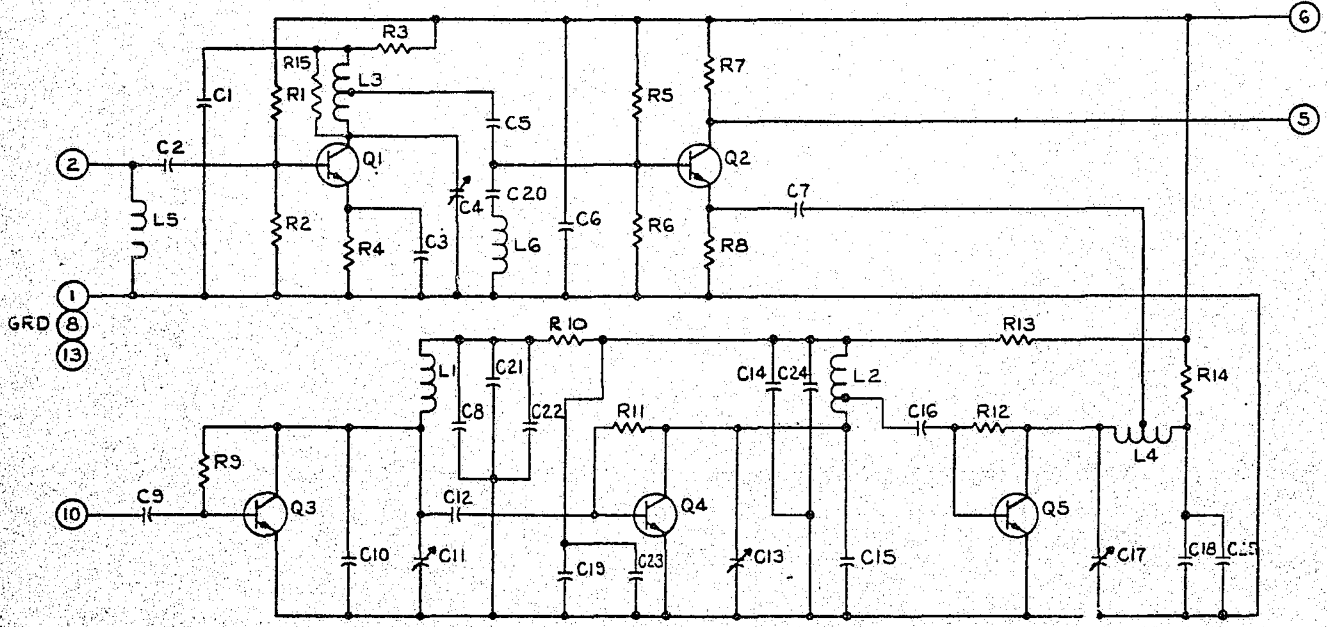


Figure 27. UHF Frontend Module Schematic Diagram

6.15 VHF FRONT END MODULES

The DOJ VHF frontend module (62500145) is very similar to the DOJ UHF frontend module, with the exception of the multiplier chain (Figure 28). The multiplier stages receive the 33-MHz signal presented by the VHF oscillator filter at pin 13 and multiply the frequency by four. The result is a 132-MHz local oscillator signal (the eighth harmonic of the crystal oscillator) at approximately 0 dBm. The RF amplifier stage, the mixer stage, and the module signal levels and power consumption are similar to the DOJ UHF front end module.

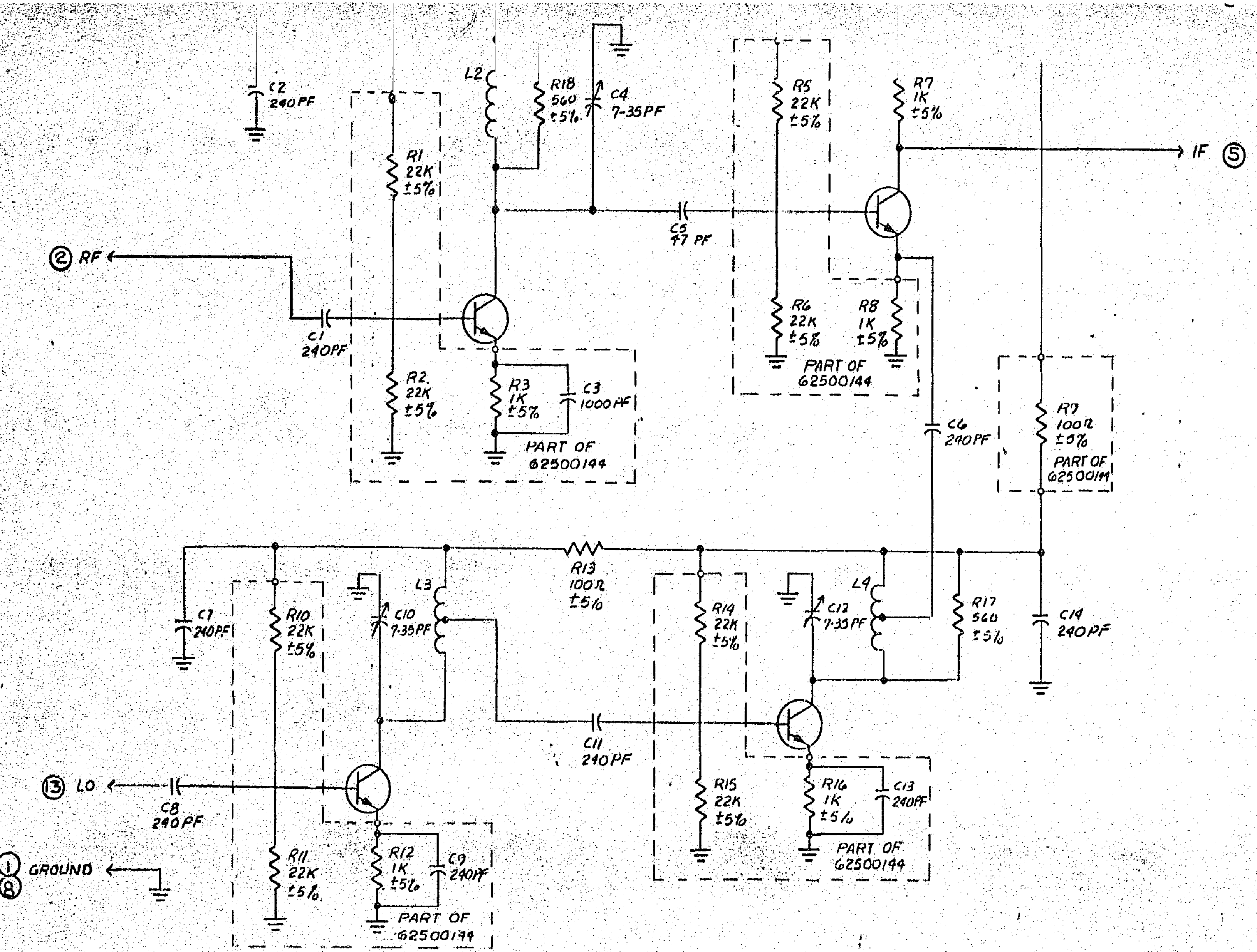
The AF VHF frontend module (H078) is electrically identical to the DOJ VHF frontend module, except that base injection of the LO is utilized instead of emitter injection (Figure 29). The LO signal level is -15 dBm, instead of the 0 dBM level necessary for emitter injection. The Air Force module is built on a ceramic substrate using hybrid microcircuit techniques. The DOJ versions are built on epoxy printed circuit board.

6.16 VHF OSCILLATOR FILTER MODULE

The VHF oscillator filter module (62500086) is composed of a two-pole bandpass filter centered at the second harmonic of the input frequency, followed by a common collector amplifier stage (Figure 30). The two-pole Tschebyscheff filter passes the second harmonic of the crystal oscillator at approximately 33 MHz, while attenuating the fundamental and all other harmonics. Tuning the filter is accomplished by adjusting capacitors C301 and C303. The filter is followed by an amplifier stage designed to provide a high input impedance and a low output impedance. The amplifier output level is approximately -10 dBm, which is 45 to 50 dB above the other output responses. The module requires +6 volts at 1 milliampere for proper operation.

6.17 UHF OSCILLATOR FILTER MODULE

The UHF oscillator filter module (62500087) is composed of a three-pole bandpass filter centered at the third harmonic of the input frequency, followed by a common collector amplifier stage (Figure 31). The three-pole bandpass Tschebyscheff filter passes the third harmonic of the crystal oscillator at approximately 54 MHz, while attenuating all other frequencies. The filter is tuned to center frequency by adjusting capacitors C401, C404, and C406. The amplifier stage following the filter is identical to one in the VHF oscillator filter module and provides high input impedance to the filter and low output impedance from the module. The amplifier output level is approximately -10 dBm, which is 45 to 50 dB above the other output responses. The module requires +6 volts at 1 milliampere for proper operation.



NOTES:

1. PARTIAL REFERENCE DESIGNATIONS ARE SHOWN; FOR COMPLETE DESIGNATION PREFIX WITH UNIT NUMBER OR SUBASSEMBLY DESIGNATIONS.
2. UNLESS OTHERWISE SPECIFIED; ALL RESISTANCE VALUES ARE IN OHMS.

Figure 28. DOJ VHF Frontend Module Schematic Diagram

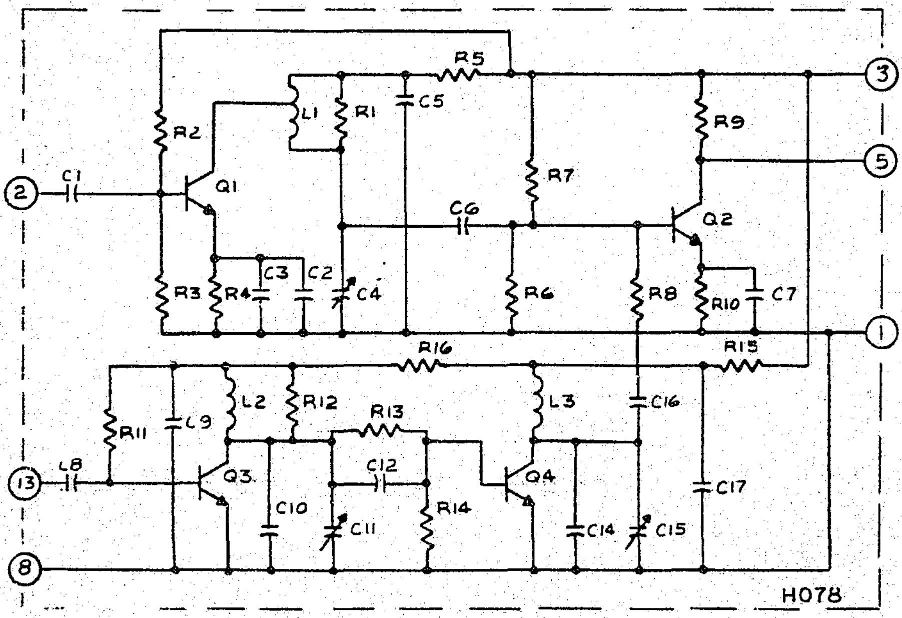


Figure 29. AF VHF Frontend Module Schematic Diagram

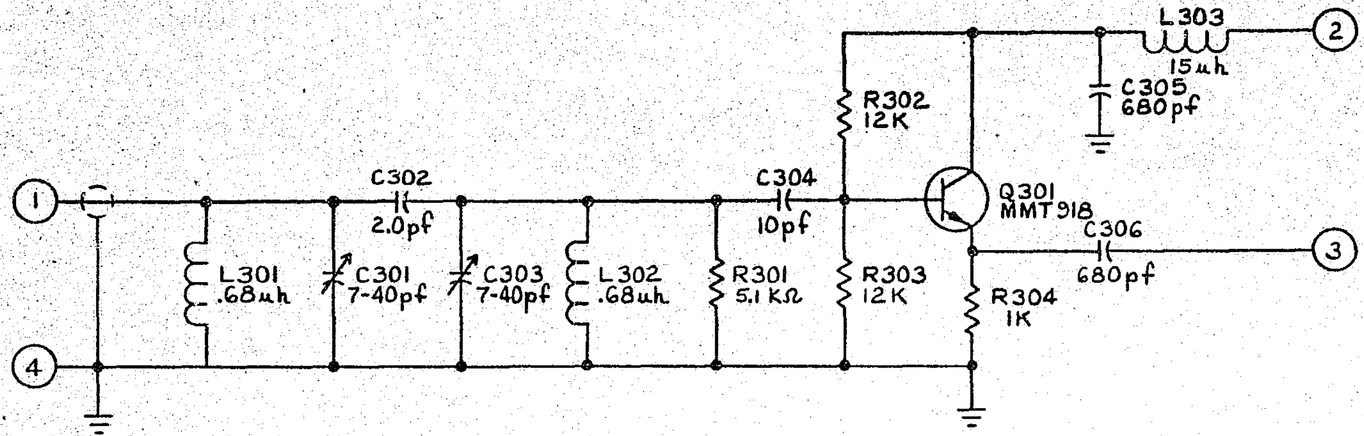


Figure 30. VHF Oscillator Filter Module Schematic Diagram

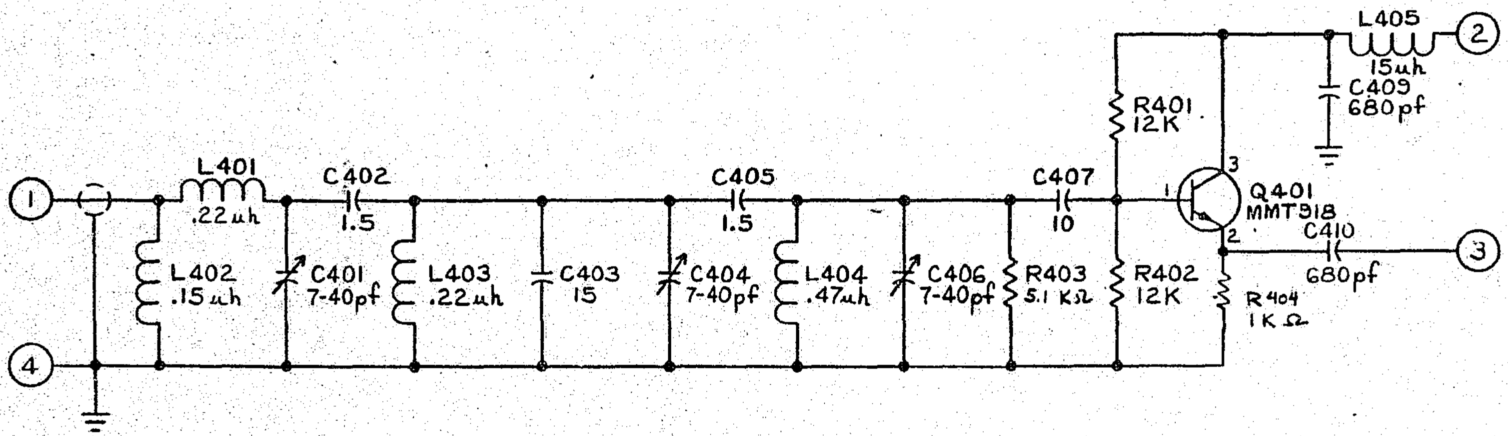


Figure 31. UHF Oscillator Filter Module Schematic Diagram

6.18 VHF POWER AMPLIFIER MODULE

The VHF power amplifier module (62500098) accepts the 0-dBm, 150-MHz signal from the multiplier module as its input at pin 12 (Figure 32). The signal is amplified in three high-gain stages, after which it leaves the module through pin 1 at a level of +37 dBm. Amplifier stages Q1, Q2, and Q3 provide 12 dB, 17 dB, and 8 dB of gain, respectively. The module bandwidth is approximately 12 MHz at the ±1-dB points while the presence of the second harmonic in the output signal is 20 to 25 dB below the level of the fundamental. Capacitors C14 and C15 are adjusted so that the module presents a 50-ohm output impedance.

Switched +9 volts from the regulator module is applied at pin 11. This voltage powers the first stage and biases the first and second stages. Collector power to the second and third stages is applied from an unswitched +9-volt line connected at pin 4. An unswitched supply is used in the higher level amplifier stages because of the large currents involved. Until the switched +9 volts is applied to pin 11 (unit in the transmit mode), transistors Q2 and Q3 are cut off, and thus draw very low collector leakage currents (approximately 100 microamperes). During normal transmit operation, the module uses 800 to 900 milliamperes of current at +9 milliamperes of current at +9 volts.

6.19 IMPEDANCE MATCHING MODULES

The four matching circuits are passive, resistor-capacitor-inductor networks (62500054, Z0001-Z0004). Each is designed to match the impedance presented to its input with the impedance at its output at the desired frequency of operation (Figure 33). Each module is fully potted and shielded. Use of impedance matching modules permits the use of three identical H105, IF modules in the receivers.

6.20 IF CRYSTAL BANDPASS FILTER

Two crystal bandpass filter modules (62542402) are used in each transceiver IF section and provide the major portion of the IF selectivity. The module consists of a four-pole crystal bandpass filter, centered at the IF frequency, with the following electrical characteristics:

Frequency of operation	21.4 MHz, ±200 Hz
3-dB bandwidth	±7.5 kHz, minimum
30-dB bandwidth	±15.0 kHz, maximum
40-dB bandwidth	±25.0 kHz maximum
Ultimate attenuation	75 dB minimum
Ripple	1.0 dB maximum
Insertion loss	2.5 dB, maximum
Nominal termination	1100 ohms
Spurious responses	50 dB, maximum

The modules are procured (no schematic is provided).

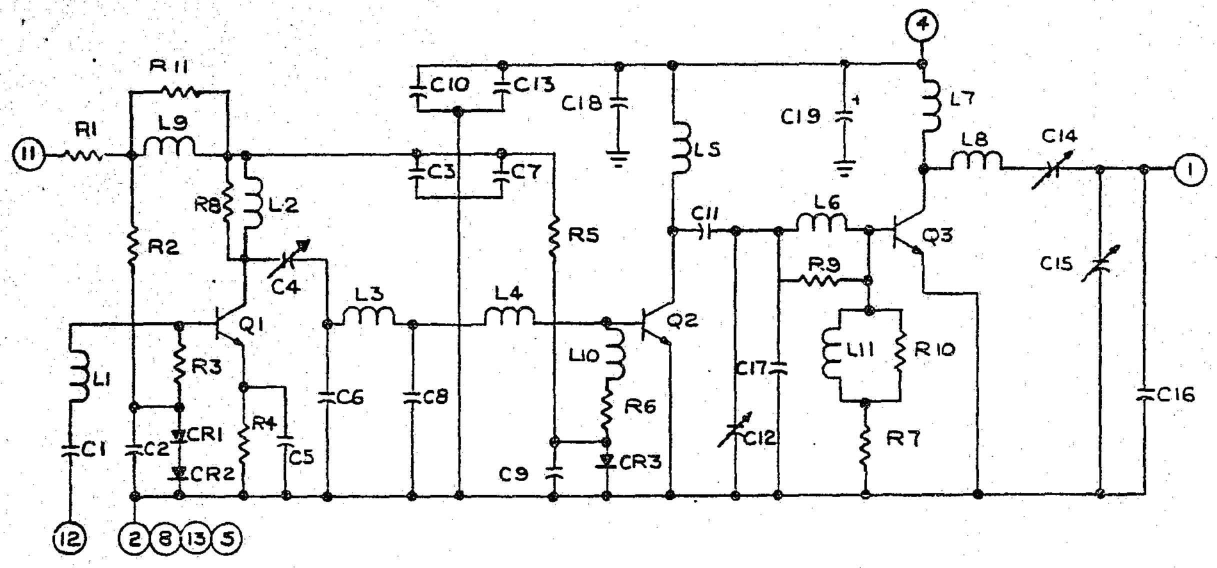


Figure 32. VHF Power Amplifier Module Schematic Diagram

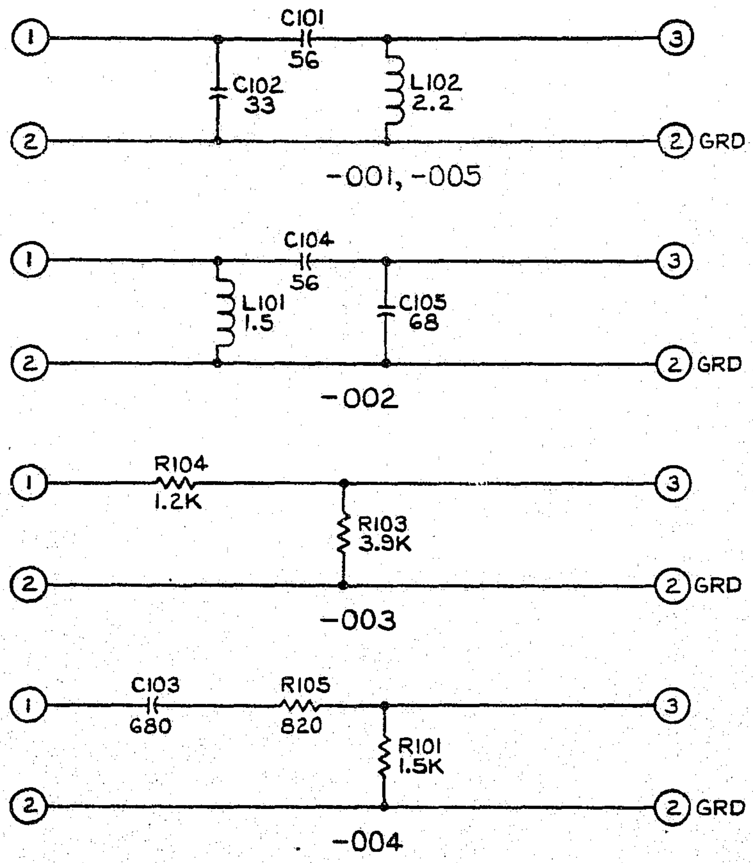


Figure 33. Impedance Matching Module Schematic Diagram

SECTION VI

DESIGN APPROACH

1.0 INTRODUCTION

The overall approach to the personal transceiver design was to produce an innovative design for minimum size and weight by using advanced techniques that would be conducive to low cost in high-volume production. Rather than produce a refined design of existing conventional transceivers, the Martin Mareitta approach was to investigate new concepts that could potentially produce the greatest advance in the electrical and mechanical designs for future personal transceivers. It was the objective of this program, therefore, not only to deliver the specified transceivers per a contract line item but also to establish which new techniques are not only possible and practical but can be used to develop improved, next generation personal transceivers. This section contains a summary of the most significant approaches, concepts, investigations, and results that led to the final transceiver design together with the recommendations for the final production design.

2.0 ELECTRICAL DESIGN

2.1 GENERAL DESIGN APPROACH

The major electrical efforts that involved new technology for a smaller, lighter weight, personal transceiver were:

1 Development of thick-film hybrid designs.

2 Inductorless circuit development.

3 Transducer/speaker performance evaluation.

From the research and development conducted on these tasks, definite conclusions were obtained as to which new electrical techniques are feasible for both technical and cost parameters in a production design.

The first major electrical decision involved determining the packaging method for the electrical circuit modules that would be most effective in obtaining minimum size at practical costs, while meeting the electrical performance requirements. Three packaging methods were considered:

1 Conventional small printed wiring boards with miniature discrete components.

2 Thick-film hybrid substrates.

3 Monolithic large-scale integration (LSI).

Miniature discrete component modules had several advantages:

1 They are constructed from readily available components.

2 They are conducive to good electrical performance by using components with consistent parameters.

3 They are quick and easy to implement.

The use of discrete component modules would allow a maximum of design improvements to be made over a given period of time, and was potentially the lowest risk approach in meeting electrical performance requirements. The disadvantage, however, was that even with highly dense packaging it would be difficult, if not impossible, to package exclusively with discrete components and not exceed the size specifications.

The smallest sized packages can be produced in LSI. However, LSI is not conducive to designs requiring inductors, large value capacitors, good high-frequency isolation, or high heat dissipation circuits. Therefore, LSI is not practical for high-frequency RF circuits or some audio circuits. Certain circuits, such as IF amplifiers can be packaged in very small sizes and have the lowest production costs with custom designed integrated circuits (IC) or LSI. However, the high development cost of up to $25,000 per circuit, along with the long development time required, made this packaging technique impractical for this program. Furthermore, in practicality, a design should be committed to custom LSI or IC development only after prototype hardware has been completely tested and verified (i.e., after the prototype program).

Packaging with thick-film hybrid substrates had the advantage of being potentially applicable to essentially all transceiver circuits except those requiring mechanical devices (such as with the receiver helical resonators). Another advantage was that thick-film configurations were potentially conducive to automated, high-volume production assembly processes, resulting in low production costs. Obtaining low production costs for RF circuits would be difficult to achieve by any other means, especially where minimum size is a requirement. Most importantly, packaging of audio and low-frequency RF circuits in thick-film would require considerably less volume than with miniature discrete component modules, and would present little risk in meeting electrical performance. The major technical risks lay in obtaining the required electrical performance in the high-frequency circuits and in having sufficient time to conduct the necessary thick-film development effort.

From these tradeoffs, thick film substrate packaging was selected for all active circuit modules as the most feasible approach in obtaining the minimum size objectives. The approach had definite technical risks, since complex, high-frequency designs such as a receiver front end and an entire UHF 4-watt transmitter were definite challenges with technology as it existed then. However, the goal was to build an innovative transceiver, and thick film hybrid circuits were believed to provide the most practical means of building a transceiver significantly smaller than those currently available.

2.2 DEVELOPMENT OF THICK-FILM HYBRID DESIGNS

After laboratory breadboard circuits were tested, all designs were committed to hybrid layouts. The first major difficulty occurred during packaging (i.e., fitting the amount of circuit components necessary within the hybrid surface area limitations dictated by transceiver size requirements). The transceiver mechanical design required a nominal 1.25 x 0.67 x 0.1 inch substrate, while the layout size guidelines issued by the microelectronics facility indicated that double this surface area per substrate would be required to accommodate all components if standard layout procedures were to be followed. At this point, a rigorous effort was made to improve the packaging density. Certain discrete chip components, such as capacitors, were mounted on top of deposited resistors, and components were mounted on surfaces providing the minimum contact area. The electrical designs were scaled to reduce capacitor values, and were modified, where possible, to completely eliminate capacitors. The overall effort was successful, and all circuits were packaged on the desired size substrates.

The substrate layouts were completed; prototypes of all circuits were then made. The circuits were tested for mechanical layout errors and abnormalities in performance due to differences between the electrical characteristics of the initial discrete component breadboards and the corresponding substrate circuit. After two substrate layouts of each module, the low-frequency circuits were made operational. However, after several months of work on the substrates of the VHF power amplifier, UHF power amplifier, and UHF frontend, they could not be made to function properly. This was due primarily to interaction at VHF and UHF frequencies as a result of the inability to provide adequate RF isolation, crowding caused by the extremely high density of packaging, comparatively high resistance conductors, and in some cases, poorer performance of the chip semiconductors as compared to their discrete component equivalents. At this time, the VHF frontend substrate design was functional, and additional efforts to improve performance by upgrading the layout and using high performance semiconductors was started. Also at this time, the VHF-PA, UHF-PA, and UHF frontend were repackaged on small printed-circuit boards, using miniature components, with the ground rules that they had to fit in the same spaces allocated for the equivalent substrate module; this was accomplished.

The completed modules were then installed on a common transceiver motherboard and system integration checkout was performed. Here again, electrical interaction between modules occurred due to the close proximity of the modules, and further modifications to the modules, in addition to providing more bypassing and decoupling on the motherboard, had to be made to prevent RF oscillations. The final transceiver circuits were the results of many performance tradeoffs, to provide the best possible overall operation within the size requirements.

2.3 INDUCTORLESS CIRCUIT DEVELOPMENT

A second effort was made to develop high-frequency RF circuits by using a new inductorless technique in which a tuned response could be obtained by using resistors and capacitors in conjunction with transistors biased for inductorless transformation. The advantage of this approach was a possible 25 to 30 percent reduction in the applicable RF circuits together with a configuration that was more amenable to automatic assembly of hybrid substrates. Several months of effort were devoted to developing inductorless VHF receiver frontends and transmitter and local oscillator multiplier circuits. Although proper functional performance was realized, the primary current requirements were three to five times those of conventional circuits. Since low battery drain was essential, conventional circuits were used. It was also believed that conventional electrical circuits would be more repeatable than the inductorless versions.

The inductorless technique consisted of using a circuit comprised of resistors, capacitors, and transistors to produce a tuned response identical to that produced by an LC tuned circuit. This technique is not to be confused with the wideband amplifier techniques or gyrator techniques where phase shifts are realized by using semiconductors operating within the normal frequency range for which they were designed. In the inductorless approach, transistors are operated at frequencies approaching their maximum frequency of operation; f_t, rather than at or near their cutoff frequency, f_c. Specifically, the transistor stages are configured and biased to produce a 90-degree phase shift from input to output, or vice versa. This technique permits a low-cost, low-frequency transistor to be used in a high-frequency RF application while at the same time eliminating bulky inductors.

Figure 34 is a pictorial representation of the basic inductorless technique. Transistor Q1 is biased to generate a 90-degree phase shift from base to emitter, thereby transforming R2 and C4 to L and R respectively at the output. Similiarly, Q2 transforms R1 to C1 at the base of Q2 and C3 is transformed to a negative resistance -R. Capacitor C2 is added for tuning. The net circuit is shown at the bottom of Figure 34. The values of R and -R are selected to provide the desired Q. Note that the circuit can be made to oscillate when the absolute values of R and -R are equal.

Figure 35 shows the 150-MHz RF amplifier that was built by using the inductorless technique. The load is taken from the collector of Q1 to isolate as much as possible the load from the inductorless mechanism. Capacitor C1 is used for tuning the realized inductor, allowing selective frequency operation of the circuit. Capacitor C2 adjusts the negative resistance, in effect, setting the Q of the circuit.

The major disadvantage of the circuit was that 3 to 5 milliamperes of current were required to bias the transistors to obtain the proper transformations. Other disadvantages were that performance was significantly affected by changes in input, loading, and temperature. Since

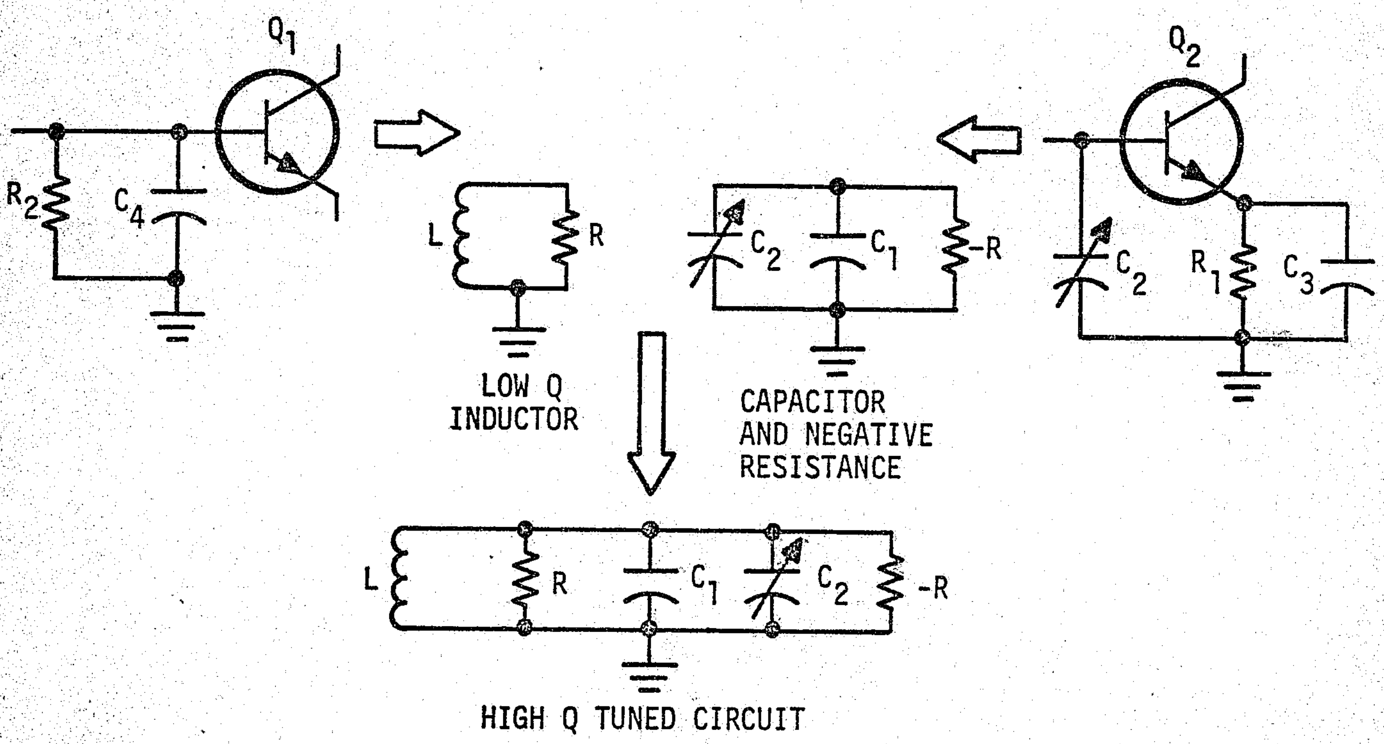


Figure 34. Inductorless Techniques

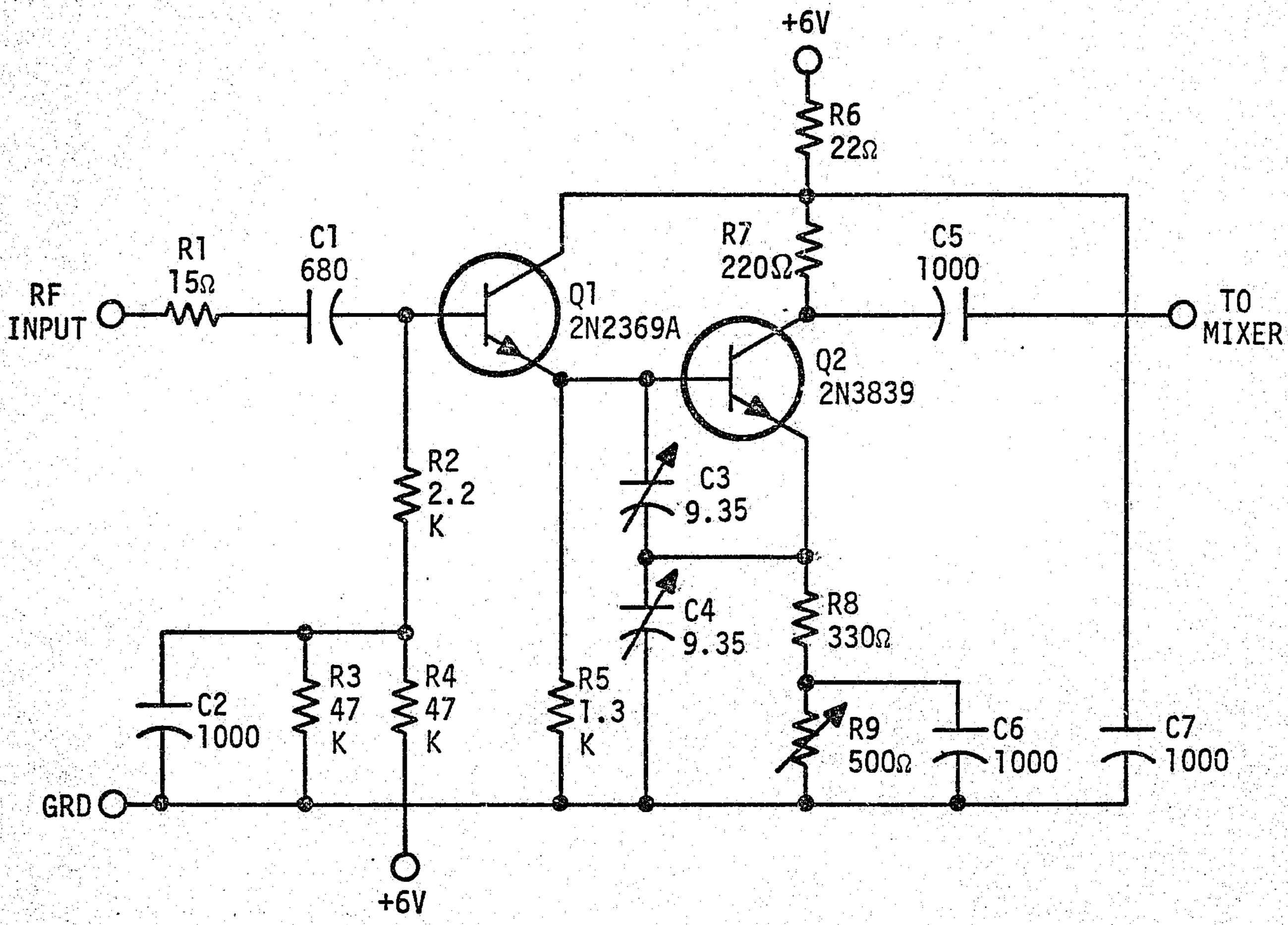


Figure 35. 150-MHz Receiver RF Amplifier Schematic Diagram

additional research was required at this time to further characterize inductorless operation to facilitate practical circuit designs, conventional design approaches were pursued for the personal radio beyond this point.

2.4 TRANSDUCER/SPEAKER PERFORMANCE EVALUATION

One of the most difficult requirements was to provide a maximum sound pressure level (SPL) of 105 dB at 5 inches from the transceiver by using only 80 milliwatts of audio power. An SPL of 105 dB was approximately 10 dB higher than could be produced with a speaker of the size that would be compatible with the transceiver size limitations and approximately 20 dB higher than could be obtained with a transducer without a cavity. Consequently, an intensive research/development/test program was conducted to select the appropriate device and/or method for sound reproduction in the transceiver. A detailed description of the research program, the data obtained, the conclusions, and recommendations are given in Appendix C.

In summarizing, a conclusion was made that significant advances would have to be realized in transducer performance before the devices would meet the stated SPL specifications, even with a small acoustical cavity, so that transducer could be considered as speakers in small portable transceivers. Meanwhile, the sound reproducing function should be performed by a speaker selected for an optimum combination of physical volume, SPL, and battery drain. Consequently, a 1.75 inch speaker was selected for use in the personal transceivers.

3.0 MECHANICAL DESIGN

3.1 EXTERNAL CONFIGURATION

3.1.1 PROPOSED CONFIGURATION

The proposed configuration for the personal transceiver was a segmented unit that was selected as the baseline configuration (Figure 36). The proposed configuration has been altered as a result of human engineering tests that were performed to verify the design concepts and as a result of the development process of selection and design of internal components to meet specification requirements. The extent of these changes are discussed in the following paragraphs.

3.1.2 HUMAN ENGINEERING TESTS

3.1.2.1 Shape Fact·

The DOJ personal transceiver dimensions were changed from the proposed 3 x 5.1 x 1 inch to 2.625 x 6.0 x 1.0. The human engineering study on the subject of the shape factor and the reasons for recommending the 2.625-inch width transceiver are discussed in more detail in Appendix A. In addition to the shape factor changes recommended by human engineering, two other significant changes were incorporated to improve the user's ability to hold and grip the transceiver. The sides of the unit were tapered such that the front of the unit is narrower than the back. This contributes significantly to the ease of holding the unit, especially for people with small hands; it also aids in the operation of the press-to-talk switch. As a result of the thermal analysis, fins or ribs were incorporated into the sides and front of the transceiver housing. These also aid in holding of the transceiver, particularly during adverse weather conditions.

3.1.2.2 Shirt Attachment Tests

Initially, a clip was to be attached to back of the transceiver housing. The purpose of the clip was to attach the unit to the user's epaulet at shoulder level or to a cloth strap sewn to the user's shirt a few inches below the top of the shoulder on the upper left shoulder area. As an alternative to this, the use of Velcro material was investigated and proved to be more satisfactory than the clip (this investigation is discussed in Appendix A). As a result of these tests, use of the clip was abandoned and a Velcro pad accessory was designed (drawing 62500130). By using the Velcro pad attachment plate, which is fixed to the back of the unit by means of three screws, the transceiver can be attached to the user's shirt by either a shoulder strap (62500133) that is looped around the epaulet at the top of the shirt or by means of a Velcro pad sewn to the upper left shoulder area of the shirt. As discussed in Appendix A, however, this method of attachment was uncomfortable due to the lack of weight distribution although the weight of the unit did appear to be acceptable for upper chest mounting.

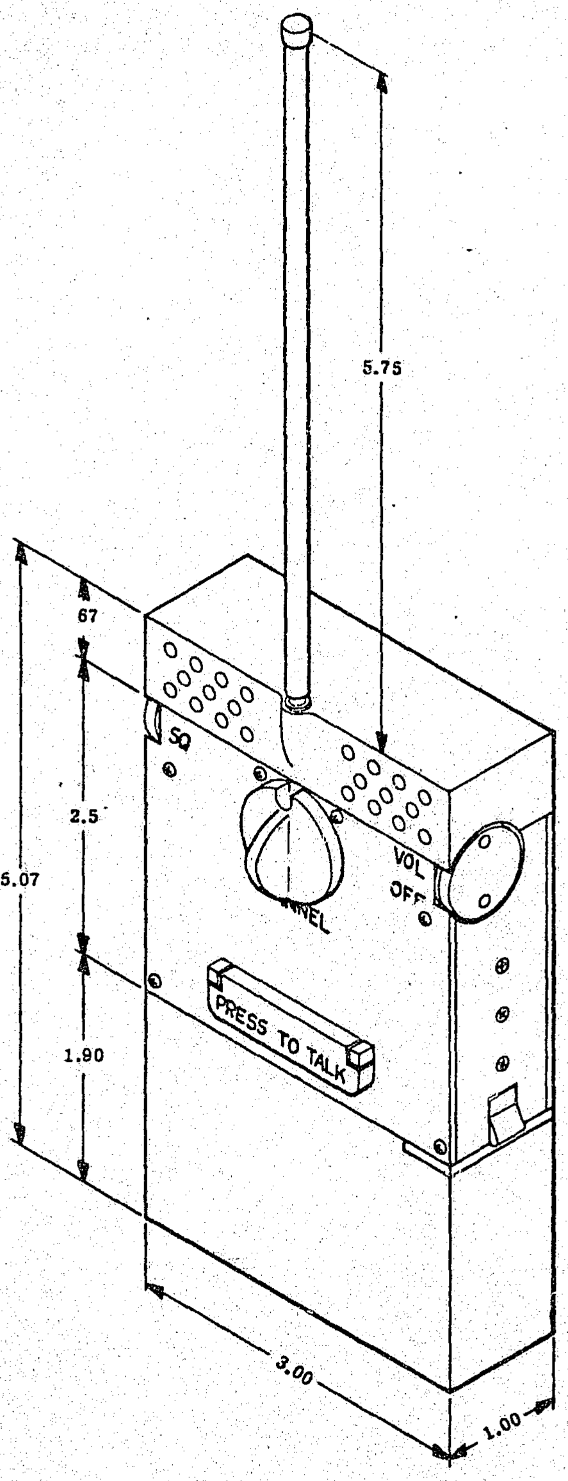


Figure 36. Proposed Segmented Configuration

3.1.2.3 Shoulder Mounting Accessories

Since direct attachment to the shirt appeared to be undesirable, several attachment means were considered and two prototype shoulder mount accessories were constructed and evaluated. Appendix A discusses the shoulder mounting accessory philosophy and gives detailed descriptions and evaluations of the two prototypes constructed. Both shoulder mount accessories were semi-rigid devices that were curved to fit the shoulder and distributed the load of transceiver across the top of the shoulder. The devices were held onto the shirt by means of a Velcro pad. While these shoulder mounts did solve some of the problems that existed in the shirt attachment mount previously discussed, they were not without problems of their own. The most significant problem was the difficulty in manufacturing a shoulder mount that would comfortably fit various size shoulders. Another problem was the large size or volume occupied by the shoulder attachment accessories.

3.1.2.4 Transceiver Sectioning Tests

Two transceiver sectioning configurations were evaluated. One of these was a nylon strap, shoulder-mount accessory; the test and evaluation of this accessory is described in Appendix A. The test results indicated that this configuration was very satisfactory from the standpoint of the wearer and should be a suitable production configuration. The other divided-unit configuration is a shoulder-mounted transceiver electronics package with a belt-mounted battery; this configuration and its evaluation is also described in Appendix A (Figure 37). While wearing this unit presented no problems and resulted in a fairly satisfactory production configuration, one evident problem was the cable hang-up. In an emergency, a fixed cable could result in the transceiver electronics being yanked off of the officers shoulder if the cable became entangled in a door handle or door knob or something of this nature. A quick-disconnect or detachable connector or breakaway cable could be used to prevent these problems. This configuration was judged to be quite comfortable to wear. The weight of the battery is not noticeable on the belt, and the weight of the electronics, including the speaker and antenna, is very confortable when attached to the upper left front of the shirt or attached to an epaulet.

3.1.3 DESIGN AND COMPONENT SELECTION

The final configuration of the personal transceiver incorporates several changes from the proposed configuration that are the result of the design and selection of internal components.

1 Loudspeaker/Microphone Unit - The decision to abandon the use of an acoustic transformer and use a microphone-loudspeaker unit substantially affected the layout of the transceiver. The use of a permanent-magnet-type, 1.75-inch diameter cone speaker resulted in a large portion of the front face of the transceiver being occupied by the speaker cone. The channel select switch was moved from the front face to the top of the transceiver while the antenna

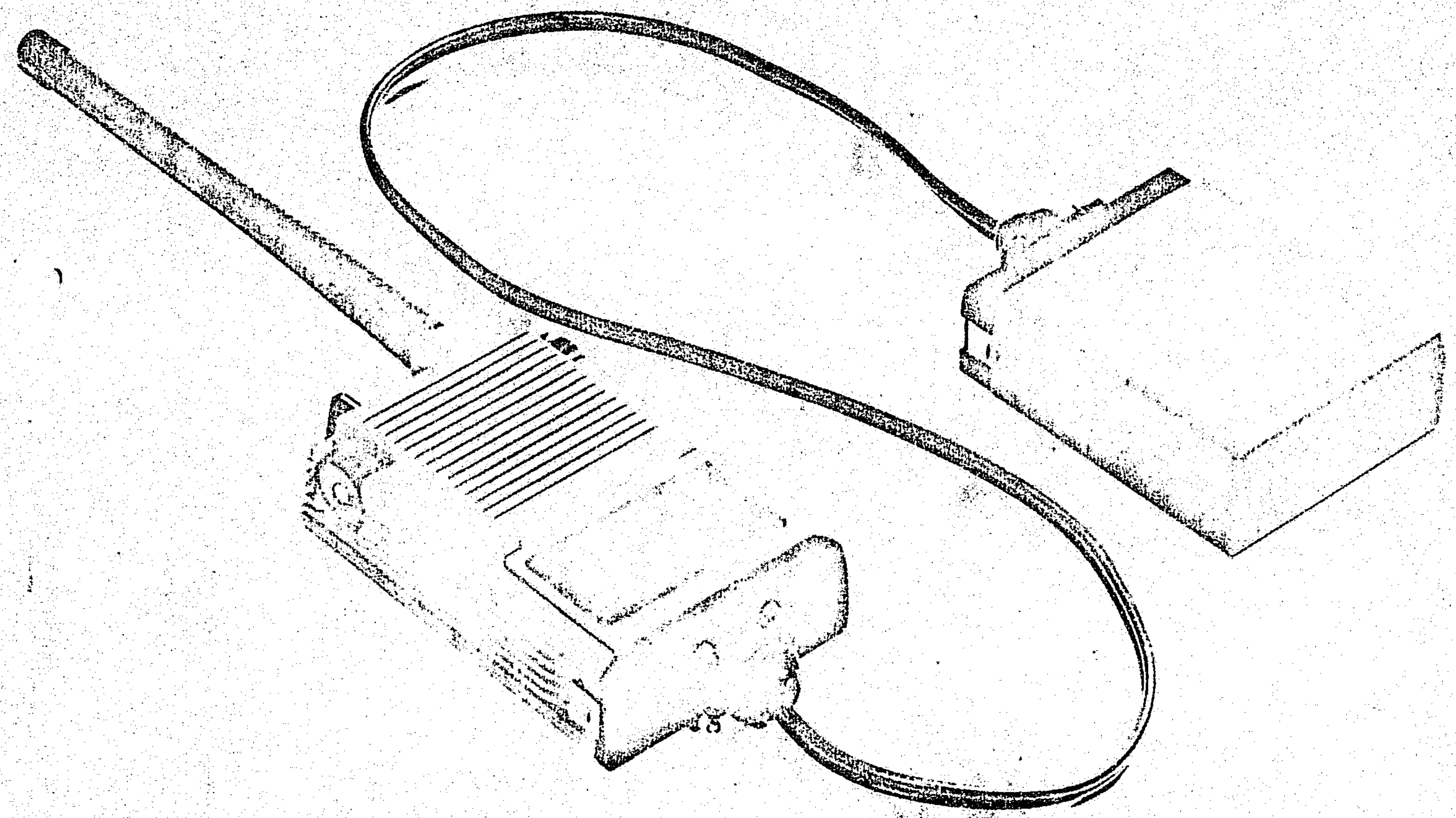


Figure 37. Shoulder-Mounted Transceiver with Belt-Mounted Battery

was relocated toward the right side of the transceiver, with the channel select switch being located at the left side of the transceiver. This was necessary in order to allow operation of a channel select knob with a gloved hand. If the transceiver is worn on the left shoulder, having the antenna near the right side of the transceiver is an advantage because it locates the antenna further away from the wearer's head.

2 Press-to-Talk Switch - It became apparent early in the design and development phase that a four-pole, double-throw, press-to-talk switch would be required. Mechanical switches made by Chicago Switch, Gordos, and Hi-Tek Corporation were investigated by tests and by layouts. The volume occupied by these switches and the installation complexity necessitated a different approach to the design. All press-to-talk switch functions were incorporated in a hybrid module and were accomplished by solid-state devices. The actual press-to-talk switch functions only to provide or interrupt the ground for the press-to-talk switch hybrid. This requirement resulted in design of a panel-type press-to-talk switch developed especially for the personal transceiver. This new switch accomplishes the press-to-talk function if the operator depresses the face at any point. The switch operation is completely noiseless and requires very little motion. Its location and size is such that it can be easily operated by the user's chin while the transceiver is being worn on the shoulder, which allows the user to operate his transceiver while both hands are busy. The press-to-talk function can also be easily accomplished with the thumb by both left- and right-handed users.

3.1.4 OTHER FEATURES

Many other features that were recommended in the proposal were also retained in the design of the personal transceiver. Among these are the following:

1 Channel Select Knob - This knob is shaped to allow the user to determine the selected channel by feel. The position of the knob is also indicated by detents.

2 Volume On/Off Control - This control is located on the left side of the transceiver near the upper left corner. The knob adjustment can be made with a light touch of a single finger on the front face of the package. To minimize accidental movement or damage during dropping of the unit, the knob is recessed into the side of the package with the edge of the knob flush with the front face and top of the package.

3 Squelch Control - This control, located on the housing near the upper right corner, is identical to the volume on/off control. The positions of the volume on/off control and the squelch control are reversed from the proposed positions because the volume control

is the one most often operated and for a right-handed user, it is more convenient if the volume control is on the left side of the unit.

4 Antenna - For ease of attachment and removal, the antenna is attached to the electronics unit with a ball-and-socket-type plug-in connector. The ball and socket also allows the antenna to be positioned up to 20° from vertical to optimize antenna location with respect to the user's body.

5 Battery - The battery is attached with a rugged, twist-block-type connector that provides both physical and electrical coupling to the electronics section. This connector allows for quick easy changes of the battery without exposing the electronics to the outside atmosphere.

3.2 MODULE PACKAGING

In the proposed configuration, the electronic section enclosed the entire transmitter, receiver, and audio circuits that were partitioned into individual plug-in modules of two basic types (discrete component modules and microcircuit modules). The RF amplifier, filter amplifier, and multiplier are predominantly discreet components and dissipate the majority of heat within the package. These components are designed as one type of plug-in module that uses printed wiring boards. The high heat dissipating components are mounted to a heat sink that is the side of a module located near the outer housing walls. After the modules are plugged into place, the module heat sink is attached to the wall of the outer housing by means of two screws in order to use the aluminum outer housing as the heat sink. The balance of the components (with the exception of the crystal) are partitioned into a second type of plug-in module that uses microminiaturization techniques. These modules are ceramic substrates attached to a plastic carrier frame with dimensions of 0.7 x 0.22 x 1.25 inches. The ceramic substrates are metalized on their rear surfaces to assist in RF shielding between modules. All modules are conformal coated to prevent contamination. Test points are located on the top of the individual modules for ease of access when the cover is removed.

The search for the plastic carrier frame to support ceramic substrates resulted in the conclusion that such a substrate carrier frame was not presently commercially available in a size required for the personal transceiver. One such carrier frame that appears to be usable except for its size was made by Dale Electronics Incorporated (SHP-40).

After partitioning the electronic circuits, the substrate or board area required for each module was calculated. The three cases considered were the discrete-components printed-wiring board-type module, the hermetically sealed substrate approach utilized hermetically sealed packages similar to those manufactured by Isotronics Incorporated (typical part numbers are CD2040, CD2030, and CD2010, all manufactured by Isotronics).

This volume study determined that based on the initial circuit design, the volume of all substrates would be 2.85 cubic inches if the substrates were open and unsealed. The volume of the substrates using the hermetically sealed packages described would be 8.00 cubic inches or 180 percent over the open substrate volume. Another approach then considered, was to design the substrate as for the open substrate design and provide a cover mounting surface around the perimeter of the substrate so that the cover could be sealed in place with epoxy. The epoxy sealed cover and substrate assembly would result in total module volume of 4.73 cubic inches or 66 percent over the open substrate volume. Figure 38 shows the typical types of substrates that were eventually designed and manufactured for the personal transceiver. The discrete-component VHF frontend shown is typical of the discrete-component modules that were fabricated. The H078 VHF frontend is typical of the thick-film hybrid substrates that were manufactured. Both modules utilize Robinson Nugent pins that engage with Robinson Nugent sockets in the motherboard. The epoxy sealed cover-mounting area can be seen on H078 as the gray border along the outer edge of the substrate and across the bottom of the substrate just above the pin. This is the area to which the drawn metal cover would be epoxied to seal the substrate.

During development of the personal transceiver, the need for frequently changing components on the modules and for changing circuits made it impractical to seal the modules. For this reason, the covers were not applied to these modules and where RF shields were required over and above the ground plane shields that were on the back of the substrate, a Scotch brand X-1245 copper foil was attached to the ground plane and wrapped across the front of the circuit elements to effect an RF shield. Figure 39 shows an H065 audio filter with its copper foil shield partially removed to show its components underneath. In those instances where this shielding was not sufficient, a thin brass box was soldered to the ground plane of the motherboard to effect a better sheild and greater isolation.

In the final personal transceiver design, the following modules were thick-film nybrids:

<u>1</u> Channel Select H011.

<u>2</u> Modulator H024.

<u>3</u> Multiplier H039.

<u>4</u> Audio filter H065.

<u>5</u> IF Amplifier H105.

<u>6</u> Audio Amplifier H006.

<u>7</u> Push-to-Talk/Regulator H113.

<u>8</u> UHF Tripler H051.

<u>9</u> VHF Frontend (AF) H078.

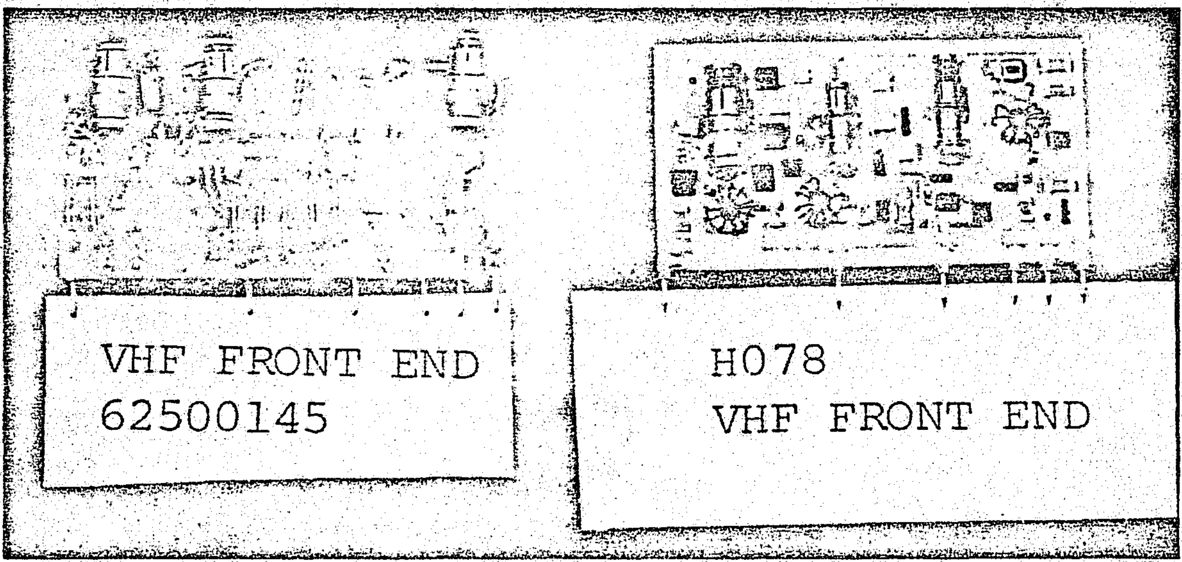


Figure 38. Typical Module Packaging

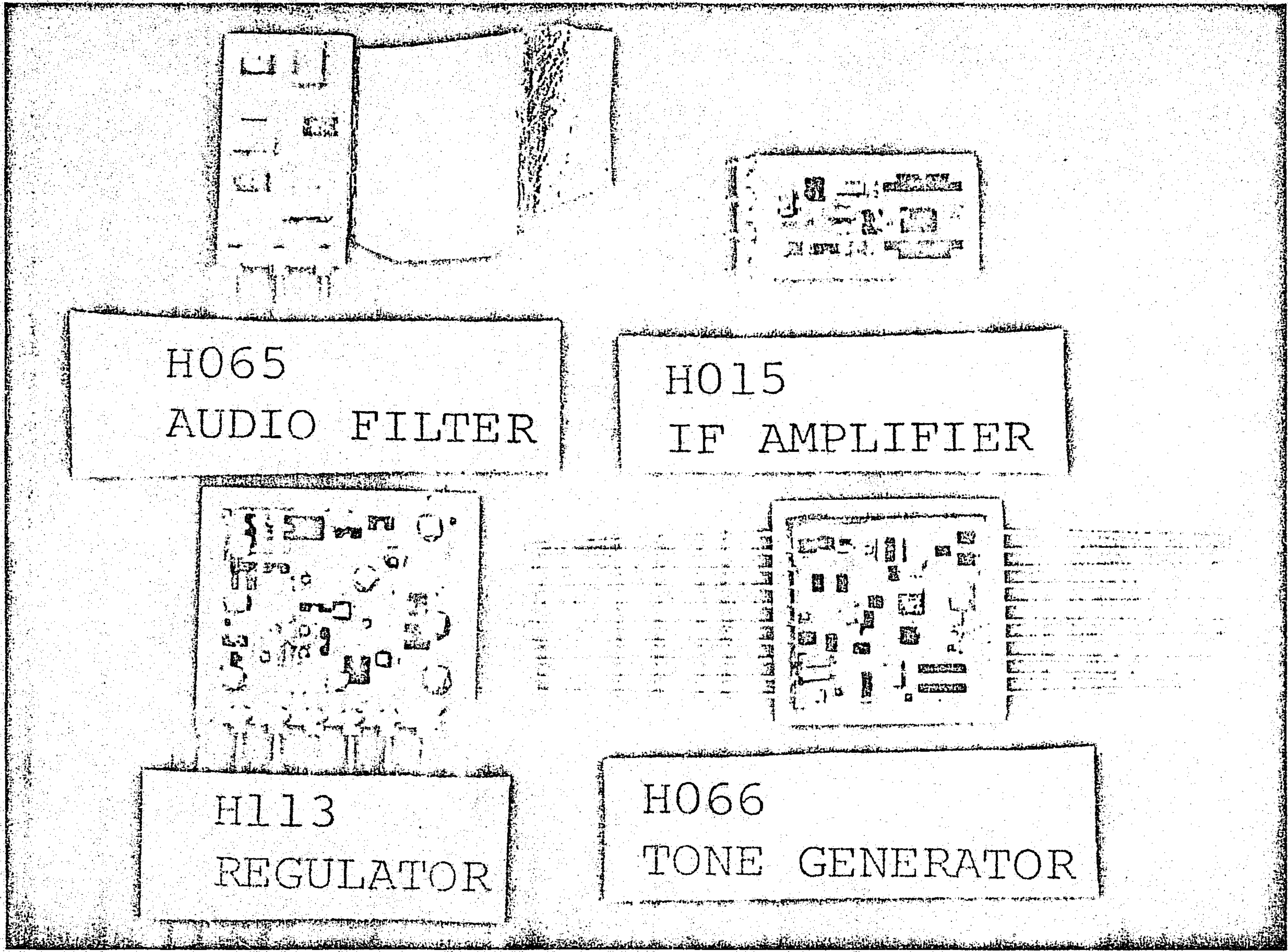


Figure 39. Typical Module Packaging

The personal transceiver incorporated the following discrete-component modules:

1 VHF Power Amplifier 62500098.

2 UHF Power Amplifier 62500092.

3 Tone Generator 62500028.

4 Antenna Matching Networks 6250042 and 62500040.

5 Oscillator Multiplier Filter 62500086 and 62500087.

6 Low-Pass Filter 62500085.

7 UHF Frontend 62500107.

8 VHF Frontend (DOJ) 62500145.

9 Filter 62525402.

10 Matching Networks 62500054.

11 Discriminator 62500045.

In the production design, the following changes to the module packaging are recommended:

1 Use a lead frame instead of the machined Robinson Nugent pins. A typical lead-frame-type clip is Amp Inc. part number CP71-19309.

2 Instead of a cover, the thick-film hybrid substrates should first be protected by a material like Dow Corning 646 on the active devices only. Then the substrates should be potted in Hysol epoxy. Typical substrates using this potting technique are shown on the Martin Marietta Pager Receiver RF board (Figures 40 and 41). The three potted modules that are shown in these figures are the IF hybrid 62453708, RF hybrid 62453706, and local oscillator mixer 62453707.

3 Instead of Robinson Nugent or Amp pin sockets, both of which have been used extensively in this and in the Pager Receiver program, the Berg miniature spring sockets (P/N 75540-001) as recommended. The Berg pin sockets are substantially more reliable than other designs and intermittent problems have been encountered with the Berg sockets.

4 The development power amplifier packages used stud-mounted transistors. This resulted in a very difficult installation. In the production design, studless transistors should be procured. These transistors should be soldered directly to a module heat sink and assembled to the aluminum case as shown in Figure 42.

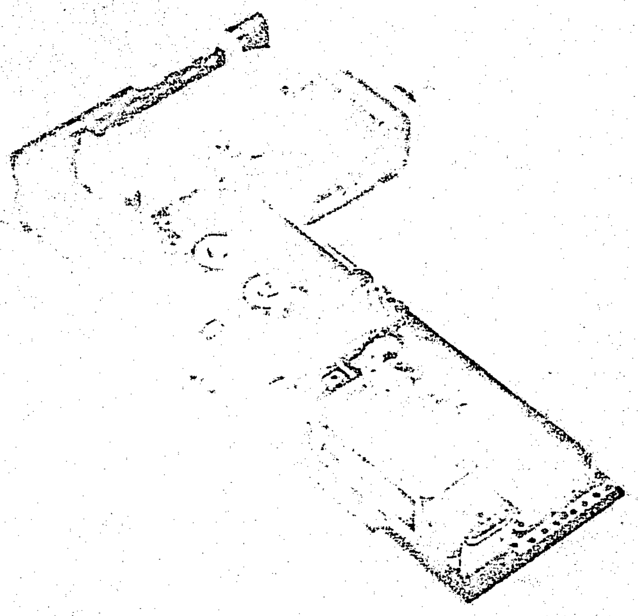


Figure 40. Typical Substrates With Hysol Epoxy Potting

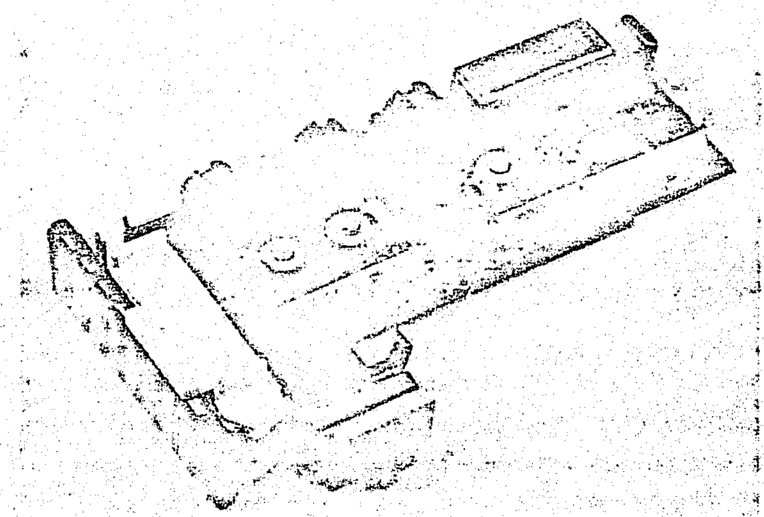


Figure 41. Typical Substrates With Hysol Epoxy Potting

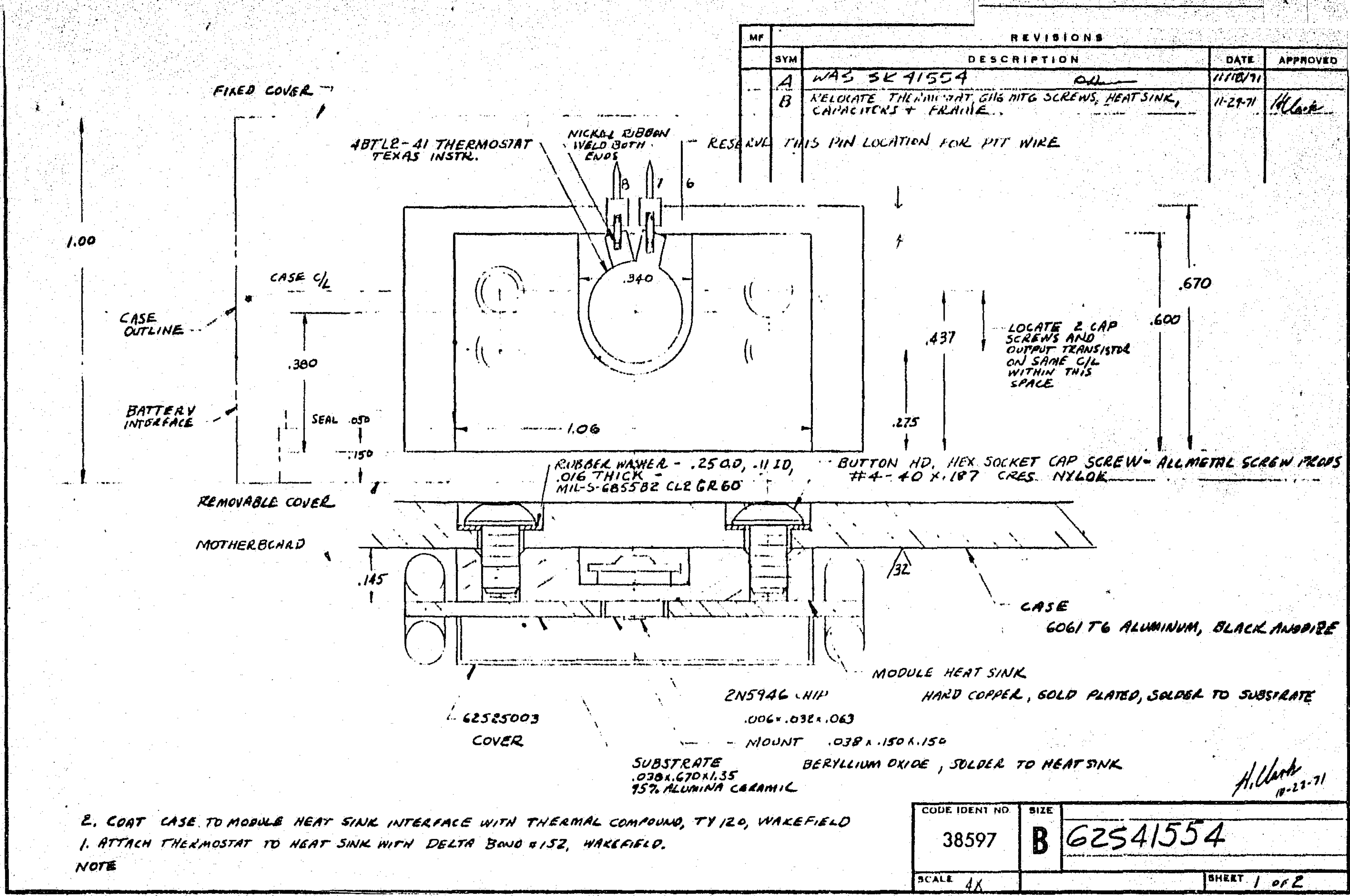


Figure 42. Typical Studless Transistor Installation

3.3 HOUSING DESIGN

The proposed housing design envisioned the housing to consist of four parts (e.g., the microphone loudspeaker housing, basic electronics section frame, front cover, and rear cover). The microphone speaker housing was to be designed as a single subassembly incorporating the microphone loudspeaker transducer and antenna receptacle. The housing was an aluminum die casting and was separately detachable from the electronics housing. The electronic housing was described as a basic frame that acted as a mount for the printed-circuit motherboard with plug-in module receptacles. The basic frame also contained the volume on/off control, squelch control, channel selector, battery receptacle, and press-to-talk switch. The frame was to be made of aluminum and would dissipate heat from the high heat dissipating components within the package. The front and rear covers, attached to this frame by means of screws, were moisture and EMI sealed.

The decision to use a permanent-magnet-type, 1.75-inch, cone speaker instead of the proposed acoustical transformer (or horn) and microphone resulted in a large portion of the front face of the transceiver being taken up by the speaker cone. This necessitated elimination of the separate microphone loudspeaker housing and incorporation of a speaker grill into the front cover. After several layout studies had been completed, it was determined that the front cover should be fixed to the basic electronics section frame instead of removable as proposed. Having the front cover integral with the frame resulted in the elimination of one seal and the cover mounting screws. This saved approximately 1/2 cubic inch in the total volume of the transceiver and allowed the sides of the transceiver to be tapered toward the front to provide more comfortable hand-held operation. With a fixed front cover on the electronic housing, it was necessary for the motherboard module assembly to be inverted (i.e., the motherboard was now placed close to the front cover and the modules were toward the rear cover).

The unique press-to-talk switch design resulted in a panel type switch that, when attached to the front of the electronics housing, acts as a small front cover. To remove the entire press-to-talk switch panel from the electronic housing requires only disconnecting the battery from the housing, pressing down on the press-to-talk switch panel, and sliding it in the direction of the battery connector. Removal of the press-to-talk switch panel exposes a large area of the motherboard that could be used for test points in troubleshooting the transceiver.

A thermal design analysis, conducted on the personal transceiver, is described in Appendix B. Figure 1 of Appendix B shows the electronics housing frame dimensions that were used in the analysis. Drawing 62541554 shows the cross-section through the power amplifier module and how it is attached to a heat sink that is embedded in the case wall. At that time, the electronic housing frame was visualized as a plastic frame with an aluminum heat sink inset in the frame. Run NO. 1 and 2 of the thermal analysis were made with this configuration. These two runs show that the plastic frame with an inset heat sink was inadequate and that the USAF duty cycle resulted in higher temperatures than did the DOJ cycle. Run NO.3 of thermal analysis used the USAF duty cycle and an all-aluminum frame with fins. This run showed that during 122°F ambient normal operation, the high heat dissipating transistors did remain well within their maximum reliable operating temperatures. Thermal analysis run No. 5 was conducted to investigate operation of the power amplifier with the antenna removed from the personal transceiver. The temperature setting for a Texas Instruments 4BTL2-41 thermostat was determined by this thermal analysis. Best operation of the personal transceiver was a setting of 200°F ±8° for opening with the closing at less than 20°F below the opening temperature. Run No. 6 was performed to determine the length of time that the thermostat would allow continuous transmission for various ambient temperatures; it revealed that at -40°F ambient, the transmitter can be operated continuously for 96 minutes but for +95°F operation, the transmitter can be operating continuously for only 12 minutes, and at +122°F, for only 8 minutes. These times were concluded to be reasonable and normal. Although it was not considered in the thermal analysis, attaching the front cover permanently to the electronic housing will result in lower operating temperatures and should improve the overall performance of the transceiver in high-temperature environments.

However, after considerable experience in handling the transceivers over the course of the development program, a removable front cover is recommended for ease of maintenance. Although this change would result in increased unit cost and in slightly larger volume, these disadvantages would be outweighed by the savings in maintenance costs.

3.4 BATTERY DESIGN

The proposed battery (Figure 43) was a separately sealed package incorporating a twist lock electromechanical connector. The desirable battery features are:

1. Simultaneously electrically connects and mechanically locks the battery rigidly to the electronics section.

2. The battery can not be incorrectly connected due to the different pin diameters of the mechanical portion of the connector. This feature also allows the user to replace the battery at night by feeling the pin diameters.

3. The electrical contacts are imbedded with plastic with exposed surfaces only on the two opposite side of the projecting portion of the connector. This prevents shorting of the battery when it is placed near a conductive surface or by having a conductive material placed on the battery. This feature also prevents electrical connection to the electronics section if the transceiver is on until the battery is near final rotation and lock. This insures that a good low-loss electrical connection is made and the battery is rotated in the final lock position to prevent inadvertent loss of the battery or power.

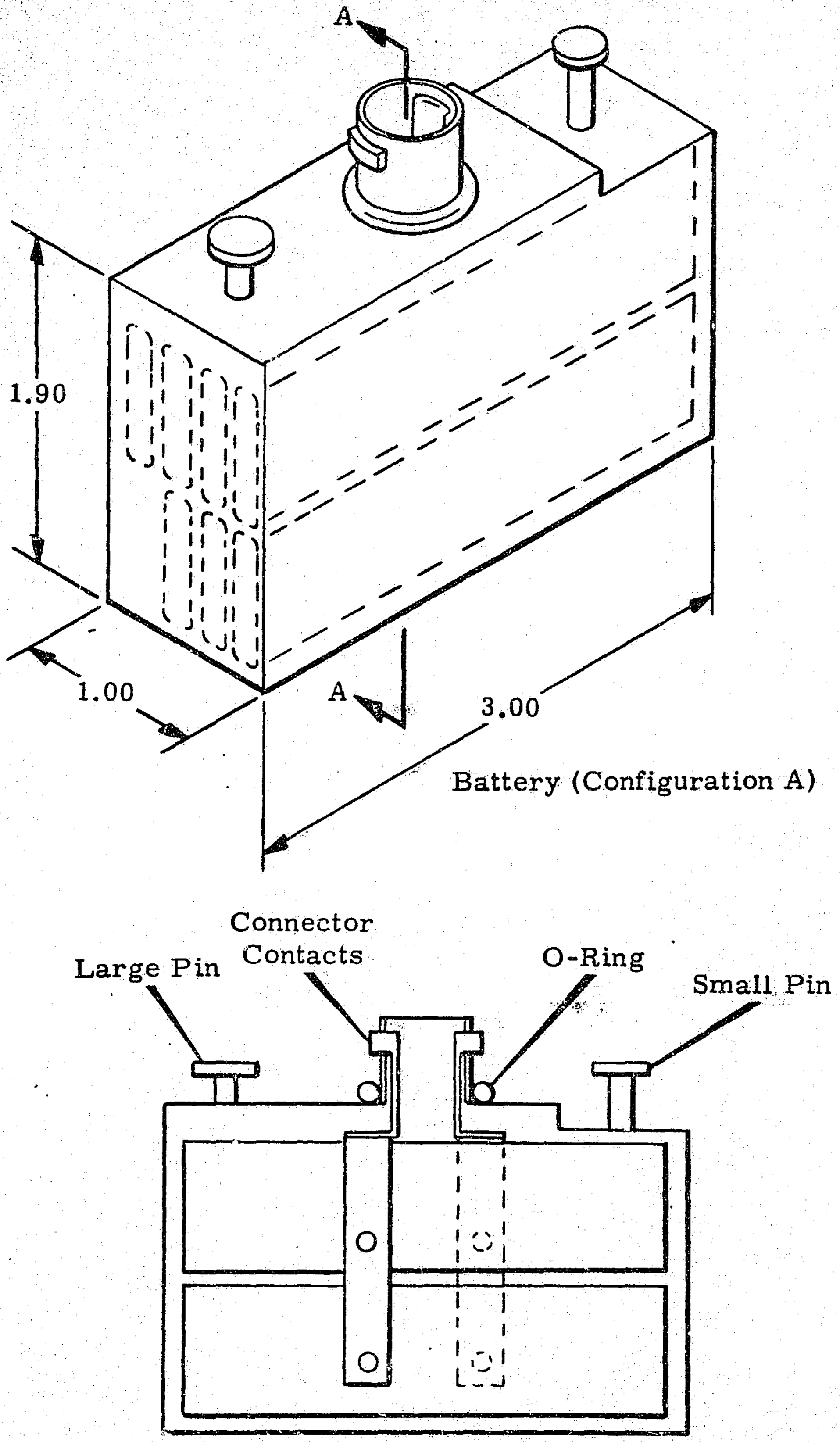


Figure 43. Proposed Battery

4 O-ring seal of the electrical contact.

The proposed total weight for battery assemblies were 8.5 ounces for DOJ and 10 ounces for USAF. The proposed total volume for the battery assemblies were 5.7 cubic inches for DOJ and 8.46 cubic inches for USAF.

The choice of the battery cell and design of the battery connector were the two most time consuming and difficult jobs in the battery assembly design. These two items are described more fully in other parts of this report. Once the choice of the cell and battery connector was made, the design of the battery assembly itself was rather straightforward. A polycarbonate housing was used to completely enclose the cell assembly. The cell assembly was made by the battery manufacturer and consisted of a stack of cells interconnected by welded nickel ribbon. Figure 44 shows two typical cell assemblies as they were assembled by Union Carbide. Figure 45 shows the installation of one of these cell assemblies into a polycarbonate housing. Following installation of the cell assembly into the housing, the connector was assembled to the cover and then welded to the cell assembly. The cover was then sealed onto the battery case by using a polycarbonate solvent. After the assembly operation and the curing required, the battery assembly was painted. Figure 46 shows a completed DOJ battery assembly being connected onto a transceiver electronics assembly. the DOJ battery cell assembly is shown on drawing 62500046, the battery assembly on 62500047; the USAF battery cell assembly is shown on 62500060 and battery assembly on 62500061).

The actual weight of the completed battery assemblies were 7 ounces for DOJ and 9.33 ounces for USAF. The actual volume for the completed battery assemblies were 5.5 cubic inches for DOJ and 8.54 cubic inches for USAF.

The design of the USAF and DOJ battery assemblies was very similar with the only significant difference being the size and shape of the cells involved in the assembly. This difference is readily apparent by examining the drawings. The battery assemblies have the following desirable features:

1 Simultaneously electrically connects and mechanically locks the battery rigidly to the electronics section.

2 The polarity of the electronic connection is correct regardless of the orientation of the battery with respect to the transceiver.

3 The battery can easily be replaced at night by an untrained user.

4 The battery can be replaced without exposing any internal circuits.

5 The battery contacts cannot be inadvertently shorted by laying the battery on a flat conductive surface.

6 When the battery is assemblied to the transceiver, both the transceiver and battery are completely sealed from the effects of external environment.

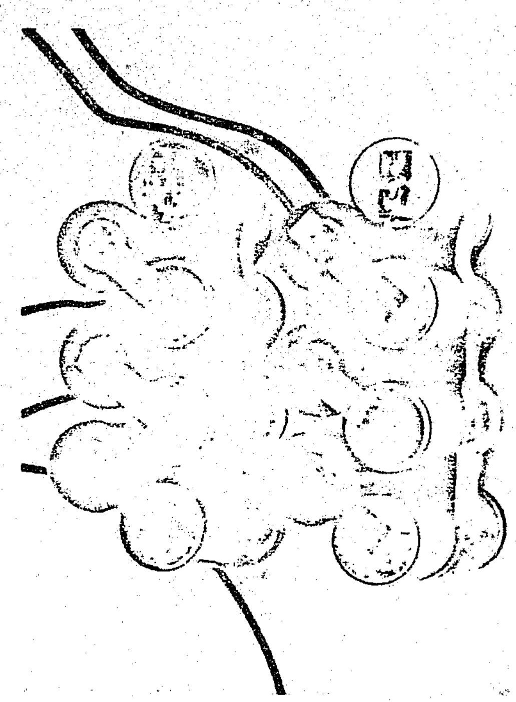


Figure 44. Typical Cell Assemblies For Battery

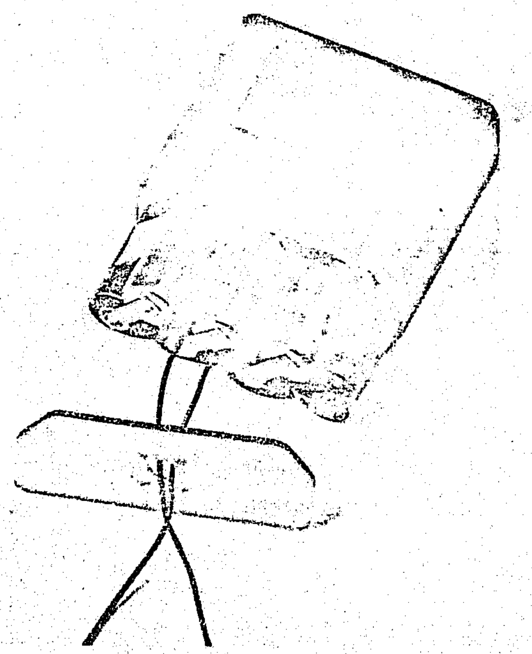


Figure 45. Typical Cell Installation in Housing

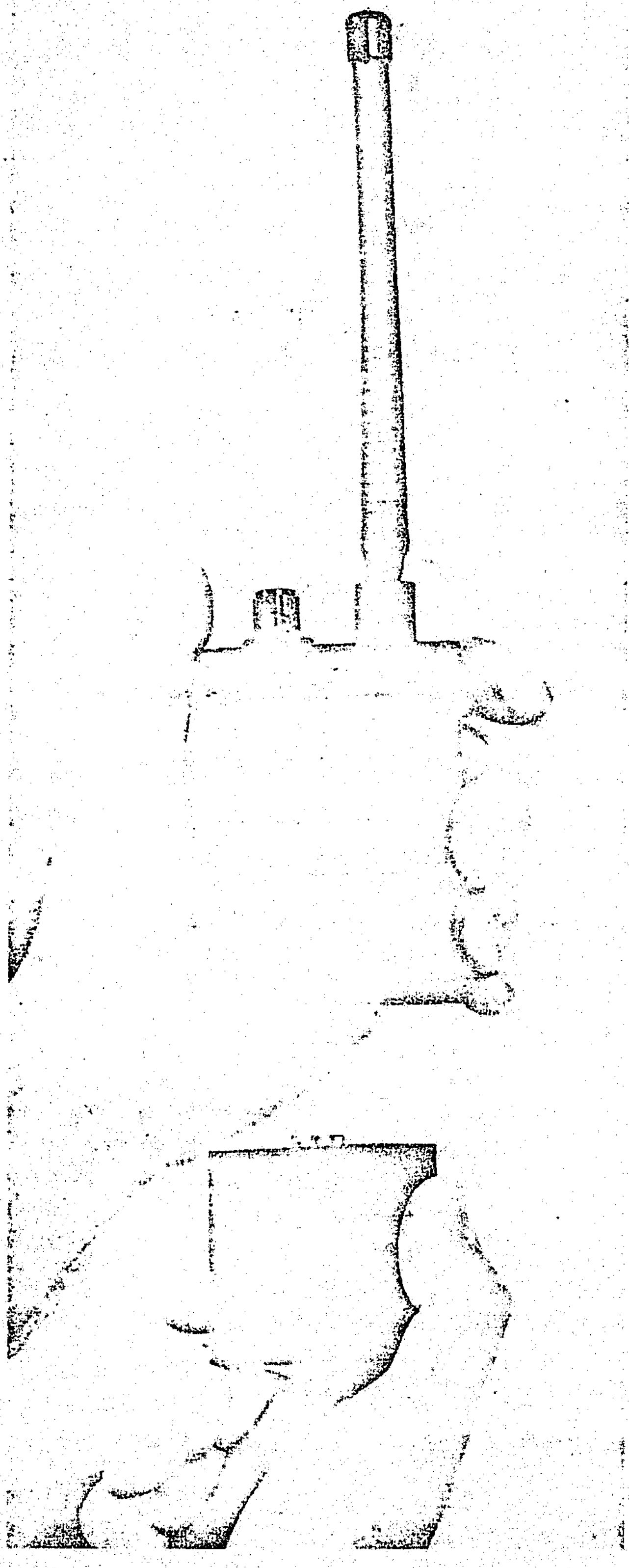


Figure 46. Completed DOJ Battery Assembly

The deliverable battery cases were "hogged" out of solid material due to the small quantity of units built. The production battery assembly is projected to use an injection molded battery housing and cover. Stampings and forgings would be used for the battery connected parts, thus completely eliminating machined parts from the battery assembly. Final assembly of the battery will be accomplished ultrasonically. The end result should be a low-cost throw-away unit that could be discarded in the event of a cell failure.

3.5 BATTERY CONNECTOR

The proposed battery assembly and battery connector configuration were shown in Figure 43. After building a model of this battery and connector and evaluating its operation and design, the following disadvantages became apparent:

1. While attaching the battery onto the electronics housing, before the battery can be rotated, the force necessary to compress the O-ring seal must be supplied by the user. It is required that the battery and electronic housing be forced together in order to compress the seal.

2. The size of the connector and pins was unnecessarily large and occupied too much of the transceiver volume.

3. The battery connector was quite vulnerable to damage, especially if it were dropped while being handled without the transceiver electronic housing. The round projecting plastic part that contains the connector contacts is a vulnerable part of the assembly.

4. If the user inadvertently assembles the battery onto the housing with the pins located behind their mating slot, then the battery cannot be rotated into position. This may result in some confusion especially if the battery is being assembled onto the receiver in the dark.

A design proposed by the Eagle Pitcher Corporation was very similar to the proposed design (Figure 43), except that the connector contacts were in the form of a helix and pins were eliminated. This design obviously solves the O-ring compression problem but it is also seriously weakened because the only structure available for holding the battery on the transceiver housing is the plastic body of the connector.

Subsequently, a 1/8-turn, quick-disconnect was conceived. This connector design is intended for a plastic housing and plastic battery case. The positive voltage connection is made by means of a spring-loaded ball that is pressed onto a contact imbedded in the plastic surface of the battery housing. The negative connection is achieved by means of a ring and plate, which also holds the battery and transceiver housing together. The plate contains four notches through which the four pins pass. When the battery was rotated into its final correct position, the pins were retained in a detent in the plate. The seal was accomplished by means of an O-ring in the housing. However, this connector was not fabricated because:

1 The size was still too large to be compatible with the internal transceiver design.

2 The O-ring seal would not stay in place when the battery is disengaged.

3 The stresses that were encountered in the plate design were too high to be practical.

4 The necessity for a plastic electronics housing.

Further design work on this connector configuration resulted in a design that still did not solve all of the problems enumerated above.

The next design approach eliminated the spring-loaded ball and imbedded contact and substituted a flat-headed and hemispherically headed rivet. The flat headed rivet was installed in the battery housing while the hemispherically headed rivet was installed in the transceiver housing. The connector plate was flattened to eliminate the detents. Two more unsuccessful seal configurations were tried, one with the groove at the top of the battery connector ring and the other in a angular retainer on top of the battery connector ring. Both failed to retain the O-ring during the engaging and disengaging process. The solution to this problem was to bond a flat rubber washer to the transceiver housing.

A connector of this type was fabricated. After the evaluation, it was determined that all objections to the proposed design have been eliminated. This became the final configuration that was used in all transceiver prototypes.

This battery connector was completely satisfactory during the prototype design and development phase. No problems were encountered during shock test, rain test, vibration, or any other adverse environments. Therefore, it was concluded that the basic design is sound and could be used in production. Some changes are necessary however for a cost reduction in the production design.

1 Self-tapping screws should be used for attaching the plate to the transceiver housing.

2 The connector plate should be fabricated by stamping or fine blanking.

3 The connector ring should be forged, sintered, or cast.

4 The connector ring attachment to the battery housing should be changed to eliminate the screws and to substitute instead rivets or some other faster means of attachment onto the battery top.

3.6 ANTENNA

The continuously loaded whip was selected as the baseline antenna and Antenna Specialist Company model PB-4 was modified and tested. The final configuration measured 5.75 inches long including a ball that is inserted into a receptacle in the microphone speaker unit (Figure 47). The proposed concept was to equip an Antenna Specialist antenna with a 3/8-inch diameter steel ball rather than the standard 3/8-inch threaded end. The antenna was intended to snap in and out of a receptacle in the housing. The snap-out force should be high to prevent the antenna from being knocked out during normal activities yet should be low enough to allow an assailant to yank the antenna off without also removing the transceiver. Furthermore, it was determined that the antenna must tilt 20° in all directions and remain in any tilted position during normal use such as running, walking, driving, etc.

Soon after beginning the development program of the personal transceiver, three concepts evolved for the antenna connector:

1. The concept that was proposed (i.e., a 3/8-inch diameter ball attached to the end of the antenna, mating with a snap-on type connector mounted on the top of the transceiver).

2. A 3/8-inch diameter ball permanently retained in a socket in the top of the transceiver much in the same manner as a rod-end bearing or Uniball bearing. The ball would have a hole into which a mating banana-plug-type connector on the antenna would be inserted. The banana plug would provide engagement and disengagement, while the retained ball would provide the tilting.

3. A spring-loaded ball detent that would be mounted in the transceiver and would engage a grooved cylinder attached to the bottom of the antenna. Tilting would be accomplished by means of a hinged knuckle joint at the base of the antenna.

An Antenna Specialist PA-4 antenna was modified to incorporate a 3/8-inch diameter ball end. The antenna weighed 31 grams and the center of gravity was located 2.5 inches from the ball end. In the initial design, it was assumed that the tipover force should be sufficient to hold the antenna without slipping under up to 2 G conditions. This was converted to force of 62 grams at the CG and 50 grams was assumed to be the minimum tipover force required. Insertion and withdrawal force was assumed to be 2 to 6 pounds.

An antenna test tool model was fabricated to test the ball and socket idea. This model revealed that the 3/8-inch diameter ball end antenna and antenna test tool could be adjusted so that the insertion force was 5 pounds and the tipover force was 50 grams at 2-1/2-inches above the ball end. It was observed, however, that the tipover force of 50 grams occurred in only two directions (i.e., in the direction of the spring axes). If the antenna

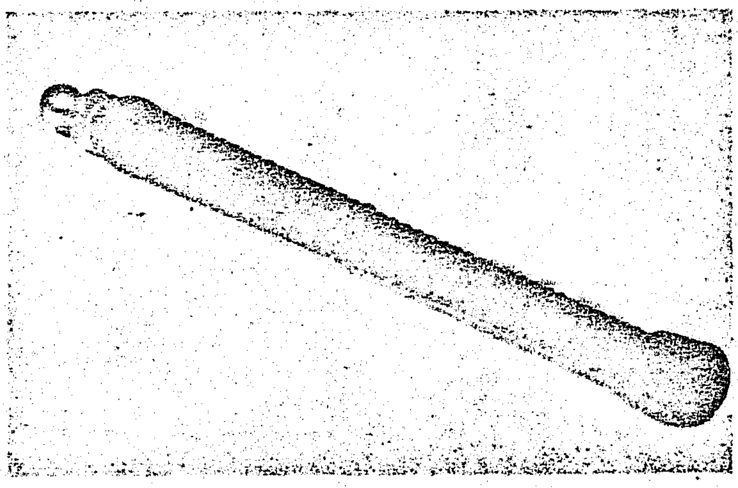


Figure 47. Baseline Antenna

was pulled at right angle to the spring axes, the tipover force was very low (less than 5 grams). Therefore, it was concluded that this test tool was not a good design from a practical standpoint.

A 1/4-inch ball was substituted for the 3/8-inch ball end on the antenna and the test tool was modified to accommodate the 1/4-inch ball. Test of this device revealed the same problem. Except for the same insertion force, the tipover force was lower, which is to be expected with a smaller ball.

Next, a connector for the third concept was fabricated and a new test tool was built. The connector used a cylindrical tip on the bottom of the antenna with a hinged joint and groove that mated with a spring-loaded ball detent in the housing. Insertion and tipover were easily controlled since they were separate; the tipover force was determined by the tightness of the hinge and joint insertion determined by the diameter ball. The disadvantage of this design was that it would only tip in one plane. This appeared to be a very impractical design from the standpoint of breakage of the antenna connector because of the hinge joint.

In a design review attended by AF and DOJ representatives, it was determined that the insertion and withdrawal force be increased to 3 to 7 pounds and that the tipover force be increased from 50 grams to 175 grams at the 2.5-inch point. After reviewing the design calculations, it appeared that it was not possible to accomplish this tipover force with such a relatively low insertion and withdrawal force which using a ball end on the antenna. The obvious solution then to achieve such a high tipover force compared to the insertion/withdrawal force was to use concept 2 above (i.e., permanently captivate the ball in the socket and apply whatever pressure was necessary to achieve the 175 gram tipover force). Then, by drilling a hole in the ball and inserting a banana-plug-type connector with adjustable springs, the 3 to 7 pound insertion/withdrawal force could be achieved.

A specification was written for the antenna connector and was sent to three vendors with requests for a proposal on prototype units of this connector. The vendors were Americon, TED, and Microdot. Subsequently, a purchase order was placed with Microdot. The connector and antenna design were successful in meeting the connector specifications and appears to be satisfactory for production if a suitable price can be achieved.

The only problem that occurred with this connector during the prototype development program was that of breakage, which occurred in the antenna portion of the connector. Three of the connectors were broken by handling, which led to the conclusion that this would continue to be a problem if it were in production. The antenna cannot be pulled sideways (i.e., at right angles to the axis of the antenna from the transceiver) without breaking or bending the male portion of the connector. During the earlier test program with the ball-end connector, it was observed that the antenna can be pulled at right angles to the axis of the antenna with a sudden blow or with a slow pull and successfully disengage itself from the socket without any damage. Because of this problem, it is recommended that the ball-end antenna be subjected to further development. With enough time and development work, such a configuration would be successful and would be satisfactory for production. Mr. Herb Balmer of the TED Corporation is likewise convinced that this design could be satisfactorily solved for a production connector. Another alternative is to use the screw-thread-type connector. This design obviously would be less expensive than the quick-disconnect connector, but has the disadvantage of allowing an assailant to grab the antenna and yank the entire radio off the officer's shoulder. However, the screw-thread-type connector is recommended for production on the basis of cost and ruggedness.

3.7 PRESS-TO-TALK SWITCH

The proposed press-to-talk switch function was two single-pole, double-throw switches that were mounted on either side of the battery receptacle and operated by press-to-talk bar on the outer cover. At that time, some switches (Hi-Tek Corporation part number 772-40007 and Chicago Switch part number 23-020-001) appeared to very attractive from the standpoint of size and cost. Samples of these were obtained and evaluated. Both switches appeared to be satisfactory for the application.

Subsequent circuit developments resulted in the requirement being changed from two single-pole double-throw switches to four single-pole double-throw switches. At this point, the design could use either four of the SP-DT switches, attempting to synchronize their operation mechanically, or a four-pole double-throw switch (such as Chicago Switch Incorporated part number 23-004-001). Some of these switches were obtained and also evaluated. The biggest drawback with the 4P-DT switch was its size; it occupies a large amount of space in the receiver for the function that it accomplished.

To alleviate the volume problem for the press-to-talk function, idea of using diode switching was suggested. The switch module that was developed is the H113, which is operated by a single-pole single-throw switch; this requirement resulted in a concept for the press-to-talk that was utilized in the personal transceiver.

Figure 48 shows an experimental press-to-talk switch that was fabricated to check the concept of conductive rubber and printed wiring board as the switch. Details of the model are shown in Figure 49; tests of this model were successful enough to proceed to completion of the final design, which is shown in Figure 50 both in the assembled form and in the detailed breakdown form. The components of this switch are very simple, relatively inexpensive, and can be mass produced as an assembly for less than $3.00. The press-to-talk switch assembly is shown and described in detail on drawing 62500029.

The only significant problem encountered with the development and use of the final press-to-talk switch design is described in detail in report

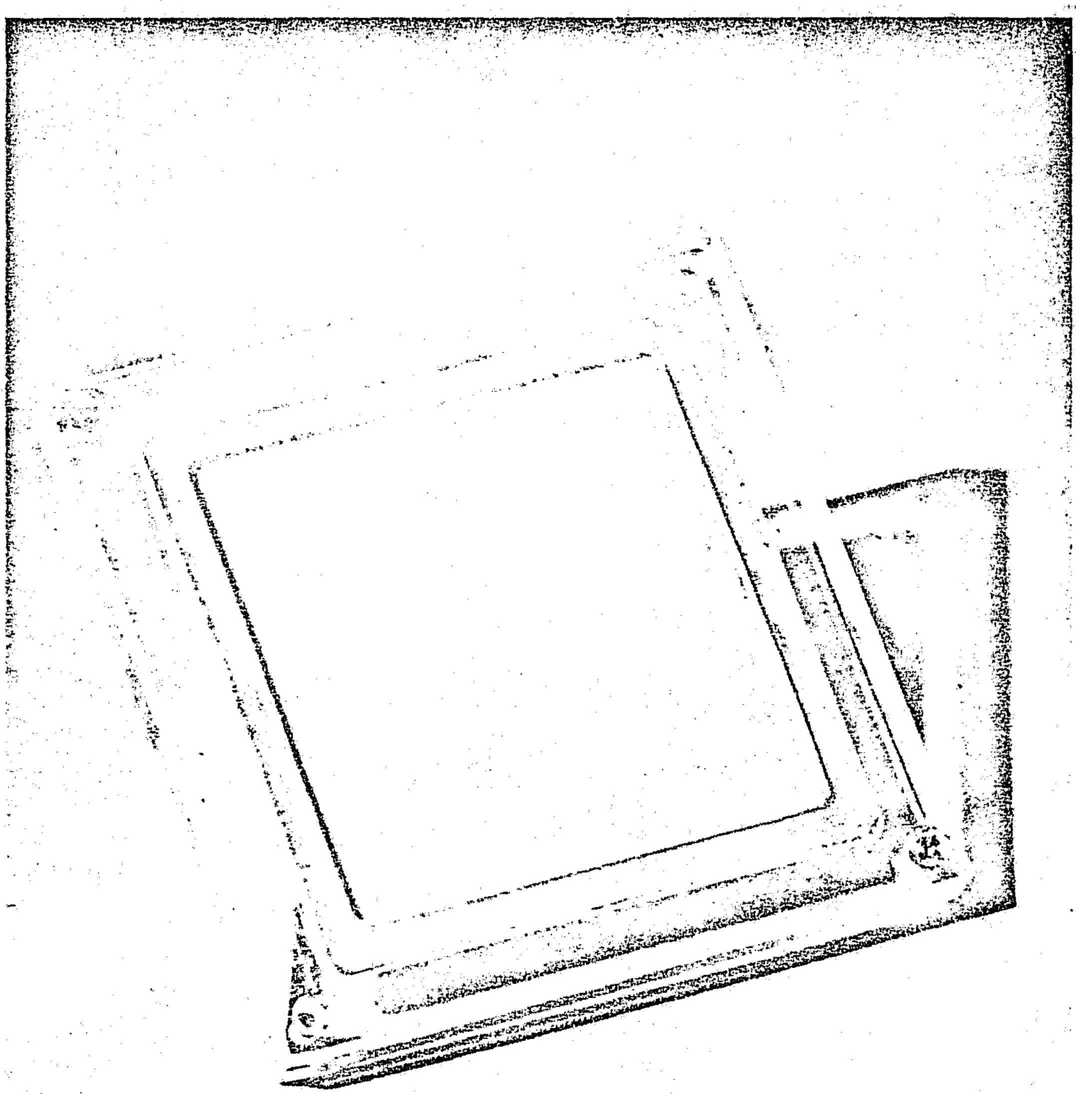


Figure 48. Experimented Press-to-Talk Switch

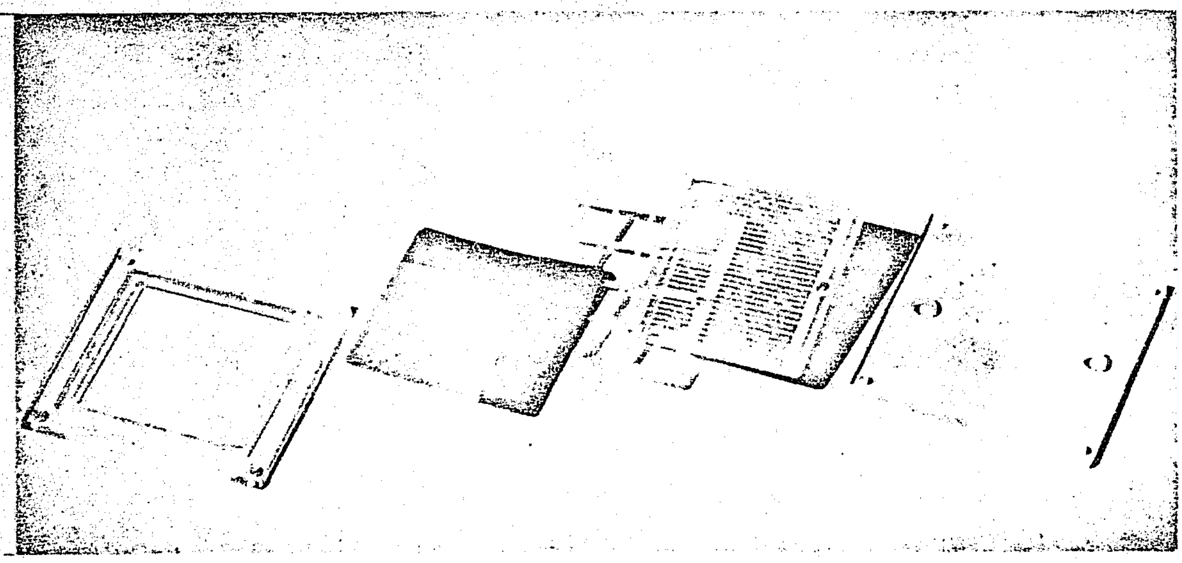


Figure 49. Details of Experimented Press-to-Talk Switch

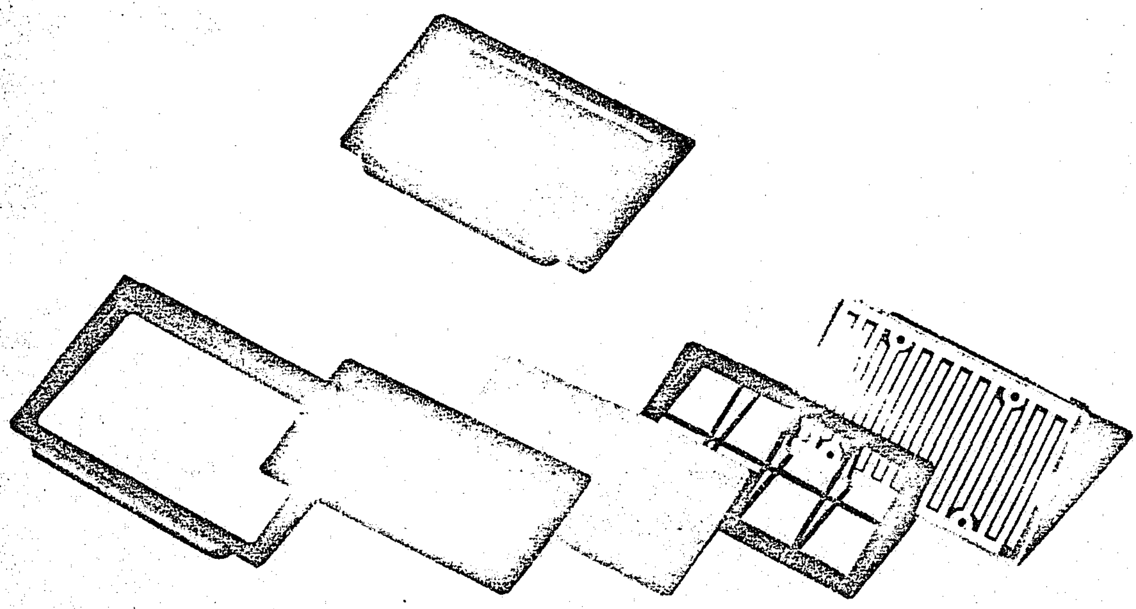


Figure 50. Final Design of Press-to-Talk Switch

OR 12,304, "Equipment Test Report for US Air Force Prototype Personal Transceiver". Appendix A of this report describes the problems and solutions of the problems. The presence of Dow Corning 92-018 sealant in the switches resulted in a shorting of the printed wiring board; use of 0.020-inch conductive rubber resulted in shorts at low temperature. Simply changing to Dow Corning 92-024 sealant which is non-conductive and changing the conductive rubber material to a 0.031-inch thickness solved the shorting problem.

In production, it is recommended that the press-to-talk switch be obtained as a complete assembly from a Vendor such as Chomerics Incorporated for use in the personal transceiver. The internal parts should be die-stamped, the frame of the press-to-talk switch should die-cast, and the assembly should be done with Dow Corning 92-024 adhesive and staking.

3.8 CHANNEL SELECT SWITCH

The initial design and development of the channel select switch was directed along the lines shown in the proposal. Figure 51 shows how the channel select switch was preassembled to its knob and bushing and then plugged into the chassis frame with the pins located at the back end of the channel select switch to engage directly into a printed circuit motherboard. As originally proposed the channel select switch was required to be a simple single-pole, four-position rotary switch. The channel select switch was to be located on the front of the transceiver; that is, the knob projected from the front face of the transceiver just below the loudspeaker, microphone, transducer housing. A 1/2-inch body diameter switch was developed by Grayhill for this application; it was a modification of their standard 50 series to provide one-pole, four-position, 90-degree angle of throw. Samples of these switches were received, tested, and were found to be satisfactory.

Based on this switch design a preliminary specification drawing (SK41465) of the switch was developed. The installation design for this switch as well as the channel select knob requirements were developed as shown on SK41466. An alternate vendor (CTS of Elkhart) was also considered for the supply of this switch. Without further development, their switch had the two problems of a 36-degree angle of throw and a length that was approximately 1/16 inch longer in body than the Grayhill switch.

The 50 series, single-pole, four-position rotary switch with 90-degree angle of throw was subsequently production tooled by Grayhill and production parts were available in July 1971. Subsequent changes in the crystal oscillator electronic circuits made it appear that the switch could not be used in the personal transceiver. At this time, Grayhill was asked to build a 4-position, 3-pole, single-throw, single-level switch; their reply was that this would be extremely difficult to do and, in fact, they did not have a good idea of how to accomplish it. Following this, Martin Marietta developed with Grayhill a modification to their series 51 rotary switch (part number 51MY29013) to provide a single, common pin plus 12 other pins. The

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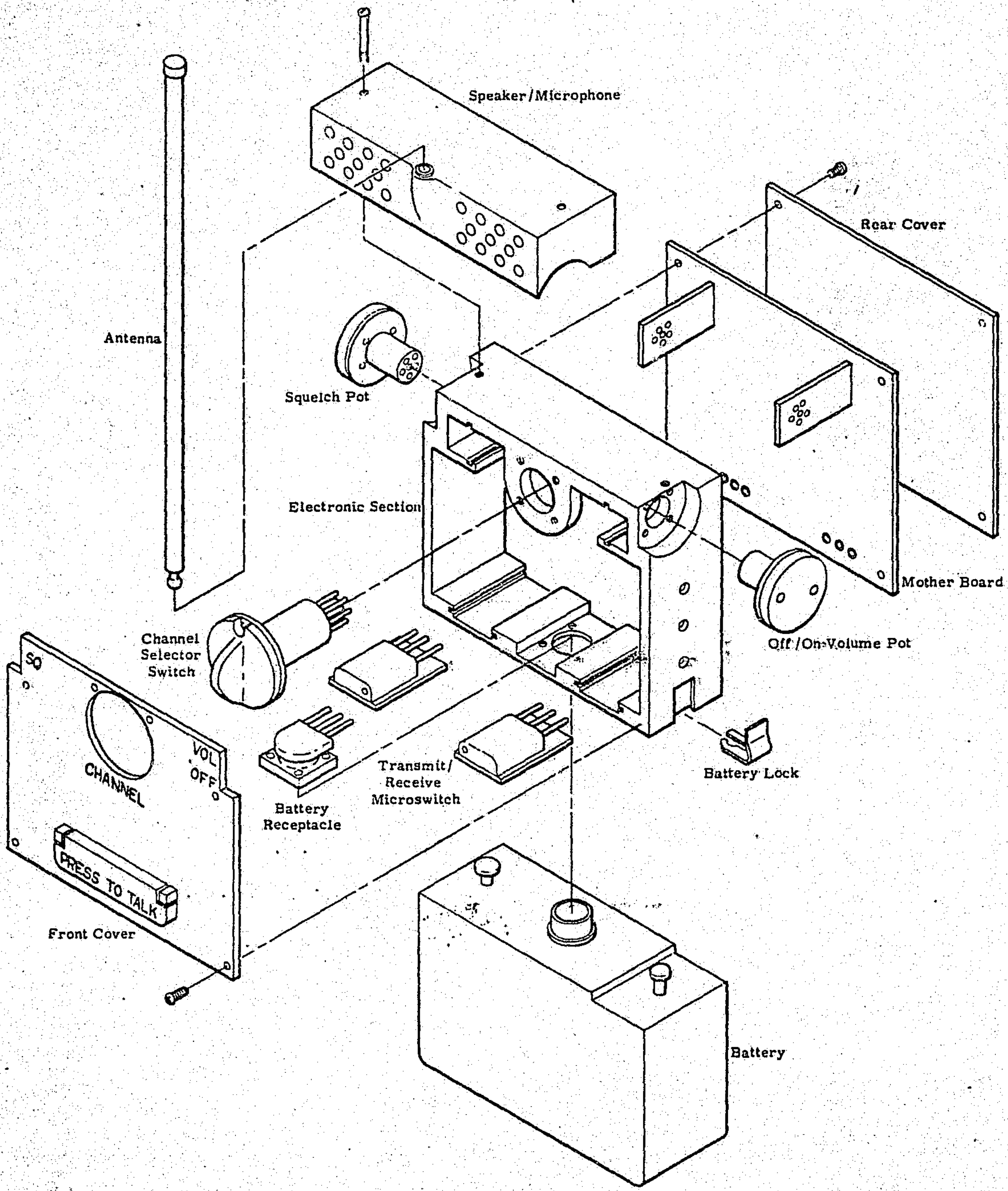

Figure 51. Assembly of Proposed Channel Select Switch

function of the switch was such that the single common pin was shorted to pins 1, 2 and 3 with the channel select switch in position 1; all other pins were open at this time. Moving the channel select switch to position 2 shorted pins 4, 5, and 6 with all other pins being open. This switch was tooled and subsequently fabricated for the personal transceiver prototypes by Grayhill.

The decision to abandon use of an acoustical horn and microphone-loudspeaker unit substantially affected the layout of the transceiver. Use of a permanent-magnet type, 1-3/4-inch diameter cone speaker resulted in a large portion of the front face of the transceiver being occupied by the speaker cone. Because of this, the channel select switch was moved from the front face to the top of the transceiver. Locating the channel select switch at the top of the transceiver above the speaker armature made it necessary for the channel select switch to be connected to the motherboard with long stranded wires and caused the channel select switch location to be considerably further from the crystal than was originally planned. The bushing type mount and plug-in features originally planned for the channel select switch were abandoned and a simple panel mount with stranded wire connections was utilized.

A tactile type channel select knob was developed that allowed the user to determine the selected channel by sight or by feel. The knob's design is considered to be satisfactory for production, provided the necessary tooling is developed.

Further development of the electrical design resulted in the requirement for a 12-pin, 3-pole, 4-position switch of the nonshorting type. A 9/16-inch diameter, single-deck switch of this type is manufactured by RCL (part number S13-RB-4) and is shown on the channel select switch control drawing 62500080. This switch configuration is the one that was used in the prototype personal transceivers.

For the production design, the circuits should be modified so that the channel select switch is switching DC only and that the switch be a simple single-pole, 4-position switch. This switch should be connected to the motherboard by means of flexible circuits. The switch should use printed-circuit terminals that are soldered to the flexible circuits. For a production design, the new Grayhill 75-YY-33000 switch is very attractive from the standpoint of size and weight and should be developed for use in the production design.

3.9 VOLUME AND SQUELCH CONTROLS

The Centralab Division of Globe Union Inc. was requested to quote on the original proposed design, which consisted of a 3/4-inch diameter knob. Immediately underneath the knob was a circular mounting plate utilizing number 0-80 mounting screws. The volume and squelch control bodies were 0.502-inch diameter with printed-circuit type pins projecting axially from this body on the opposite end from the knob. Amperex Electronic Corporation, CTS Corporation, and Bourns, Inc. were also requested to bid on the knob design. All refused to bid; however, they did submit copies of their standard designs that were currently in production.

Allen Bradley, Mallory, and CTS submitted samples of their panel-mounted type production volume and squelch controls. The Mallory controls were the least expensive but were also the largest; all controls were considered to be too large for the proposed transceiver. The body sizes were roughly 0.50 inch in diameter and 0.65 inch in length. The Mallory controls were of the MLC type; their most attractive feature was their low price.

The Allen Bradley type G volume control and type SP squelch control were evaluated. These controls, while more expensive and obviously of much better external quality than the Mallory controls, appear to have about the same performance and were very similar in volume to the Mallory controls; thus, they offered no advantage over the Mallory control. CTS only submitted a type 660 squelch control. This control was approximately half the size of those of Mallory and Allen Bradley but sold for more than $6 each and were therefore too expensive to consider. Furthermore, there was no volume control counterpart for the CTS squelch control.

In an attempt to find smaller volume and squelch controls, several other devices were investigated. For example, Bourns potentiometer (model 3365) was evaluated. This device is very attractive from a standpoint of size and weight with its 1/2-inch diameter and 0.23-inch length including the knob, but there was no equivalent device containing an on-off switch. Furthermore, this potentiometer was apparently not capable of taking the continuous motions and variations required of a volume or squelch control. It was intended primarily to be set to one value and left alone and probably would not operate over more than two or three hundred cycles. The CTS series M250 composition variable resistors were also investigated but no switch version of this potentiometer is available. The Centralab model 6 volume and squelch control were evaluated and found to be satisfactory, both from a standpoint of size and weight and from a standpoint of current carrying capability. These units also have adequate moisture protection, a long history of successful production, and were therefore chosen for use on the prototypes. The volume control is 0.6 inches in diameter over the knob and is 0.25 inches thick overall. The squelch control knob is the same diameter; the depth of the control is 0.20 inches. A minor problem encountered with these controls is that the knobs are susceptible to several of the printed-circuit cleaning solvents. A major disadvantage of these controls is that it is extremely difficult and time consuming to install and seal these controls in a transceiver housing. It requires approximately one hour to install, seal, and wire up a volume and squelch control. This is, of course, unacceptable for a production design.

For the production design, the goal is to retain the reliability, function, and knob size of the present volume and squelch control, yet provide an easier method of mounting. Several approaches should be investigated prior to making a final production design recommendation. An injection molded, plastic adapter could be designed to fit onto the back of the Centralab volume and squelch controls that would allow the volume and squelch controls to be installed from the inside of the chassis after removal of the knob. At the present time, the volume and squelch controls must be installed from the outside of the chassis and two small nuts plus associated wiring must be connected or installed on the back of the volume and squelch controls after they are in place in the chassis. Installing the volume and squelch controls on an adapter ring would allow them to be assembled on the adapter ring externally to the case, and then to be assembled into the case by simply pressing the cylindrical body of the volume and squelch controls through a hole. An appropriate RTV adhesive would be put in place on the adapter ring prior to pressing the control into the hole. After the RTV adhesive sets, the knob could be put in place. The combination of the knob plus the adapter ring would prevent the volume and squelch controls from falling out of the case or into the case. As for the wiring of the volume and squelch control, we strongly recommend for production the flexible wiring, or the flexible wiring and hardboard backing combination which is manufactured by the G.T. Schjeldahl Company of Northfield, Minnesota. Their Capton-insulated, flexible, printed circuits could easily be soldered onto the volume and squelch controls while the circuits are out on the bench. Installation of the motherboard could then be accomplished. After installation of the motherboard, the volume and squelch controls hang onto the motherboard, attached to the motherboard by means of the flexible circuits. At this time, the RTV could be applied and they could be pushed into place in the case with no soldering required while the unit is in the case.

Recently received prototypes of a volume and squelch control are those developed by CTS of Asheville, Inc. The squelch control is a 25K linear potentiometer (part number 14659-MM). The volume control is a 5K $\pm$30% audio taper (part number 14658-MM). The knob of these units is 0.330 inch diameter with an overall thickness of 1/10-inch, including the knob. The configuration of the potentiometer is somewhat similar to that of a Motorola Micro-T transistor package with ribbon leads extending radially from the rear of the potentiometer package. These controls could very readily be mounted on Schjeldahl flexible printed circuits by reflow soldering and when the motherboard is installed in the chassis, the volume and squelch control could be pressed into their respective mounting holes by using RTV or an adhesive for sealing. Installing the knob on the outside of the control would lock the units in place. This design merits further test and investigation and appears to be the most attractive from the standpoint of size, weight, and cost for the production transceiver. A similar set of volume and squelch control knobs is presently being sold to another transceiver manufacturer for a production design.

SECTION VII.

TEST RESULTS

This section outlines a summary of results of the various tests run on both the DOJ and AF transceivers. The figures and tests presented are as follows:

Figure No.	Title
52	AF Acceptance Tests on Six Units
53	AF Environmental Test for Temperature
54	AF Environmental Test for Humidity, Altitude, Rain and Vibration
55	AF EMI Test Results
56	DOJ Acceptance Tests on Six Units
57	DOJ Environmental Test for Temperature
58	DOJ Environmental Test for Humidity, Altitude, Rain and Vibration

Detailed descriptions of the test results and the reasons for variances between the specifications and measured values are contained in the following data items previously submitted:

1. A020 Equipment Test Report for U.S. Air Force Prototype Personal Transceiver
2. B020 Equipment Test Report for Department of Justice Prototype Personal Transceiver
3. B020 EMC Test Report for Prototype Personal Transceiver
4. A021 Acceptance Test Report for Prototype Personal Transceiver
5. B021 Acceptance Test Report for Prototype Personal Transceiver

ITEM: Personal VHF Transceiver CONTR: USAF (AFSC), Hanscom Field, Bedford, Mass. MFR'S TYPE: 62500025

CONTRACT: F33657-71-C-0832 MFR: Martin Marietta Corporation, Orlando, Fla. TEST DATES: 10/10/72 to 11/28/72

No.	Data Sheet Ref. Para.	Test Group	Test Item	Spec Limit	Measured Values					
					S/N 1	S/N 2	S/N 3	S/N 4	S/N 5	S/N 6
1	5.1	Rcvr	Spurious Response	85 dB min	94	102	60	47	40	73
2	5.2	"	IM Spurious Atten	65 dB min	66	72	58	68	59	64
3	5.3	"	Dynamic Range	80 dB min	93	79	72	83	77	78
4	5.4	"	Selectivity	80 dB min	78	79	71	86	77	76
5	5.5	"	Mod Accept Bandwidth	± 7.5 kHz min	± 9.5	± 8.5	± 8.5	± 7.5	± 8.5	± 7.5
6	5.6	"	Sensitivity	0.35 μv max	0.53	0.34	0.32	0.28	0.34	0.40
7	5.7	"	LO Freq Stability	± 0.0005% max	*	*	*	*	*	*
8	5.8	"	Acoustic SP Level	105 dB min	93, 96	93, 95	94, 96	94, 95	95, 99	94, 98
9	5.9	"	Audio Output Power	80 mW max	165	150	88	138	125	150
10	5.10	"	Audio Dist/Noise	5% max	4.5	2.5	3.4	2.2	2.3	1.0
				50 dB min	52	52	50	52	51	63
11	5.11	"	Audio Response	+1, -3 dB	**	**	**	**	**	**
12	5.12	"	Tone Squelch	NA						
13	5.13	Xmtr	Subaudible Tone Gen	NA						
14	5.14	"	Xmtr Freq Stability	± 0.0005% max	*	*	*	*	*	*
15	5.15	"	Audio Distortion	5% max	4.6	4.0	4.2	4.4	3.2	4.8
16	5.16	"	Frequency Response	+1, -3 dB	**	**	**	**	**	**
17	5.17	"	FM Noise and Hum	40 dB min	37	44	38	37.5	42	38
18	5.18	"	Deviation Limit	± 5 kHz max	4.8	4.9	5.0	4.3	4.6	5.0
19	5.19	"	AM Hum and Noise	35 dB min	>40	>40	>40	>40	>40	>40
20	5.20	"	RF Power Output	3.2 to 5.0 W	3.7	4.1	4.4	3.3	3.4	4.8

* Data deferred until recrystallization.

** See Data Sheets

NA Not Applicable (Department of Justice transceivers only)

Figure 52. AF Acceptance Tests on Six Units

PARAMETER		TEMPERATURE +25°C	-40°C	-20°C	0°C	+20°C	+50°C	+70°C
Transmitter Power Output	Specification:	3.2 - 5.0 w	1.6 - 5.0 w	N/A	N/A	N/A	1.6 - 5.0 w	3.2 - 5.0 w
	*Requested Limit:	3.2 - 5.0 w	1.6 - 5.0 w	N/A	N/A	N/A	1.6 - 5.0 w	3.2 - 5.0 w
	Measured:	3.4 w	1.8 w	N/A	N/A	N/A	2.6 w	3.3 w
FM Noise and Hum	Specification:	40 dB min	30 dB min	N/A	N/A	N/A	30 dB min	40 dB min
	*Requested Limit:	35 dB min	25 dB min	N/A	N/A	N/A	25 dB min	35 dB min
	Measured:	37.5 dB	36.2 dB	N/A	N/A	N/A	37 dB	47 dB
Transmitter Frequency Stability	Specification:	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	*Requested Limit:	± 0.0005% max	± 0.0010% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	Measured:	Reference	0.00074%	0.00007%	0.00001%	0.00002%	0.00006%	0.00050%
Receiver LO Frequency Stability	Specification:	N/A	N/A	± 0.0005% max	± 0.0005% max	± 0.0005% max	N/A	N/A
	*Requested Limit:	N/A	N/A	± 0.0005% max	± 0.0005% max	± 0.0005% max	N/A	N/A
	Measured:	N/A	N/A	0.00044%	0.00003%	0.00004%	N/A	N/A
Receiver Selectivity	Specification:	80 dB min	68 dB min	N/A	N/A	N/A	68 dB min	80 dB min
	*Requested Limit:	70 dB min	58 dB min	N/A	N/A	N/A	58 dB min	70 dB min
	Measured:	86 dB	82 dB	N/A	N/A	N/A	80 dB	89 dB
Receiver Sensitivity	Specification:	0.35 μv max	1.1 μv max	N/A	N/A	N/A	1.1 μv max	0.35 μv max
	*Requested Limit:	0.50 μv max	1.6 μv max	N/A	N/A	N/A	1.6 μv max	0.50 μv max
	Measured:	0.33 μv	0.22 μv	N/A	N/A	N/A	0.55 μv	0.38 μv
Modulation Acceptance Bandwidth	Specification:	± 7.5 kHz min	± 6.0 kHz min	N/A	N/A	N/A	± 6.0 kHz min	± 7.5 kHz min
	*Requested Limit:	± 7.5 kHz min	± 6.0 kHz min	N/A	N/A	N/A	± 6.0 kHz min	± 7.5 kHz min
	Measured:	± 7.5 kHz	± 9.0 kHz	N/A	N/A	N/A	± 9.2 kHz	± 7.5 kHz
Audio Power Output	Specification:	80 mW min	Ambient -6 dB	N/A	N/A	N/A	Ambient -6 dB	80 mW min
	*Requested Limit:	80 mW min	20 mW min	N/A	N/A	N/A	20 mW min	80 mW min
	Measured:	132 mW	165 mW	N/A	N/A	N/A	151 mW	151 mW

* Requested acceptable prototype performance.

Figure 53. AF Acceptance Test for Temperature

Parameter		Humidity	Altitude	Rain	Vibration
Transmitter Power Output	Specification:	1.6 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts
	*Requested Limit:	1.6 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts
	Measured:	3.2 watts	3.2 watts	4.0 watts	4.5 watts
FM Noise and Hum	Specification:	34 dB minimum	40 dB minimum	40 dB minimum	40 dB minimum
	*Requested Limit:	29 dB minimum	35 dB minimum	35 dB minimum	35 dB minimum
	Measured:	39 dB	44 dB	48 dB	40 dB
Transmitter Frequency Stability	Specification:	± 0.0005% maximum	± 0.0005% maximum	± 0.0005% maximum	± 0.0005% maximum
	*Requested Limit:	± 0.0005% maximum	± 0.0010% maximum	± 0.0005% maximum	± 0.0005% maximum
	Measured:	0.00034%	0.00045%	0.00049%	0.00046%
Receiver Selectivity	Specification:	60 dB minimum	80 dB minimum	80 dB minimum	80 dB minimum
	*Requested Limit:	50 dB minimum	70 dB minimum	70 dB minimum	70 dB minimum
	Measured:	81 dB	87 dB	90 dB	75 dB
Receiver Sensitivity	Specification:	1.1 μv maximum	0.35 μv maximum	0.35 μv maximum	0.35 μv maximum
	*Requested Limit:	1.6 μv maximum	0.50 μv maximum	0.50 μv maximum	0.50 μv maximum
	Measured:	0.46 μv	0.49 μv	0.43 μv	0.48 μv
Modulation Acceptance Bandwidth	Specification	± 6.0 kHz minimum	± 7.5 kHz minimum	± 7.5 kHz minimum	± 7.5 kHz minimum
	*Requested Limit:	± 6.0 kHz minimum	± 7.5 kHz minimum	± 7.5 kHz minimum	± 7.5 kHz minimum
	Measured:	± 9.2 kHz	± 10.1 kHz	± 8.5 kHz	± 10.5 kHz
Audio Power Output	Specification:	20 mW maximum	80 mW maximum	80 mW maximum	80 mW maximum
	*Requested Limit:	20 mW minimum	80 mW minimum	80 mW minimum	80 mW minimum
	Measured:	551 mW	320 mW	720 mW	383 mW

Figure 54. AF Acceptance Test for Humidity, Altitude, Rain, and Vibration

* Requested acceptable prototype performance.

Figure 55. AF EMI Test Results

Test Number	Test Type	Mode	Channel Number	Results		
				Within MIL-STD-461A Limits	Above MIL-STD-461A Limits	
1	CS03 (Intermodulation Response)	N/A	N/A		Frequency (MHz)	dB above Spec
					152.554	6.0
					153.811	8.0
					152.418	6.0
					147.510	4.0
2	CS04 (Spurious Response)	Receive	1		Frequency (MHz)	dB above Spec
					168.8733	19.0
					175.2423	10.0
					185.2661	20.0
					201.6465	9.0
					224.3975	10.0
					142.4694	14.0
					136.1006	20.0
3	CS07 (Squelch Circuits)	N/A	N/A	✓		
4	RE02 (Radiated Emission Electric Field - Broadband)	Receive, Transmit	1, 2, 3	✓		
5	RE02 (Radiated Emission Electric Field - Narrowband)	Receive	1, 2, 3	✓		
		Transmit	1		Frequency (Harmonic No.)	dB above Spec
					2	10.0
					7	20.0
					8	11.0
					9	11.2
					10	5.0
					14	7.0
			2		2	21.0
					3	14.0
					7	20.0
					8	5.0
					9	6.2
					10	0.5
					11	2.4
					14	5.2
			3		2	20.0
					3	16.0
					7	11.3
					8	15.5
					9	4.5
					11	0.2
6	CE06 (Antenna Terminal Conducted Broadband)			✓		
7	CE06 (Antenna Terminal Conducted Narrowband)	Receive	1	✓		
			2	✓		
			3		Frequency (Harmonic No.)	dB above Spec
					9	11.0
		Transmit	1	✓		
			2		(Harmonic No.)	dB above Spec
					7	13.0
					9	8.0
			3	✓		

ITEM: Department of Justice Transceiver CONTR: USAF (AFSC), Hanscom Field, Bedford, Mass. MFR'S TYPE: 62500001

CONTRACT: F33657-71-C-0832 MFR: Martin Marietta Aerospace, Orlando, Fla. TEST DATES: 12/72 to 6/73

No.	Data Sheet Ref. Para.	Test Group	Test Item	Spec Limit	Measured Values 62500001-039 S/N 1	62500001-039 S/N 2	62500001-019 S/N 1	62500001-029 S/N 1	62500001-009 S/N 1	62500001-009 S/N 2
1	5.1	Rcvr	Spurious Response	85 dB min	50	59	54	53	49	49
2	5.2	"	IM Spurious Atten	65 dB min	56	65	62	57	57	56
3	5.3	"	Dynamic Range	80 dB min	74	77	80	74	70	71
4	5.4	"	Selectivity	80 dB min	72	77	70	75	77	74
5	5.5	"	Mod Accept Bandwidth	±7.5 kHz min	±8.7	±12	±9.5	±8.5	±20	±9.8
6	5.6	"	Sensitivity	0.35 µv max	0.22, 0.22, 0.23, 0.22	0.26, 0.26, 0.26, 0.26	0.5, 0.39, 0.42, 0.5	0.40, 0.45, 0.41, 0.45	0.35, 0.37, 0.35, 0.39	0.34, 0.34, 0.33, 0.35
7	5.7	"	LO Freq Stability	±0.0005% max	*	*	*	*	*	*
8	5.8	"	Acoustic SP Level	105 dB min	93	93	94	92	93	94
9	5.9	"	Audio Output Power	80 mW max	185	125	280	125	125	84
10	5.10	"	Audio Dist/Noise	5% max 50 dB min	2.2 59	2.5 55	3.2 55	2.8 63	2.8 >50	3.9 61
11	5.11	"	Audio Response	+1, -3 dB	+.4,-1.9**	+.4,-8**	+.2,-2.9**	+.7,-5.9**	+.2,-3.4**	+.2,-2.4**
12	5.12	"	Tone Squelch	±0.5% BW ≤ 6 dB sens	✓	✓	✓	✓	✓	✓
13	5.13	Xmtr	Subaudible Tone Gen	±0.5%	+.28,-0	+.28,-.16	+.1,-.3	+.2,-0	+.5,-0	+.06,-.05
14	5.14	"	Xmtr Freq Stability	±0.0005% max	*	*	*	*	*	*
15	5.15	"	Audio Distortion	5% max	4	4	4.6	4.8	5	4.5
16	5.16	"	Frequency Response	+1, -3 dB	+0,-7.5	+.1,-7.5	+.1,-7.5	+0,-8.5	+0,-8.5	+.6,-11
17	5.17	"	FM Noise and Hum	40 dB min	37	40	52	40	45	36
18	5.18	"	Deviation Limit	± 5 kHz max	✓	✓	✓	✓	✓	✓
19	5.19	"	AM Hum and Noise	35 dB min	> 35	> 40	> 40	> 40	> 40	> 35
20	5.20	"	RF Power Output	3.2 to 5 W	3.6, 3.4, 3.6, 3.4	4.1, 4.3, 3.7, 3.5	4.4, 3.8, 4.4, 3.6	3.8, 3.8, 3.8, 3.7	3.7, 3.7, 3.3, 3.3	3.5, 3.5, 3.5, 3.7

* 0.0005%, -20°C to +50°C (0.001%, -40°C to -20°C)

** Frequencies between 600 to 3000 Hz

Figure 56. DOJ Acceptance Tests on Six Units

PARAMETER		TEMPERATURE						
		+25°C	-40°C	-20°C	0°C	+20°C	+50°C	+70°C
Transmitter Power Output	Specification:	3.2 - 5.0 w	1.6 - 5.0 w	N/A	N/A	N/A	1.6 - 5.0 w	3.2 - 5.0 w
	*Requested Limit:	3.2 - 5.0 w	1.6 - 5.0 w	N/A	N/A	N/A	1.6 - 5.0 w	3.2 - 5.0 w
	Measured: (min)	3.4 w	1.6 w	N/A	N/A	N/A	1.6 w	3.2 w
FM Noise and Hum	Specification:	40 dB min	30 dB min	N/A	N/A	N/A	30 dB min	40 dB min
	*Requested Limit:	35 dB min	25 dB min	N/A	N/A	N/A	25 dB min	35 dB min
	Measured:	35 dB	32 dB	N/A	N/A	N/A	33 dB	35 dB
Transmitter Frequency Stability	Specification:	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	*Requested Limit:	± 0.0005% max	± 0.0010% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	Measured:	Reference	0.0007%	0.0003%	0.0004%	0.0002%	0.0005%	0.0001%
Receiver LO Frequency Stability	Specification:	N/A	N/A	± 0.0005% max	± 0.0005% max	± 0.0005% max	N/A	N/A
	*Requested Limit:	N/A	N/A	± 0.0005% max	± 0.0005% max	± 0.0005% max	N/A	N/A
	Measured:	N/A	N/A	0.0004%	0.0003%	0.0003%	N/A	N/A
Receiver Selectivity	Specification:	80 dB min	68 dB min	N/A	N/A	N/A	68 dB min	80 dB min
	*Requested Limit:	70 dB min	58 dB min	N/A	N/A	N/A	58 dB min	70 dB min
	Measured:	70 dB	70 dB	N/A	N/A	N/A	69 dB	71 dB
Receiver Sensitivity	Specification:	0.35 μv max	1.1 μv max	N/A	N/A	N/A	1.1 μv max	0.35 μv max
	*Requested Limit:	0.50 μv max	1.6 μv max	N/A	N/A	N/A	1.6 μv max	0.50 μv max
	Measured: (max)	0.45 μv	1.1 μv	N/A	N/A	N/A	0.36 μv	0.44 μv
Modulation Acceptance Bandwidth	Specification:	± 7.5 kHz min	± 6.0 kHz min	N/A	N/A	N/A	± 6.0 kHz min	± 7.5 kHz min
	*Requested Limit:	± 7.5 kHz min	± 6.0 kHz min	N/A	N/A	N/A	± 6.0 kHz min	± 7.5 kHz min
	Measured:	± 7.8 kHz	± 7.5 kHz	N/A	N/A	N/A	± 7.5 kHz	± 7.5 kHz
Audio Power Output	Specification:	80 mW max	Ambient -6 dB	N/A	N/A	N/A	Ambient -6 dB	80 mW max
	*Requested Limit:	80 mW min	20 mW min	N/A	N/A	N/A	20 mW min	80 mW min
	Measured:	121 mW	80 mW	N/A	N/A	N/A	121 mW	121 mW
Tone Stability	Specification:	N/A	N/A	± 0.5%	± 0.5%	± 0.5%	N/A	N/A
	*Requested Limit:	N/A	N/A	± 0.5%	± 0.5%	± 0.5%	N/A	N/A
	Measured:	N/A	N/A	0.04%	0%	0%	N/A	N/A

* Requested acceptable prototype performance.

Figure 57. DOJ Acceptance Test for Temperature

Parameter		Humidity	Altitude	Rain	Vibration
Transmitter Power Output	Specification:	1.6 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts
	* Requested Limit:	1.6 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts	3.2 - 5.0 watts
	Measured: (min)	2.3 watts	3.9 watts	3.4 watts	3.2 watts
FM Noise and Hum	Specification:	34 dB min	40 dB min	40 dB min	40 dB min
	*Requested Limit:	29 dB min	35 dB min	35 dB min	35 dB min
	Measured:	30 dB	37 dB	36 dB	35 dB
Transmitter Frequency Stability	Specification:	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	*Requested Limit:	± 0.0005% max	± 0.0005% max	± 0.0005% max	± 0.0005% max
	Measured:	0.0003%	0.0005%	0.0003%	0.0002%
Receiver Selectivity	Specification:	60 dB min	80 dB min	80 dB min	80 dB min
	*Requested Limit:	50 dB min	70 dB min	70 dB min	70 dB min
	Measured:	67 dB	70 dB	71 dB	72 dB
Receiver Sensitivity	Specification:	1.1 μv max	0.35 μv max	0.35 μv max	0.35 μv max
	*Requested Limit:	1.6 μv max	0.50 μv max	0.50 μv max	0.50 μv max
	Measured: (max)	0.80 μv	0.41 μv	0.45 μv	0.46 μv
Modulation Acceptance Bandwidth	Specification:	± 6.0 kHz min	± 7.5 kHz min	± 7.5 kHz min	± 7.5 kHz min
	*Requested Limit:	± 6.0 kHz min	± 7.5 kHz min	± 7.5 kHz min	± 7.5 kHz min
	Measured:	± 7.0 kHz	± 7.5 kHz	± 7.5 kHz	± 7.5 kHz
Audio Power Output	Specification:	20 mW max	80 mW max	80 mW max	80 mW max
	*Requested Limit:	20 mW min	80 mW min	80 mW min	80 mW min
	Measured:	80 mW	113 mW	151 mW	210 mW

* Requested acceptable prototype performance.

Figure 58. DOJ Acceptance Test for Humidity, Altitude, Rain, and Vibration

SECTION VIII.

CONCLUSIONS AND RECOMMENDATIONS

1.0 INTRODUCTION

Martin Marietta has performed the design and development of prototype models of an improved personal transceiver that is smaller in size and lighter in weight than any comparable unit on the market today. Furthermore, the transceiver modular microelectronic design is far in advance of any other equipment in the field.

The hardware developed on this contract provides the credibility that personal VHF and UHF transceivers can be built by using modular, microelectronic techniques and that a subsequent production design is feasible. During the performance of the contract, extensive design, breadboard, and experimentation efforts were performed to meet the combination of requirements that included size, weight, and electrical performance. As a result of these efforts, recommendations can be made on the features, performance specifications, and design of the production versions that are conducive to high-volume production at practical costs while having the necessary features and performance for the intended usage. These Martin Marietta recommendations and the recommendations that evolve as the result of independent Air Force and Department of Justice performance and human factors test programs should be combined to totally define the subsequent production transceivers. The following general recommendations are made:

1 The transceiver configuration consisting of an electronics unit, a detachable battery, and removable antenna should be retained.

2 The transceiver should retain the capability to be used as either a hand-held or shoulder-mount unit.

3 Modular construction should be retained for ease of maintainability.

4 Microelectronic and miniature packaging techniques should be retained. From experience obtained on the prototype program, the optimum packaging method for each functional module should be re-selected based on tradeoffs of performance, size, and cost.

5 The size and weight goals specified for the prototype transceivers should be retained for user convenience and comfort.

6 Certain performance specifications should be relaxed in order to obtain the size, weight, and cost goals.

7 On the DOJ transceivers, a single tone should be common to all channels rather than a separate tone for each channel for reduced cost, savings of volume, and reduced RFI problems involved in channel switching.

When combined for size, weight, modularity, electrical performance, and features, the specifications for the prototype transceivers exceeded the state-of-the-art techniques. The most significantly improved features that are apparent to the potential users are size, weight, and modularity. Therefore, it is recommended that these improvements take priority in the production units over additional electrical performance and features beyond what is deemed necessary for the user. Most of the goals that were not fully met in the prototype program were in some way associated with the packaging constraints and the exceedingly stringent temperature requirements. Specifically, requirements involving improved filtering (such as the receiver spurious response) and requirements requiring high battery drain (such as intermodulation attenuation and dynamic range) directly or indirectly have significant impact on volume needs. Therefore, tradeoffs were continually made during the course of the program to obtain the best overall results.

The temperature specification of -40°C to +50°C and the sound pressure level (SPL) of 105 dB caused the most design difficulty and are considered an overdesign for production units on the basis of production costs (approximately $150 for crystals) and volumetric efficiency, respectively.

2.0 ELECTRICAL SPECIFICATIONS

Most of the electrical specifications, although difficult to meet, are reasonable when considering that the prototype transceiver was to be designed for the ultimate desirable performance. However, actual implementation indicated that some of the requirements were not compatible with reasonable unit cost, unit size, and acceptable battery life. Consequently, priorities can now be established designating the performance criteria that absolutely should be met to provide operational requirements and the parameters that should be relaxed to practical limits in order to meet the higher priority physical characteristics.

Table V contains the recommended electrical specifications for a cost-effective production version of a personal portable transceiver that consists of a practical tradeoff between desirable electrical performance and physical criteria while providing the functional and

TABLE V.

Recommended Production Specifications

Parameter	Contract Specification	Recommended Specification
Receiver Spurious Attenuation	85 dB, min	70 dB, min
Intermodulation Attenuation	65 dB, min	55 dB, min
Dynamic Range	80 dB, min	75 dB, min
Selectivity	80 dB, min	75 dB, min
Modulation Acceptance Bandwidth	±7.5 kHz	±7.5 kHz
Quieting Sensitivity	0.35 µv	0.35 µv (VHF) 0.50 µv (UHF)
LO Frequency Stability	±0.0005%, max	±0.0005%
Acoustic Sound Pressure Level	105 dB, min	Delete
Audio Power Output	80 mW, max	125 mW, min
Audio Distortion and Noise	5%, max 50 dB, min	5%, max 50 dB, min
Audio Response, Receiver	+1, -3 dB	+2, -6 dB
Transmitter Frequency Stability	±0.0005%, max	±0.0005%
Audio Distortion, Transmitter	5%, max	5%, max
Audio Response, Transmitter	+1, -3 dB	+1, -3 dB
FM Noise and Hum	40 dB, min	40 dB, min
Deviation Limiter	5 kHz, max	5 kHz, max
AM Hum and Noise	35 dB, max	35 dB, max
RF Power Output	4 W, ±1 dB	4 W, ±1 dB
Temperature Range	-40°C to +50°C	-30°C to +50°C
Tone Squelch Sensitivity Turn-on Time	≤ 6 dB ≤ 250 msec	≤ 6 dB ≤ 250 msec
Tone Gen Stability Turn-on Time	±0.5% ≤ 50 msec	±0.5% ≤ 50 msec

operational requirements of the user. The recommended specifications either meet or exceed EIA specifications and FCC requirements for type acceptance. Some of the recommended specification limits exceed the performance measured on the prototype transceivers. By analyzing the results obtained on the prototype transceivers, it is projected that specific improvements can be incorporated into the partitioning and packaging of the modules and by relaxing certain "over-specified" parameters, that the production transceivers will meet or exceed the recommended specifications.

The receiver sensitivity and transmitter power output are the most important electrical functional parameters and are maintained at 0.35 microvolts and 4 watts, respectively, for VHF units. A 0.5-microvolt sensitivity is recommended for UHF units due to the extreme difficulty in obtaining better performance within the size constraints at UHF frequencies due to difficulty in obtaining adequate RF isolation and ground plane. A UHF transmitter power output of 4 watts can be readily obtained and should be specified for the production units.

The recommended receiver spurious attenuations limit is 70 dB, minimum. Improved performance over that of the prototype unit can be achieved by relaxing the low temperature specification limit to -30°C instead of -40°C and by increasing the allocated volume for associated circuits for additional filtering. The volume allocation can be increased by decreasing the size of the receiver IF and audio modules.

The intermodulation attenuation and dynamic range limits represent an optimum tradeoff between performance and battery drain.

The recommended selectivity limit of 75 dB is identical to the dynamic range limit since the EIA method of measuring selectivity results in the usable, or net, receiver selectivity being limited by the dynamic range of the receiver.

A sound pressure level (SPL) of 105 dB minimum as specified in the contract can only be obtained with one to two watts of audio power into a speaker at least 2-1/4 inches in diameter (or larger) or with a low-power transducer housed in a large acoustical cavity. Neither solution is practical for a small (18 to 19 cubic inch) transceiver. It is recommended that sound pressure level be deleted as a specification item, since the important factor is the apparent sound level detected by the ear, whereas a measure of SPL gives the false impression of loudness. Transducers are inherently poor in low-frequency response, and sound "tinny" to the ear, whereas PM speakers have a response that is more symmetrical (upper and lower frequency cutoff limits) to human speech and are more intelligible and pleasing to the ear. Consequently, for a given SPL, the apparent loudness and fidelity of a PM speaker exceeds that of a transducer. Therefore, apparent loudness is a function of the audio power output, the net audio response of the transmitter and receiver circuits, and the response of the audio reproduction device used. Specifying the audio power output and the net audio frequency response is deemed adequate to characterize the audio output.

The original specification of 80 milliwatts maximum for audio power output was made on the assumption that it would be feasible to package a highly efficient, high SPL transducer in the small confines of a miniature personal handheld transceiver; however, this is not feasible with state-of-the-art transducers. In order to provide adequate loudness and use minimum volume with a small 1-3/4 inch PM speaker or any speaker of this diameter, a minimum of 80 milliwatts of audio output is required to obtain acceptable loudness. However, an audio power output of 125 milliwatts minimum is recommended to assure sufficient loudness without causing excessive battery drain. Approximately 92 to 96 dB of SPL can be expected for 125 milliwatts of output power to the speaker.

An operating temperature range of -30°C to +50°C is recommended as compared to the prototype specification of -40°C to +50°C. The technical problem is one of consistently maintaining oscillator frequency stability within ±5 ppm over the temperature range in high-volume production. The frequency shift of the crystal over the range of -30°C to -40°C is excessive (on the order of 10 ppm). The shift for this 10°C range is as great as the shift over the entire -30°C to +50°C range. To accommodate a low-temperature limit of -40°C requires expensive, compensated, high tolerance crystals and highly complex oscillator circuits that result in considerably more cost than involved in a -30°C limit. The recommended temperature range is comensurate with the best personal transceivers available and practical usage.

The recommended specification for the receiver audio response (+2, -6 dB) is consistent with production tolerances and adequate operation. More stringent limits on the audio response would be masked by the poorer response of the speaker, particularly at the lower frequencies. Therefore, the recommended limits are economically and functionally practical.

The recommended specifications for the production transceiver that remain the same as those for the prototype units are:

1 Modulation acceptance bandwidth.

2 LO frequency stability.

3 Audio distortion and noise.

4 Transmitter frequency stability.

5 Audio distortion, transmitter.

6 Audio response, transmitter.

7 FM hum and noise.

8 Deviation limiting.

9 AM hum and noise.

10 RF power output.

11 Tone squelch.

12 Tone generation.

A nine-hour life requirement was specified for the prototype batteries, using a duty factor of 5-75-20 (transmit-receive-standby) for the DOJ and 10-10-80 for the AF units. The measured life of the DOJ units was approximately 6.5 hours at the required duty factor, which corresponds to a 9-hour life at a 4-4-92 duty factor. The AF batteries measured a 7.5-hour life at a 10-10-80 duty factor and a 9-hour life at a duty factor of 7-7-86.

The battery requirements were evaluated as late in the program as feasible, to obtain as much current drain data as possible on completed circuits and still allow time to design, fabricate, and assemble the battery packs. The total current drain requirements were projected by using actual data on completed circuits and estimating the drain on the circuits not completed. This data was used to determine the total energy requirement for each transceiver, based on the appropriate duty factor. Applicable nickel-cadmium batteries were procured from several vendors and tested. Among those that met the minimum requirements, the batteries having the highest capacity were selected. A battery case was then designed to accommodate the selected battery and the deliverable units were fabricated and assembled.

Later in the program, the receiver current drain had to be increased to maintain proper operation at -40°C, and the realizable transmitter efficiency fell slightly below the design goal. As a result, the battery pack will provide the performance as stated earlier in this section. The lower-than-rated performance was a tradeoff with overall transceiver size, transceiver electrical performance, and battery capacity.

The life of the production battery packs are expected to exceed the performance of the prototype units as a result of the following:

1 Selection of batteries with slightly larger ampere-hour capacity.

2 Lower receiver current drain possible with a -30° to +50°C temperature range rather than a -40°C to +50°C range.

3 Use of newer and more efficient power transistors in the transmitter that will be available in the production time frame.

The duty factors specified for the prototype units should be further evaluated by the Air Force and Department of Justice to determine if the requirements are realistic. Specifically, a 75 percent receive factor does not seem realistic for a unit requiring tone squelch (i.e., why have a squelch that is actuated 75 percent, squelched 15 percent and turned off 5 percent of the time).

Significant effort is being concentrated on obtaining minimum transceiver size and weight by developing microcircuits, miniature components, low-current circuits, etc. A battery pack that is 25 percent over capacity can add more size and weight to the transceiver than can be eliminated by miniature package techniques, etc.

The battery volume can be reduced by approximately 20 percent (or the capacity increased while maintaining the prototype size) by having a custom battery developed by a battery manufacturer. Furthermore, a custom battery pack would probably be lower in cost in high-volume production than one of the prototype configuration that uses standard, off-the-shelf batteries. It is also recommended that low-capacity and high-capacity batteries be built in production. The low-capacity battery would be appropriate for short-period, handheld applications while the larger unit for standard 9-hour usage when mounted on the belt.

3.0 MECHANICAL SPECIFICATIONS

The following specific recommendations relating to the mechanical design are presented for incorporation in the production transceivers:

1 The basic appearance and configuration of the prototype transceivers should be retained.

2 The electronics assembly housing should be die cast, made of aluminum, and have a removable front and rear cover.

3 The battery assembly should use an injection molded, Lexan housing and cover, and stamped forgings should be used on the battery connector parts rather than mechanical parts.

4 A standard screw-type antenna connector is recommended. Use of this type antenna connector will not only reduce the cost of this item by approximately one-sixth, but also will result in a more rugged unit. The rationale of quick disconnect (to prevent the transceiver from being pulled off the wearer by the antenna) must be weighed against increased cost, reduced

operating capability when the antenna is pulled off, and possible loss of antennas due to accidents and mishandling in the field.

5 Robinson-Nugent sockets should be replaced with Berg Minisert sockets to greatly increase the reliability of the substrate-to-motherboard interconnections. Also, lead-frame-type flat pins should be used on the substrates instead of the round machined pins presently used. This will effect a substantial cost savings in production.

6 Internal construction consisting of a single motherboard with plug-in and solder-in modules and subassemblies should be retained.

7 The press-to-talk switch design should be retained.

8 The channel selector switch wiring to the motherboard should consist of a flexible printed wiring harness.

9 Volume and squelch controls that can be installed from the inside of the electronics housing and can be interconnected to the motherboard with a flexible harness should be used. Controls that install from the outside of the housing, as specified for the prototype units, are not conducive to ease of maintenance or disassembly.

Table VI lists the recommended packaging method for each module and subassembly to be used in the production transceivers. The recommended methods have been optimized based on tradeoffs involving cost, performance, and size.

TABLE VI.

Recommended Module Package Methods

Part Number	Description	Prototype Packaging Method	Recommended Production Packaging Method
H006	Audio, Receiver	Hybrid	IC and/or LSI
H011	Oscillator	Hybrid	Hybrid
H024	Modulator	Hybrid	IC/Hybrid
H039	Multiplier-Transmitter	Hybrid	Hybrid
H051	UHF Tripler	Hybrid	Hybrid
H065	Filter-Audio	Hybrid	Hybrid
H105	Amplifier, IF	Hybrid	IC
H113	Regulator, Switch	Hybrid	Hybrid
62500028	Generator, Tone	Hybrid/Discrete	Hybrid/Discrete
62500040, 41, 42	Filter, Receiver Antenna	Subassembly	Subassembly
62500045	Discriminator	Discrete	Discrete
62500085	Filter, Low-Pass (VHF)	Discrete	Discrete
62500155	Power Amplifier (UHF)	Discrete	Discrete
62500107	Frontend (UHF)	Discrete	Discrete
H078	Frontend (AF-VHF)	Hybrid	Hybrid/Discrete
62500145	Frontend (DOJ-VHF)	Discrete	Hybrid/Discrete
62500086	Oscillator Filter (VHF)	Discrete	Hybrid
62500087	Oscillator Filter (UHF)	Discrete	Hybrid
62500098	Power Amplifier (VHF)	Discrete	Discrete or Hybrid
62500054	Network, Impedance Matching	Discrete	Eliminated
62525402	Filter, Crystal Bandpass	Discrete	Discrete - to contain impedance matching to input and output

IC - Conventional Integrated Circuit
LSI - Large-Scale Integrated Circuit
Hybrid - Thick-Film Hybrid Substrate Module
Discrete - PC Board Module with Miniature Discrete Components
Subassembly - Subassembly Consisting of Miniature Components and Hardware

APPENDIX A

CONFIGURATION/SHAPE FACTOR EVALUATION

1.0 SHAPE FACTOR

The personal nature of the transceiver makes it shape an important factor in its convenience of use. As a result of additional tests with transceiver mockups and investigation of operational factors, it appeared that the transceiver shape given in the contract proposal should be slightly modified.

Operational characteristics of small transceivers were studied by observing Orlando, Florida police officers in their daily use of shoulder-mounted speaker/antenna units. The electronics and battery packages are belt mounted. Most officers observed normally removed the speaker unit from the shoulder and operated it in a hand-held position. Furthermore, consultation with professional law enforcement personnel revealed that a universal capability of carrying the transceiver would be desirable. It should be adaptable to shoulder use, being hand-held, or carried in the pocket of a uniform or civilian clothes when on special assignments. The 3-inch wide proposed configuration was found to be too wide for convenient one-hand operation. Tests with the mockup revealed that people with small hands and with gloves would find it inconvenient and uncomfortable to grasp firmly. It was also found to be too wide for easy pocket use either in shirtfront or in inside uniform pockets. Investigation showed that a 2.625-inch width is comfortable for hand-held use, permits easy thumb manipulation of the press-to-talk switch, and fits very well into shirt front and inside uniform pockets. When both the narrow and wide transceiver mockups were tested in the wear tests, the narrow transceiver was also found to be more comfortable when worn on the shoulder. The narrow width permitted free movement of the arm, greater flexibility of locating the unit on the shoulder, better balance, and better conformance to the physiological characteristics of the shoulder area. A summary of features compared for the two widths is given in Table A-I.

As a result of this human engineering study, consultation with law enforcement personnel, and with the test program, the narrow, longer shape of the transceiver was recommended by Martin Marietta Corporation Human Engineering.

2.0 SHIRT ATTACHMENT TEST

A 3 X 5.1 X 1 inch model of the personal transceiver was used for this test. The model was weighted to simulate the weight of the actual unit described in the proposal. The electronics housing, loudspeaker-microphone unit, and antenna assembly weighs 10 ounces while the battery assembly weighs 8.5 ounces.

A commercial grade of 3/4-inch wide black Velcro pile material was applied to the back of the model. The Velcro pile material was cemented to the back of the electronics housing only in parallel, horizontal rows by using epoxy patch kit adhesive. The Velcro hook material was sewn to

TABLE A-I.

Comparison of Narrow and Wide Transceiver Case

	Narrow Case	Wide Case
More comfortable on shoulder mount (DOJ requirement)	X	
Easier supported on shoulder	X	
Permits greater flexibility to shoulder and arm when shoulder mounted	X	
Fits better in average uniform pocket	X	
Fits better in average hand	X	
Permits better placement of operating controls	EQUAL	EQUAL
Best configuration for a complete self-contained, hand-held radio (AF requirement)	X	
Allows better placement of components		X
More compatible with batteries of standard size and shape	X	
Stronger and lighter design of case	EQUAL	EQUAL
Convenient to use when wearing gloves	X	

Of the 11 features forming the basis of this comparison, 8 favored the narrow case width, one favored the wide case width, and two were judged equally as good for each case width.

to the upper left front shoulder area of a khaki Army shirt of summer weight. The Velcro material was positioned on the shirt to locate the transceiver in the position shown in Figure A-1.

On July 13, 1971, the wearer put on the shirt and installed the transceiver by using a simple direct push to engage the Velcro hook and pile material. Subsequent to this single application of the transceiver, it was not removed and no attempt was made to replace or reposition it or to put it back onto the shoulder in any way during the entire test period, which covered a period of one week. During the first hour that the wearer wore the transceiver, the channel select knob was moved 20 times while the volume control and squelch control knobs were both moved 10 times each. Also, during this first hour, a 15-minute exercise program was performed. This exercise program is described in a book titled, "Royal Canadian Air Force Exercise Plans for Physical Fitness". The exercise plan followed is shown on pages 72 and 73 of this book. Level C on page 72 was the exercise level performed. By examining the exercises performed, there are several times (particularly in exercise 3 and 4) where the wearer is facing the floor and the tendency is for the transceiver to fall away from the shirt. However, there was no loosening to the attachment of the transceiver to the shirt during the exercise period. During the period when running was performed, the transceiver bounced rather hard against the chest area. This was quite annoying but did not result in any loosening of the Velcro. Following the performance of the exercise period, a photograph was taken of the transceiver and then the shirt was removed with the transceiver intact and the shirt was buttoned on a hanger. During the following four days of the test period, the transceiver and shirt were left on the hanger inside an automobile that was driven approximately 200 miles during this period. On the fourth day of the test program, the shirt and transceiver combination were once again put on. Following this, approximately four hours of normal activities were performed (such as driving the car, getting in and out of the car, operating the car radio, operating another portable transceiver in the car, simulated operation of the portable transceiver); following this 4-hour test period, the exercise program was once again performed. The transceiver and shirt combination were then returned to the coat hanger and hung in the automobile without any attempt to replace the transceiver onto the shirt. On the seventh day of the test period, the transceiver and shirt combination were worn again for a period of three hours, during which the exercise program was once again performed. The car was driven approximately 30 miles, the wearer walked, and ran up and down stairs, then performed normal office activities for the remainder of the test period. At the end of the test period, there was no visible loosening of the transceiver from the shirt. Almost all of the Velcro material that had been engaged at the beginning of the test was still engaged and it is the wearer's opinion that this kind of activity could go on for a long time without the transceiver falling off.

Next, the force required to "peel" the transceiver off the shirt was measured by using a Hunter spring gauge. When a pure tension load was applied to the transceiver speaker enclosure, gradually increasing

Figure A-1. Wide Transceiver Model Using Shirt Attachment the load until the transceiver peeled off the shirt, the average load was 2-3/4 pounds. When the tension load was applied to the base of the antenna, the average load was 1-3/4 pounds.

These tests indicate that the Velcro hook and pile material is completely adequate for attachment of this transceiver to the shoulder area of a police officer's uniform as described in the proposal. Based on the low cost, simplicity of attachment, ease of attachment, and comfort to the user, it would appear that this material is better for a police officer than either a strap or a hook as described in the proposal.

As a result of this test, it appears that the personal transceiver is an uncomfortable device to wear when attached to the shirt in the position shown in the proposal as Configuration A. The primary reason for this discomfort is the poor support provided by the shirt. After wearing the unit continuously for a period of approximately three hours, there was some pain and muscular discomfort in the area of the right rear of the neck; there was considerable chafing of the skin under the arm and also on the right side of the neck and the radio was no longer in the shoulder position shown in the proposal. The radio would pull the shirttail out and slide forward on the wearer's chest to a lower position than that shown in the proposal. After evaluation of the test results, it was the conclusion of the wearer, human engineering, and program manager that more adequate means of mounting the unit to distribute the weight comfortably over the shoulder should be determined.

3.0 SHOULDER MOUNTING ACCESSORIES

Preliminary tests were performed on methods of mounting the transceiver. The first series of tests were performed on mounting the transceiver directly on the shirt as described earlier. The methods tested consisted of attaching it to the epaulets or by means of Velcro strips on the shirt front and on the transceiver. These were found to be unsatisfactory because the weight of the transceiver pulls the shirt out of shape and is transferred by the shirt which exerts pressures on the neck and under the armpit of the user. This is especially annoying when the user has to bend down, run, jump, or perform other activities. It was concluded that a shoulder mounting accessory was needed to provide a firmer attachment method, distribute the weight over a wider area of the body, and prevent slapping of the unit when running. Although a family of mounting provisions such as harnesses, belts, etc., is possible, a more practical method consists of a U-shaped semi-rigid harness shaped to the shoulder, which holds the transceiver firmly to the shoulder and attaches loosely to the shirt to prevent its slippage. The weight is spread over the entire supporting shoulder and not concentrated in the restricted sensitive areas as when shirt-mounted. Use of straps and belts around the body were rejected due to the ability of an assailant to use them as an aid in incapacitating him.

As a result of this preliminary study, four shoulder mounting accessories were constructed for evaluation. Transceiver models that simulated the external configuration, weight, and center of gravity of the live units were attached to the mounts. Wear tests of these types of accessories are described in the following sections.

4.0 WEAR TEST - PLASTIC SHOULDER MOUNT ACCESSORY

The plastic mount (Figure A-2) was fitted with an area of Velcro (approximately 3 X 3 inches) on the underside for attachment to the top of the left shoulder and a 3 X 4-inch area to the lower front for attaching the transceiver model. Nine square inches of mating Velcro hook material was attached to the shoulder of a medium weight summer shirt. The attachment was positioned on the top of the shoulder from the edge to 3.5 inches inboard on the wearer. The transceiver model was positioned 2-3/4 inches above the shirt pocket providing unhampered access and extended approximately one inch above the shoulder, which positioned the speaker section close to the ear without touching the head (Figure A-3 and A-4). The weight of the transceiver model including the carrying attachment was 21.8 ounces.

Tests were commenced at 10 AM on October 26, 1971 with the narrow configuration. Two hours were spent in general activities involving sitting, walking, and simulating operation of the on-off switch and volume control, squelch, and push-to-talk switches. The following thirty minutes involved entering, leaving, and driving a car and simulating operation of the unit. The car had a 4-speed gear shift that caused the wearer/driver to move almost continuously while driving within the greater Orlando area. General activities were resumed for the next hour but included were 12 push ups. The next 2-1/2 hours were occupied with performing activities that involved sitting and standing while bending over slightly 25 percent of the time and performing some physical exertion.

The unit was comfortable during the initial portion of the tests where little physical activity or unusual work was involved. Since the carrying device was essentially rigid, it would slide slightly forward when bending forward and would not return to its original location when the wearer returned to his exact position. As activity increased, this sliding forward characteristic became an annoying feature since the wearer could gradually forget about the units' existence until this happened. After approximately four hours, a sore spot was noticeable at the top outer edge of the shoulder where the carrying device rubbed when bending forward. At this time, the stiff plastic device did not feel comfortable against the collar bone, which might have been alleviated by a slightly narrower width or some form of padding under the device. The test was concluded at six hours due to discomfort of the wearer.

There were no restrictions to the simulated operation of the unit and operating the unit while attached to the shoulder did not seem awkward after wearing and operating it for a short time. There was complete ease of movement except when bending over in a forward direction or when

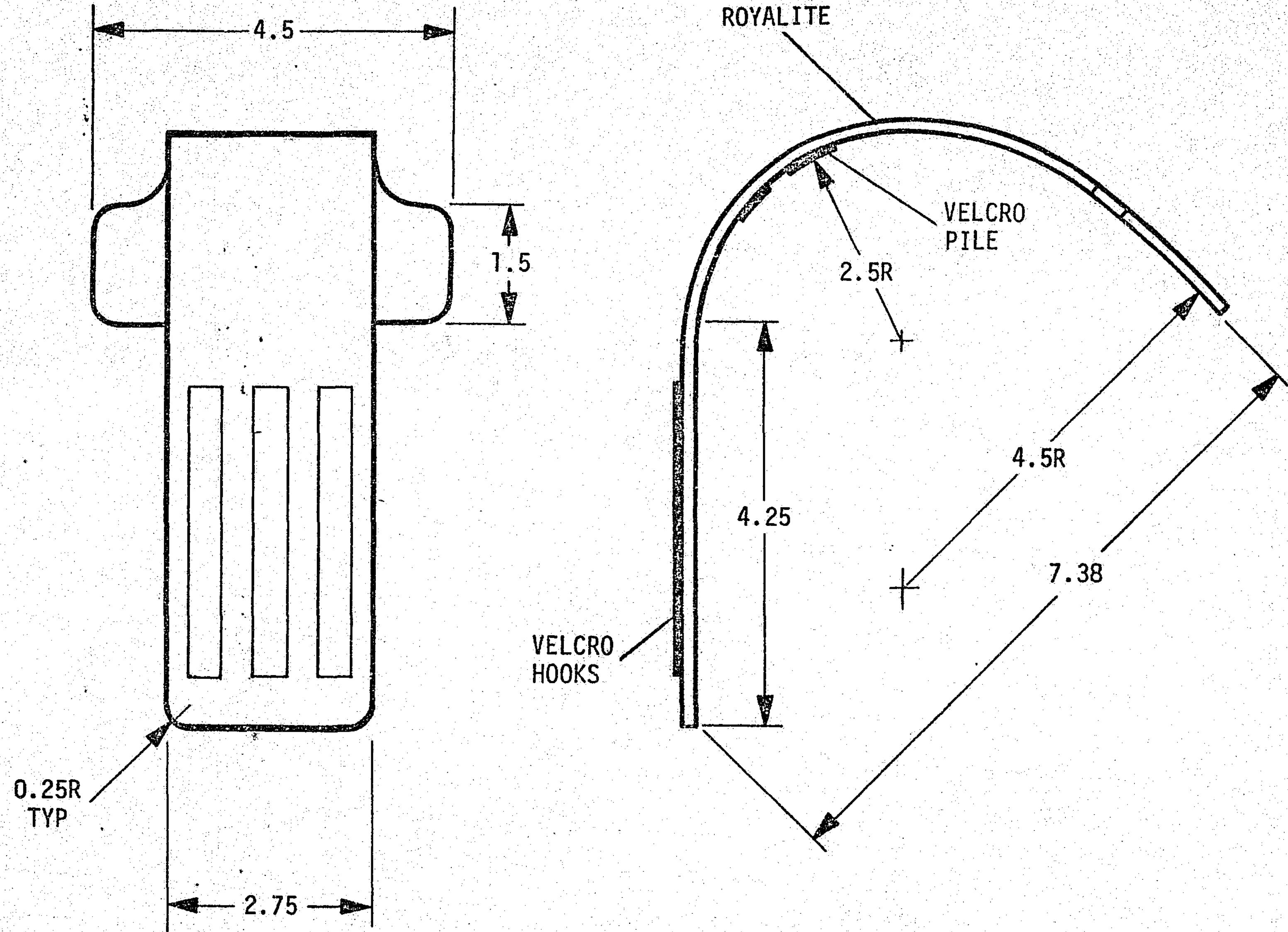

Figure A-2. Plastic Mounting Accessory

Figure A-3. Front View of Narrow Transceiver Model with Plastic Mount

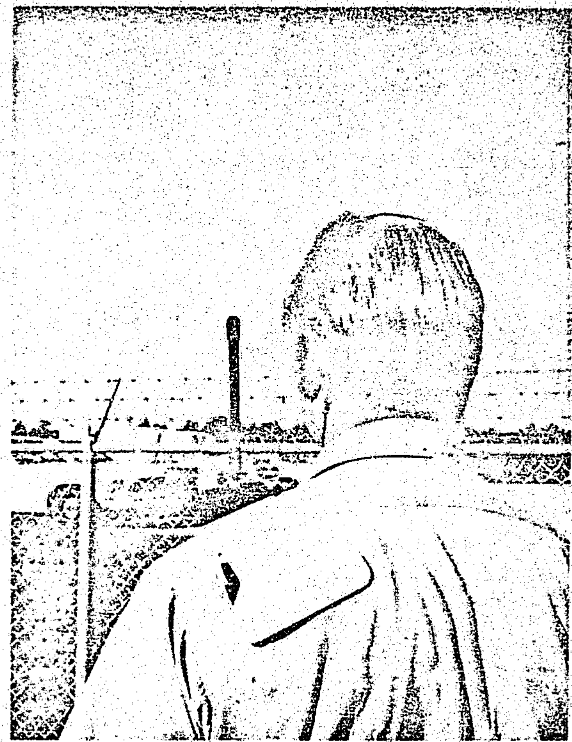

Figure A-4. Rear View of Narrow Transceiver Model with Plastic Mount

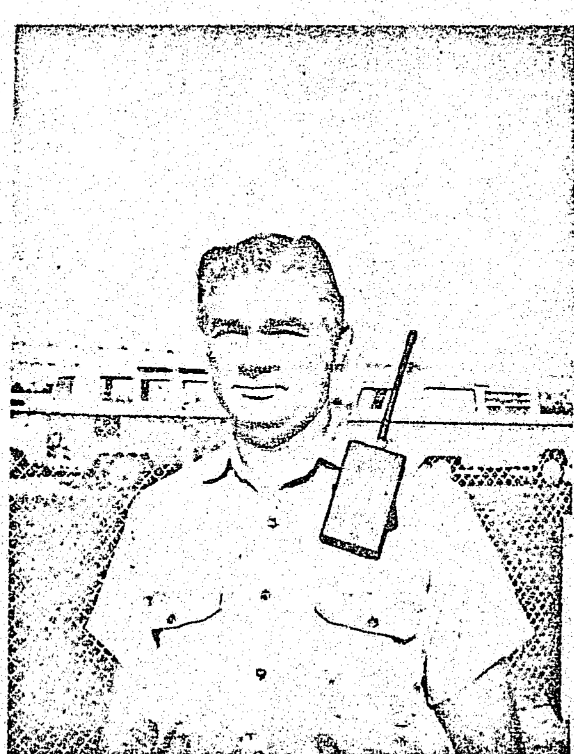

Figure A-5. Front View of Wide Transceiver Model with Plastic Mount the arms were completely outstretched in a forward direction while trying to perform some activity. In the former case, it was more a case of discomfort when the carrying device slipped forward rather than a restriction of movement.

The transceiver was retained by the Velcro during the whole 6-hour test. The test indicated that Velcro is a good method for attaching the model to a mount.

The plastic carrying device concentrated the weight on the shoulder and at the lower front where the transceiver was attached. This was mainly due to the fact that the device did not conform snugly to the back and little pressure was exerted there. A more flexible, tighter fitting, and softer cushioned device seemed more desirable.

At the end of the test, the 3-inch wide transceiver model was substituted for the 2.625-inch unit to determine any difference in restriction of movement or comfort (Figure A-5). There was no noticeable distribution of weight difference between the two units. The only restriction to the user in moving about was due to the width of the unit. The mount was so wide and rigid that little repositioning or shaping for comfort was possible. The mount was too wide to fit between the edge of the shoulder and the collar bone, which was the most comfortable position for the wearer. It was obvious that a narrower mount and transducer would permit greater individual user positioning and arm and body flexion.

5.0 WEAR TEST - NYLON AND STEEL SHOULDER MOUNT ACCESSORY

The transceiver and the nylon and steel accessory (Figure A-6) were attached to the wearer by means of Velcro hook material that was sewn to the upper left shoulder area of a khaki army shirt of summer weight. Five and one half square inches of Velcro were used on the shirt. The vertical position of the transceiver was high enough so that the left front shirt pocket was readily accessible, the speaker was close to the wearer's ear, and the unit did not touch the wearer's face during normal activities. The transceiver lateral position on the shoulder was such that the outer edge of the transceiver was coincident with the interception of the shoulder muscle and the chest wall, or about 6 inches from the center line of the chest front (Figures A-7 and A-8). The actual total weight of the transceiver dummy and shoulder mount accessory used in this test was 23.6 ounces.

On October 25, 1971, the wearer put on the shirt and installed the transceiver by using a direct push onto the shoulder to engage the Velcro hook and pile material. Following this, a 15-minute exercise program was performed. This exercise program is described in a book titled "Royal Canadian Air Force Exercise Plan for Physical Fitness." The exercise plan is shown on pages 72 and 73 of this book. Level C on page 72 was the exercise level performed. While performing exercise 2 (situps), the

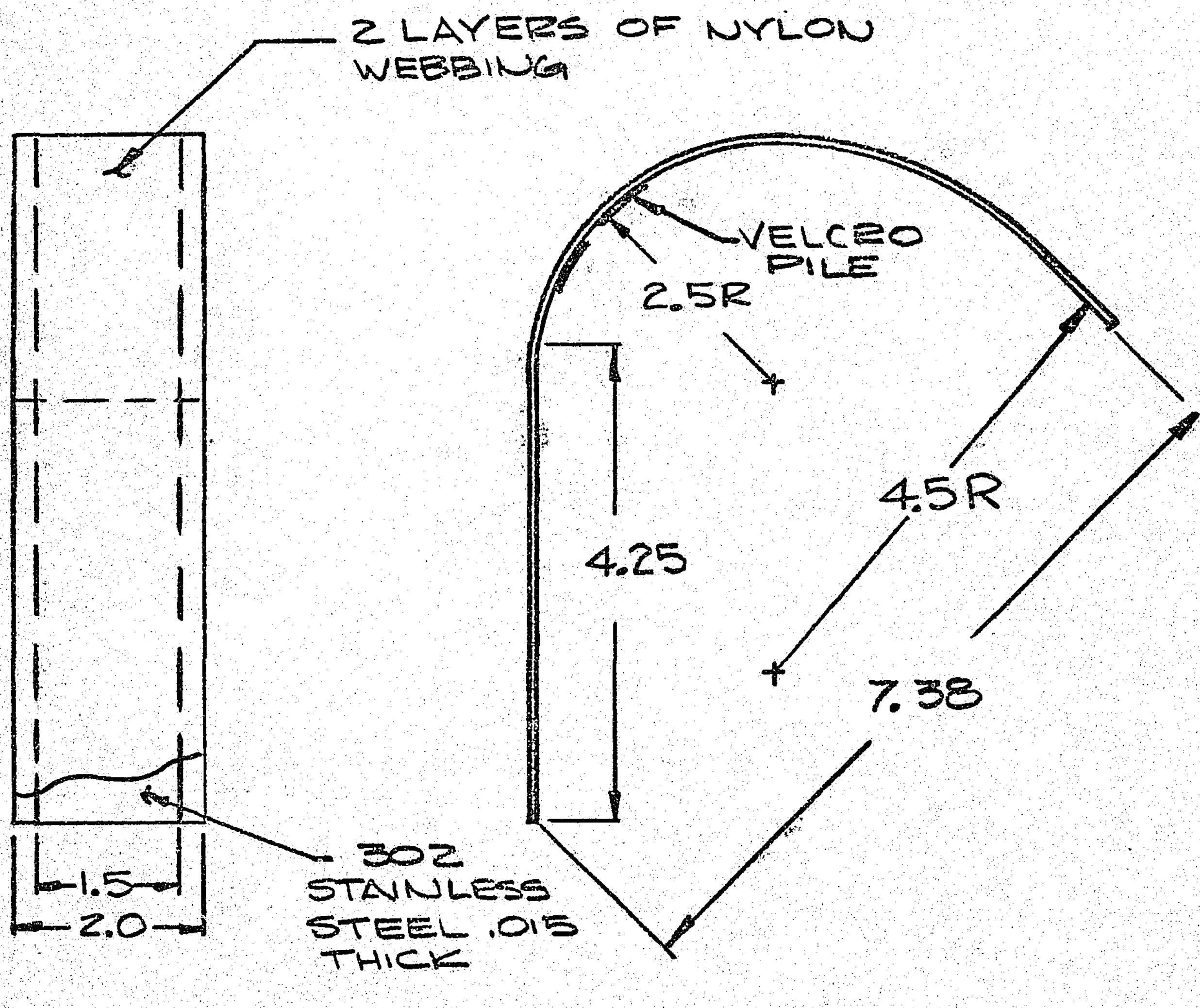

Figure A-6. Nylon/Steel Mounting Accessory

Figure A-7. Front View of Narrow Transceiver Model with Nylon/Steel Mount

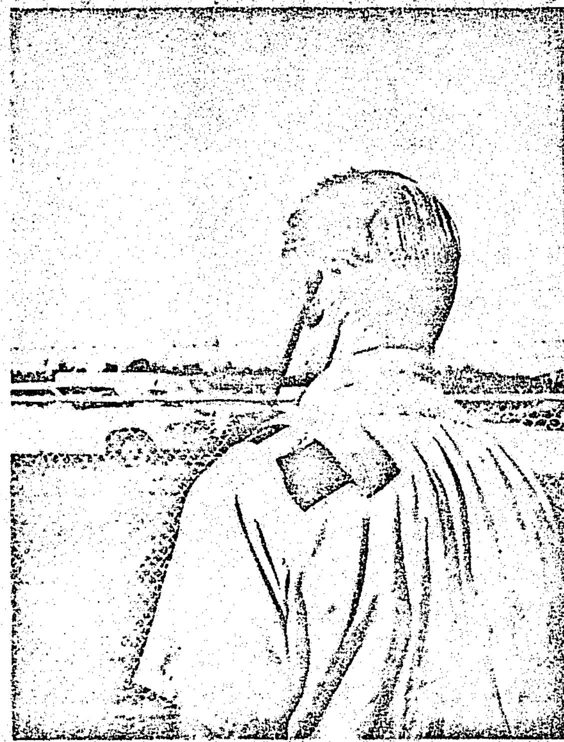

Figure A-8. Rear View of Narrow Transceiver Model with Nylon/Steel Mount

Figure A-9. Front View of Wide Transceiver Model with Nylon/Steel Mount transceiver slid sideways on the wearer's chest and became detached from the shirt. Upon completion of exercise 2, the transceiver was once again located on the shoulder and the subsequent exercises were performed without any further need for re-attachment to the shirt. It is significant to note here that during exercise 3 and 4 where the wearer previously had problems with the transceiver falling away from the chest carrying the shirt with it that in the case of the nylon and steel shoulder mount accessory, this falling away was not a problem. Also, the previously encountered bouncing of the radio on the chest area was not a problem during the running exercise. Subsequent to this exercise program, the radio was not removed and no attempt was made to replace or reposition the radio or to put it back onto the shoulder in any way during the entire test period, which covered a total of 10 hours. During this test period, the wearer drove an automobile for approximately 65 miles, during which the car was entered, started, driven, and stopped at least four times. During the periods of automobile operation, activities were performed such as operating the automobile radio, operating another portable radio in the automobile, simulated operation of the transceiver, and reaching across the automobile into the glove compartment. During the remainder of the test period, the wearer was engaged in normal office or work activities such as writing, reading, answering the telephone, walking up and down stairs, consulting with designers, draftsmen, and other engineers.

During this test, fatigue was a minor problem to the wearer. This transceiver configuration and nylon and steel shoulder mount accessory was the best of any tested to date. Several times during the test period, the wearer was able to completely forget that the transceiver dummy was being worn. There were no pressure points or other abrasion points to annoy the wearer during the course of the use of this particular dummy. Normal movements and activities as described were not impaired or impeded in any way by the presence of the transceiver. The only problem occurred during the performance of situps during the exercise period when the transceiver tended to fall off the chest area. The unit was very comfortable to wear during periods of normal walking, sitting, running, operating an automobile, and other activities of this nature. The unit was judged to be in a location that would make operation of the unit simple and easy. The volume and squelch controls could be operated with either hand while the press-to-talk switch could be operated with either hand or with the jaw.

At the end of the test, the 3-inch wide transceiver model was substituted for the 2.625-inch unit to determine any difference in restriction of movement or comfort (Figure A-9). There was no noticeable distribution of weight difference between the two units. The only restriction to the user in moving about was due to the width of the unit. The mount was so wide and rigid that little repositioning or shaping for comfort was possible. The mount was too wide to fit between the edge of the shoulder and the collar bone which was the most comfortable position for the wearer. It was obvious that a narrower mount and transducer would permit greater individual user positioning and arm and body flexion.

A possible problem, which became apparent during preparation of a model for this test, is the design of this shoulder mount accessory to comfortably fit humans whose size ranges over the fifth to ninety-fifth percentile group of the population. Of special significance is the chest depth variation and the shape of the chest and shoulder in the area where the transceiver and shoulder mount rests. A 2-1/2 inch chest depth variation can be accommodated by the spring in the shoulder mount, but if the unit is designed to fit the smallest chest depth then the pressure exerted in the rear shoulder of the larger chest depth would cause discomfort. Conversely, if the spring were shaped to fit the largest chest depth comfortably, then it would be noticeably loose on the smallest chest depth. The shape of the shoulder mount was conformed to the configuration of the wearer who actually performed this test, and it was comfortable for this wearer. It is apparent that this shape may not be comfortable for all wearers.

6.0 WEAR TEST - NYLON STRAP SHOULDER MOUNT ACCESSORY

For these tests, a dummy transceiver electronics assembly and a dummy battery were utilized. The dummy transceiver electronics assembly was 2-5/8 inches wide by 1-3/16 inches thick by 4 inches high and weighed 11.4 ounces. The dummy battery was 2-5/8 inches wide by 2.8 inches high by 1.15 inches thick and weighed 9.4 ounces. These two dummies were attached to a 2.5 inch wide nylon strap, 12 inches long. The dummies were attached to the end of this strap in a manner similar to the proposed configuration, known as the alternate configuration in the proposal. It was intended to be worn across a man's shoulder (i.e., with the electronics transceiver resting on the front of the chest and the battery resting on the back of the shoulder, the center of the nylon strap being located approximately at the top of the man's shoulder). The transceiver and nylon strap shoulder mount accessory were attached to the wearer by means of Velcro hook material that was sewn onto the upper left shoulder area of a khaki Army shirt of summer weight. Hook material, approximately 6 square inches of Velcro,was sewn both to the front and back of the shirt to anchor the two ends of the nylon shoulder mount straps. The transceiver's lateral position on the shoulder was such that the vertical centerline of the transceiver was 5-1/2 inches from the vertical centerline of the chest front.

On February 5, 1972, the wearer put on the shirt and installed the transceiver, first using a push onto the electronics housing to engage the Velcro hook and pile material in the chest area and then applying pressure to the battery housing that was at the rear of the shoulder to engage the Velcro hook and pile material there. After this, an 11-minute exercise program was performed. This exercise program is described in a book titled "Royal Canadian Air Force Exercise Plan for Physical Fitness" (the exercise plan used is shown on pages 72 and 73 of this book). Level C on page 72 was the exercise level performed. During the course of the exercise program, no problems were encountered with the transceiver. The transceiver did not significantly pull the shirt away from its normal fit to the body. It was attached firmly enough so that no part of the transceiver became dislodged during the exercises and there was no interference with the usual amount of mobility required in the performance of these exercises. Following the exercise program, the transceiver was not removed from the shoulder and no attempt was made to replace or reposition the transceiver or to put it back onto the shoulder in any way during the entire test period that covered a total time of 9-1/2 hours. During the 9-1/2 hour test period, the wearer drove an automobile approximately 115 miles during which the automobile was entered, started, driven, and stopped six times. During the periods of automobile operation, activities were performed such as operating the automobile radio, operating another portable radio in the automobile, simulated operation of the transceiver, and reaching across the automobile into the glove compartment. During the remainder of the test period, the wearer was engaged in normal office and work activities such as writing, reading, answering the telephone, walking up and down stairs, etc.

During this test, the wearer's opinion was that no fatigue was caused by the presence of the transceiver dummy with the nylon belt shoulder mount accessory. This transceiver configuration was the best of any tested to date. The attachment was sufficiently firm so that the radio did not bounce against the body or shift position when the wearer was running, jumping, doing pushups, operating an automobile, or any other activities of this type. There was no interference with operation of the arms or rotation of the head or twisting of the torso in either direction, bending the body backward and forward, or tilting to the right and left. There were no annoying pressure points or abrasion points observed during the course of this test and the wearer judged that the transceiver could be operated with the right hand while wearing the transceiver on the left shoulder, and the press-to-talk switch could be operated with either hand or with the jaw.

Because of the conformal nature of the nylon belt, a transceiver that is built in this configuration could be successfully and comfortably applied to fit humans whose size ranges over the 5th to 95th percentile group of the population. Chest depth variations and shoulder shape variations should present no problem to fit or comfort of this particular transceiver configuration.

7.0 WEAR TEST - SHOULDER-MOUNTED ELECTRONICS WITH BELT-MOUNTED BATTERY

The configuration tested here was similar to proposed configuration B (Figure A-10). The dummy battery utilized in this test was 2.8 X 2.65 X 1.156 inches, weighing 9.4 ounces. It was inserted into a tight fitting leather case that had a belt loop. The case was worn on the wearer's belt and was located at a point about halfway between the front center and the wearer's left side. From the dummy battery and case, a cable was extended to the shoulder area of the wearer and attached to the bottom of a dummy transceiver electronics assembly. The dummy electronics assembly was

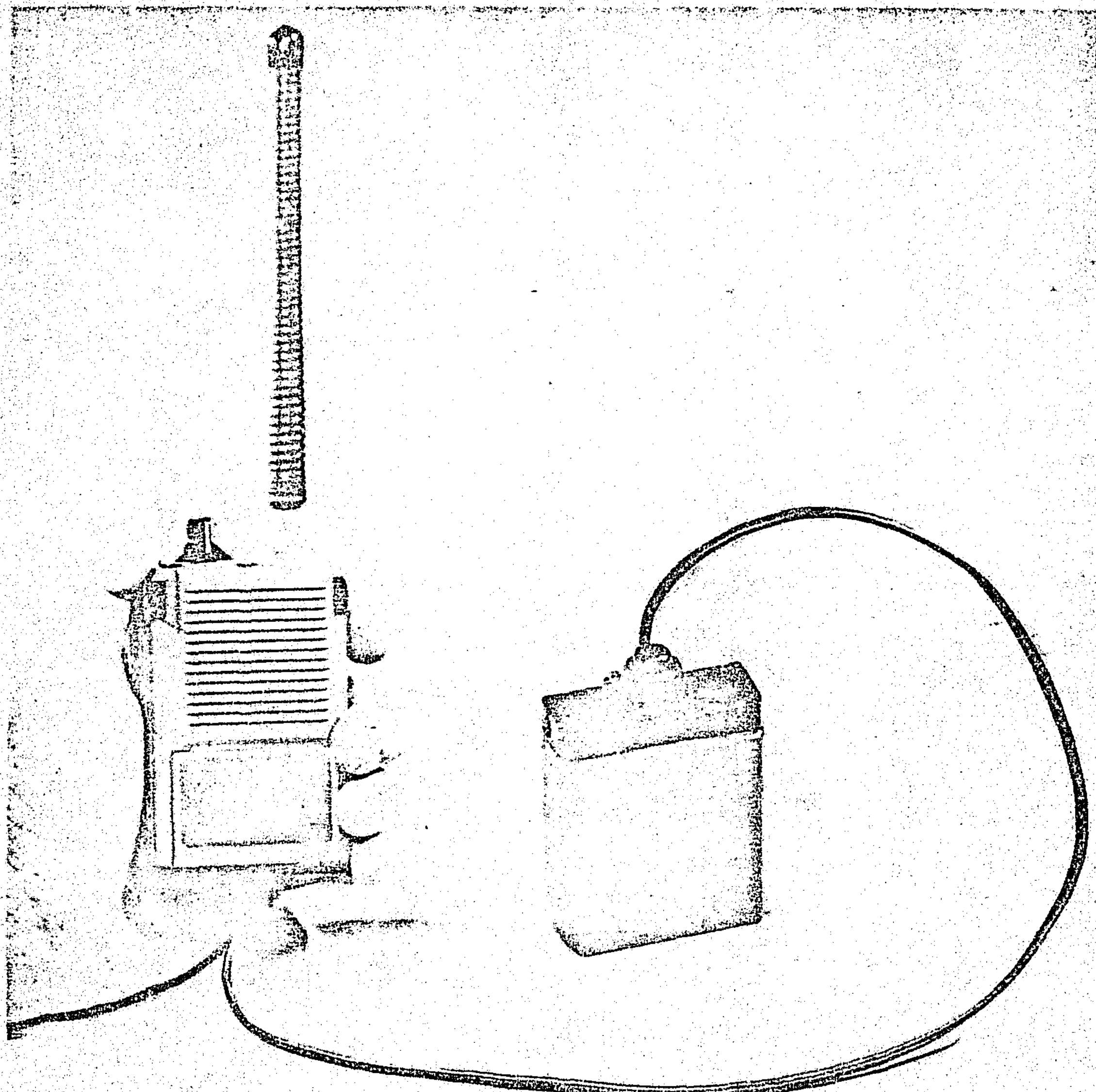

Figure A-10. Front View of Transceiver with Extender Cable for Belt-Mounted Battery

2-5/8 X 1.18 X 3-3/4 inches and weighed 11.4 ounces. The transceiver electronics dummy was attached to the wearer's shirt by means of a 2.44 X 2.0 inch area of Velcro hooks that were bonded to the back of the dummy. A 10 X 2 inch wide shoulder strap of Velcro napped loop was snapped around the epaulet of the wearer's shirt and then the transceiver Velcro hook was pressed onto this shoulder strap so that the transceiver was located on the wearer's upper left front chest cavity. The centerline of the transceiver was approximately 5 inches to the left of the wearer's chest centerline. The installation of this transceiver dummy was then very similar to that presently used by the Orlando Police Department for the Motorola transceiver (Figure A-11).

During the period from February 23 through February 25, the wearer used the shirt and transceiver described above for 6-1/2 to 8-1/2 hours per day. A typical day started with the 11-minute Royal Air Force Exercise Plan for Physical Fitness. The exercise plan shown on page 72 and 73 was used and level C was the exercise performed. While performing the exercise, no problems were encountered except the transceiver would hang down from the user's body while the wearer was doing pushups and, or course, during the pushup the transceiver would hit the floor each time the wearer touched his nose to the floor. Also, during the running period, the transceiver electronics housing did bounce on the user's chest and was somewhat uncomfortable to run with although it was judged to be not nearly so uncomfortable to run with as the test during which the entire transceiver was worn on the shoulder and attached to the shirt by Velcro. At no time during the exercise program or following the exercise program was there any tendency for the transceiver electronics or the battery to separate themselves from the wearer or become detached from the wearer. There was no attempt to replace or reposition the transceiver onto the Velcro on the shoulder during any of the test period. Following the exercise program, the wearer drove an automobile for approximately 65 miles each day during which the car was entered, started, driven, and stopped at least four times. During periods of automobile operation, activities were performed such as operating the automobile radio, operating another portable radio, simulated operation of the transceiver, and reaching across the automobile to the glove compartment. During the remainder of a typical day, the wearer was engaged in normal office activities such as writing, reading, answering telephone, walking up and down stairs, etc. During the course of this testing, fatigue was only a minor problem to the wearer. This transceiver configuration was judged to be substantially more comfortable as that configuration described as the Nylon Strap Shoulder Mount Accessory. There were no pressure points or other abrasion points to annoy the wearer during the course of the use of this particular dummy transceiver. Normal movements and activities as described were not impaired or impeded in any way by the presence of the transceiver. The only two significant problems encountered during this wear test were the tendency of the transceiver electronics unit to hang away from the upper chest during pushups and an occasional hangup of the extender cable on furniture, knobs, door handles, etc. The unit was quite comfortable to wear during periods of normal walking, sitting, running,

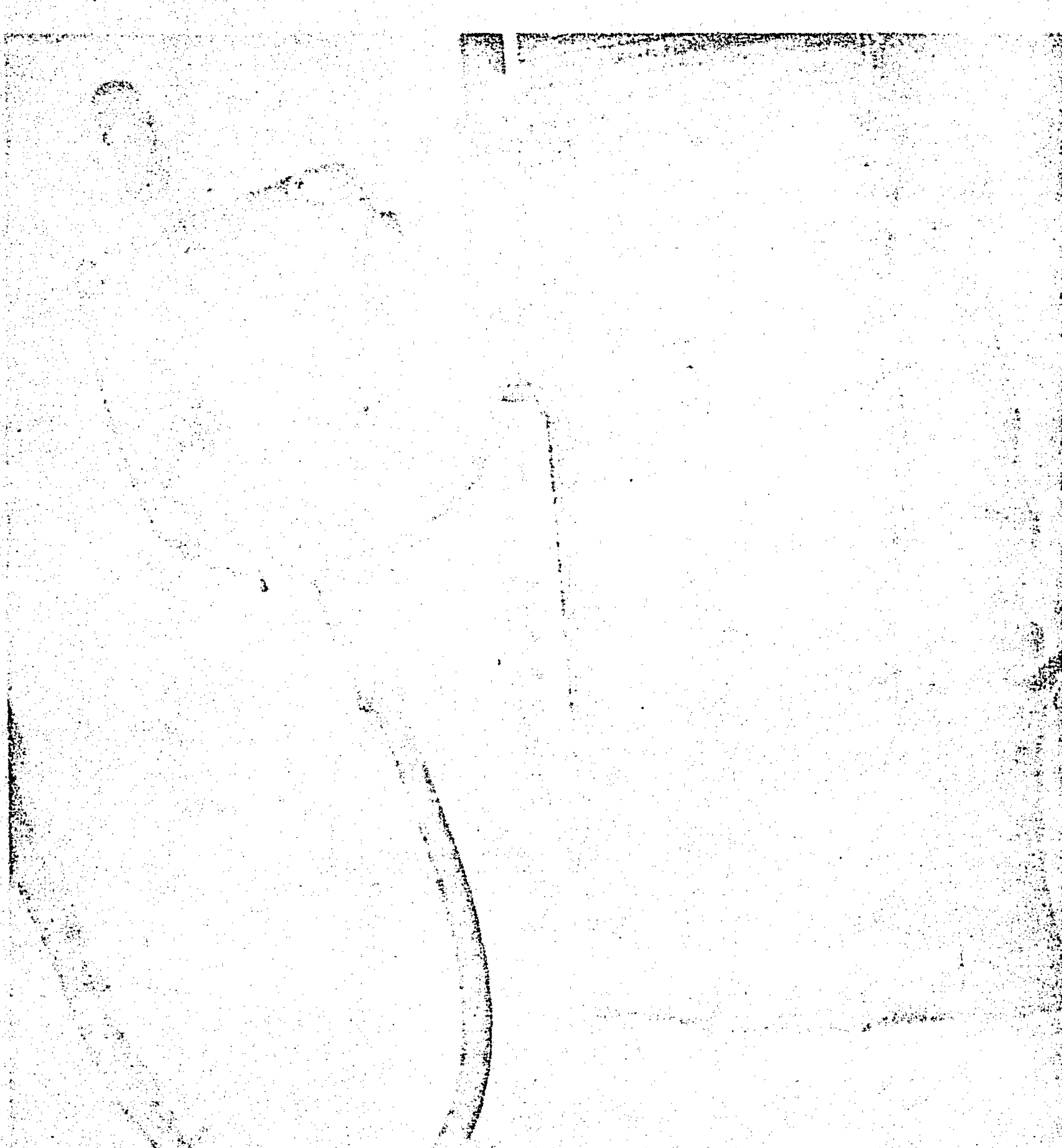

Figure A-11. Front View of Shoulder-Mounted Transceiver operating an automobile, and other activities of this nature. The unit was judged to be in a location that would make operation simple and easy; the volume and squelch controls could be operated with either hand, the channel select switch could be operated with the right hand if the unit was worn on the left shoulder, and the press-to-talk switch could be operated with either hand or with the jaw.

A production design of this configuration should attempt to solve the cable hangup problem. In an emergency, a fixed cable could result in the transceiver electronics being yanked off of the officer's shoulder if the cable becomes entangled in a door handle, door knob, or something of this nature. The transceiver electronics could also be yanked off the officer's shoulder by an assailant who merely grasps the cable. A quick disconnect, detachable connector, or breakaway cable could be used to prevent these problems.

APPENDIX B

PERSONAL TRANSCEIVER THERMAL DESIGN

1.0 INTRODUCTION

A HEATRAN thermal analysis has been performed on the personal transceiver. The overall transceiver configuration used for the analysis corresponds closely to our current concept (i.e., the basic transceiver dimensions are 1 x 2.625 x 5.79 inches, the battery is housed in a plastic case that is detachable from the electronics section, and the transducer is a 1.75-inch permanent magnet speaker). A brief summary of the configurations analyzed and results obtained is given in the following sections. Based on this thermal analysis, the following conclusion and recommendations may be made:

1 During normal operation in a 122°F ambient with either the DOJ or USAF duty cycles, the transistors will remain below their maximum reliable temperatures.

2 The USAF duty cycle results in higher temperatures than does the DOJ duty cycle.

3 During 122°F ambient normal operation, a 0.625 x 2.48 inch aluminum heat sink, with the remainder of the case being plastic, will be hot enough to burn the user (233°F). Under the same conditions, with an all-aluminum frame for the electronics section and plastic covers, the frame will reach a maximum hot spot temperature of 153°F. Therefore, the electronics section frame will be made of aluminum.

4 A thermostat that is wired to override the press-to-talk function can be set to protect the transceiver from failure due to abnormal operating conditions such as transmitting without an antenna or continuously transmitting. The thermostat setting chosen for the VHF transceiver was open at 200°F ± 8° , and close at less than 20°F below the opening temperature.

2.0 SUMMARY OF CONFIGURATIONS ANALIZED AND RESULTS OBTAINED

A. Justice Duty Cycle[1] - Normal Operation - 5/8 x 2-1/2-inch aluminum heat sink - Plastic Frame (See par. D) 122°F ambient, 122°F soaked, start at time = 0

Time	2N5946[2]	Cu[3]	2N5944	2N3571	Al. Sink
3 min. (XMIT Compl)	188°F	185°F	184	183	183
1 hr. 3 min.	206	203	201	201	201
2 hr. 3 min.	211	208	206	206	206
3 hr. 3 min.	212	210	208	208	207
4 hr. 3 min.	213	210	208	208	208
5 hr. 3 min.	213	210	208	208	208
6 hr. 3 min.	213	210	208	208	208
7 hr. 3 min.	213	210	208	208	208
8 hr. 3 min.	213	210	208	208	208

B. USAF Duty Cycle[4] - Normal Operation - 5/8 x 2-1/2-inch aluminum heat sink - Plastic Fram (See par. D) 122°F ambient, 122°F soaked, start at time = 0

Time	2N5946	Cu	2N5944	2N3571	Al. Sink
0	122	122	122	122	122
56 min. (last XMIT in first hr.)	206	203	202	201	201
116 min.	229	226	224	224	224
176 min.	236	233	231	231	231
236 min.	239	237	235	234	233
296 min.	239	236	234	234	233
356 min.	238	236	234	234	233
416 min.	238	236	234	234	233
476 min.	238	236	234	234	233
536 min.	238	236	234	234	233

Notes: 1. Justice Duty Cycle = 3 minutes continuous transmit, 45 minutes continuous receive, and 12 minutes continuous standby per hour.

2. Maximum reliable temperatures for transistors are given in paragraph E.

3. Cu = Copper between 2N5946 and thermostat.

4. U.S. Air Force Duty Cycle = 6 minutes continuous receive, followed by 30 seconds of continuous standby with the transmit and standby cycle repeated for the balance of the hour.

C. U. S. Air Force Duty Cycle - Normal Operation - 122°F ambient, all-aluminum frame with fins 122°F ambient, 122°F soaked, start at time = 0.

Time	2N5946	Cu	2N5944	2N3571	Al. Sink
0	122	122°F	122	122	122
56 min.	155	153	151	150.5	150
116 min.	158	155	153	153	153
176 min.	158	156	154	153	153
236 min.	158	156 (68°C)	154	153	153
296 min.	158	156	154	153	153
356 min.	158	156	154	153	153

Figure B-1 shows maximum temperature at various locations around the frame.

Nodes shown here were added to the program at this point during the analysis.

D. U.S. Air Force Duty Cycle - Normal Operation - all-aluminum frame with fins 95°F ambient, 95°F soaked, start at time = 0

Time	2N5946	Cu	2N5944	2N3571	Al. Frame
0	95	95°F	95	95	95
56 min.	128	126	124	124	123
116 min.	131	128	126	126	126
176 min.	131	129	127	127	126

E. Continuous transmit with no antenna - all-aluminum frame with fins

Use Texas Instruments 4BTL2-41 thermostat to limit transistor temperatures.

Drawing 6254155A shows the configuration.

1 122°F ambient, start at time = 236 min., U.S. Air Force duty cycle

Thermostat set at 252°F

Thermostat opened at 0.76 minute at 252°F.

2N5946 was at 257°F (252 limit)

2N5944 was at 240°F (350 limit)

2N3571 was at 240°F (335 limit)

2 122 °F ambient, 122°F soaked, start at time = 0

Thermostat set at 252°F

Thermostat opened in 1.14 minutes at 252°F

2N5946 was at 257°F

2N5944 was at 240°F

2N3571 was at 240°F

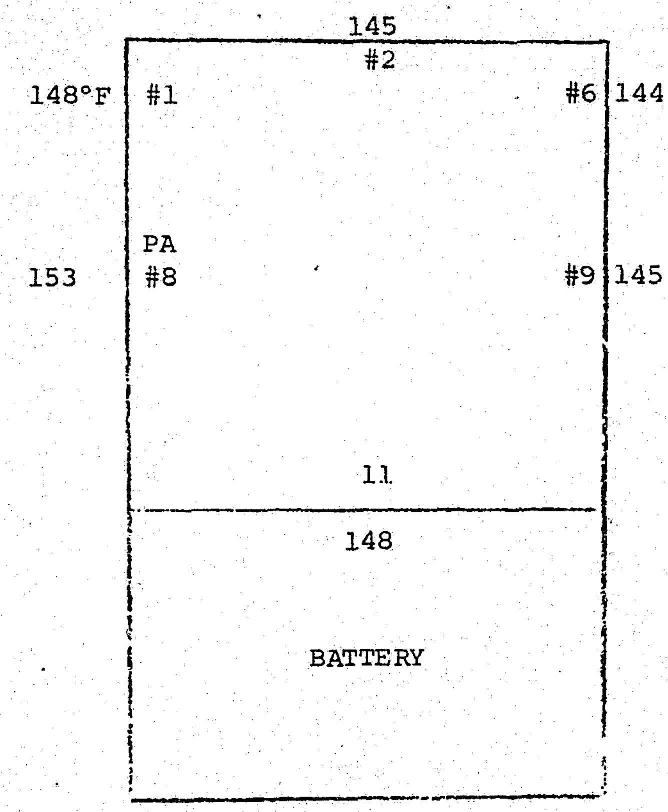

Figure B-1. Frame Temperatures (Time = 236 Minutes)

3. 122°F ambient, start at time = 236 min., U.S. Air Force duty cycle

Thermostat set at 185°F

Thermostat opened in 0.1 minutes at 185°F

2N5946 was at 190°F

2N5944 was at 174°F

2N3571 was at 174°F

Aluminum Frame was at 172°F max.

4 122"F ambient, 122°F soaked, start at time = 0

Thermostat set at 185°F

Thermostat opened in 0.32 minutes at 185°F

2N5946 was at 190°F

2N5944 was at 174°F

2N3571 was at 174°F

Aluminum Frame was at 172°F max.

Based on this data, a thermostat setting of 200°F nominal was chosen - setting tolerance ±8°F - differential 30°F

5 -40°F ambient, -40°F soak, start at time = 0

Thermostat set at 200°F

Thermostat opened in 5 minutes at 200°F

2N5946 was at 205°F

2N5944 was at 190°F

2N3571 was at 189°F

Aluminum Frame was at 188°F

F. Normal operation, except continuous transmit (no duty cycle).

All-aluminum frame with fins.

Thermostat set at 200°F

Soak at ambient temperature, start at time = 0

Ambient Temp.	2N5946	2N5944	2N3571	Al. Frame	Thermostat Opens In (Minutes)
-40°F	201°F	198°F	197°F	197	96
+95°F	201	198	198	197	12
+122	201	198	198	197	8

APPENDIX C

TRANSDUCER/SPEAKER PERFORMANCE EVALUATION

The sound pressure level (SPL) specification of 105 dB at five inches from the transceiver, using a maximum of only 80 milliwatts of audio power, was a task that required a significant amount of research and development since this output was approximately 10 dB higher than could be obtained by a small speaker. The only apparent potential solution was to use a small transducer since transducers are more efficient than small speakers at input power levels below 50 to 100 milliwatts (depending on the specific device).

In configuration A, which is a self-contained unit suitable for shoulder mount or handheld operation, little volume was available for any type of acoustical chamber to amplify the output of an acoustical device. Therefore, the initial approach was to select the most efficient transducer available that would produce the maximum SPL with an 80-milliwatt input. Then, a small, acoustically-tuned cavity would be developed to amplify the transducer output to the required 105 dB.

Transducers were obtained from several vendors and evaluated. The most applicable transducer, with the highest efficiency (output) in the size allowed, was a Knowles 1657. The Knowles unit produced an SPL of approximately 85 dB in free space, with wideband noise input at 80 milliwatts rms, which was 20 dB below that required. The maximum space that could be allowed for the transducer and an acoustic cavity to amplify the transducer output was approximately 2.0 cubic inches.

Test data available from transducer manufacturers indicated that cavities of approximately 5 to 10 times this volume limit would be required to obtain 105 dB. However, the possibility was apparent that a tuned cavity might produce the amplification required within the space limitations.

Therefore, three cavity configurations were built, each with the transducer centrally mounted in a 0.67 x 1.0 x 3.0 inch housing at the feed point of a folded horn. Exponential, conial, and rectangular horn shapes were evaluated in search of a configuration that could be tuned to amplify the transducer output above that realizable by directivity gain of the aperture (similar to the directivity gain of a directional antenna). In all cases, a gain of approximately 10 dB was obtained for a net output SPL of 95 dB. The results indicated that the amplification was strictly a function of directivity and that for the given aperture size and horn length, the shape of the cavity had no affect on SPL. No means of amplifying the transducer output beyond that which was obtained in this size cavity was apparent unless some means could be found to synthetically lengthen the horn to dimensions near the wavelengths corresponding to the voice spectrum, or a means of baffling could be found to obtain the same results.

Since the solution to the SPL problem was not obvious, a thorough search of the industry was initiated to locate manufacturers of small speakers and transducers. Subsequently, samples were again obtained and tested, and the four most promising manufacturers were visited to gather information to aid in the design effort. The evaluation of standard speakers were included in the program since the preliminary test results indicated that miniature transducers had little or no advantage over speakers in the required application; furthermore, the voice quality of transducers was less pleasing to the human ear than that produced by speakers. The following information was obtained from manufacturers on transducers operated as speakers for the required application:

1 Redesign of any of the transducers from the manufacturers consulted would not significantly improve their performance; they were new products and already optimized to the full extent of their technology.

2 None of the transducers examined or discussed would produce 105 dB of SPL at a distance of 5 inches with 80 milliwatts of white noise without assistance of a horn or cavity. A transducer could produce an SPL of 105 dB over a narrow frequency range by using a tuned horn but the distortion would be high.

3 The rear of a transducer cannot be artificially loaded to significantly improve the output level.

4 The 105-dB requirements cannot be obtained with only 80 milliwatts and only 2 cubic inches of cavity or horn volume available.

Many questions were asked of the transducer manufacturers, but no information was obtained on how to improve the performance by more than 1 to 2 dB over what Martin Marietta had obtained in tests. The only constructive information from the speaker manufacturers (that would show results of the best efficiency from speakers without causing distortion) was basically to use a magnet with high flux density.

After consulting with the manufacturers and obtaining samples of speakers and transducers, a simple voice quality test was run to eliminate extensive testing on units that definitely would not be considered due to unacceptable, poor voice quality. The test used a 2-1/4 inch diameter speaker as a quality reference since it was the size typically used (or smaller) in large, existing personal transceivers. For further comparison, an oval 2 x 3 inch speaker was included in the test program. The test consisted of a quality judgment by four persons previously tested and trained for voice intelligibility testing. Recordings of Harvard University phonetically balanced word lists and sentences spoken by a radio broadcasting station narrator were played into a high fidelity, wideband amplifier and applied to the device under test. The drive level to each device was calibrated for 80 milliwatts rms of white noise through the amplifier prior to voice testing. The results of these tests are listed in Table C-I. Of the thirteen devices evaluated, seven were selected for further performance testing.

TABLE C-I

Transducer/Speaker Voice Quality Test Results

Transducer/ Speaker	Vendor	Voice Quality	Selected for Further Testing
2 x 3 Inch Speaker	Cleveland	Excellent	No - too large
2-1/4 Inch Speaker	Shigoto	Excellent	No - too large
2 Inch Speaker	Archer	Very Good	Yes
2 Inch Speaker	GE (Master)	Very Good	Yes
2 Inch Speaker	Oaktron	Very Good	Yes
1-3/4 Inch Speaker	Shigoto	Good	Yes
1-1/2 Inch Speaker	Shigoto	Fair	Yes
1 Inch Speaker	Lafayette	Poor	No - unacceptable quality - low SPL
2 Inch Speaker/Mike	Shure	Poor	No - high distortion - low SPL
MC11 Transducer	Shure	Fair	Yes
BQ Transducer	Knowles	Fair	Yes
1657 Transducer	Knowles	Very Poor	No - unacceptable quality
1-1/2 Inch Transducer	Roanwell	Fair	No - high distortion - low SPL

A test setup (Figure C-I) was used to measure SPL, voice quality, and frequency response of the devices. All tests were run in a sound room built for voice intelligibility tests. The filter shown in the setup was a bandpass unit designed to simulate the net transceiver audio response. To house the speakers and transducers, enclosures that had the same volume as the transceiver electronics case were built. Blocks were inserted in the enclosures to simulate the internal modules. A summary of the test results is given in Table C-II.

The sound pressure levels were measured at five inches from the test units, which were mounted in a simulated transceiver case with 80 milliwatts, rms noise measured at the device after being band-limited by the system

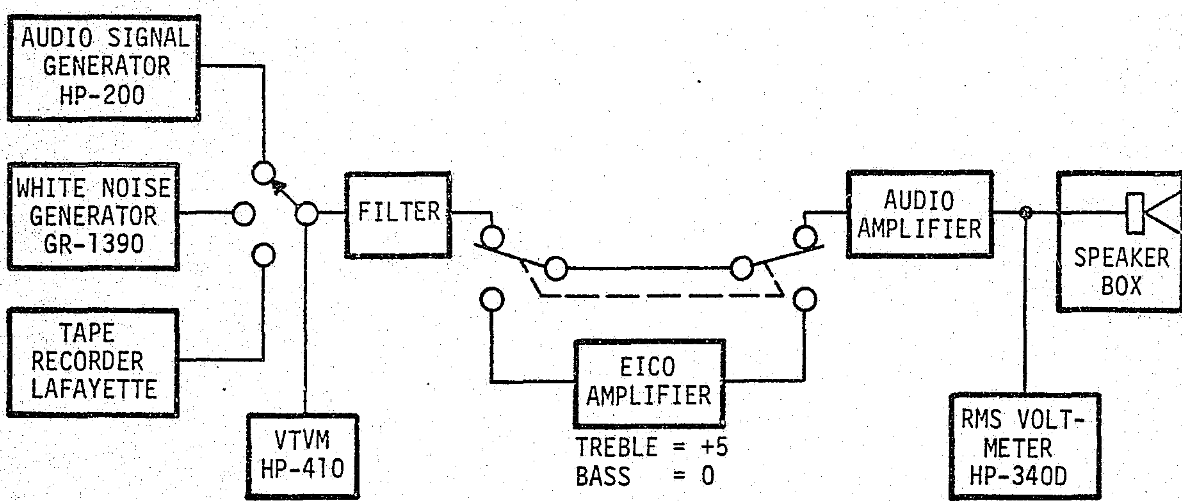

Figure C-1. Block Diagram for Sound Pressure Level Measurements and Voice Quality Tests filter. The 1.5-inch and 2-inch speakers measured an average SPL of 95 dB, while the two transducers tested produced levels of 2 and 8 dB less. Both transducers were mounted in cavities within the case that were judged optimum in configuration for the allotted volume.

TABLE C-II

Performance Test Results

Device	Vendor	Average SPL with 80-mW RMS Noise (dB)	Voice Quality
MC11 Transducer	Shure	87	5
BQ Transducer	Knowles	93	4
1-1/2 Inch Speaker	Shigoto	93	3
1-3/4 Inch Speaker	Shigoto	95	1
2 Inch Speaker	Archer	95	1
2 Inch Speaker	Oaktron	95	1
2 Inch Speaker	GE (Master)	95	1

The frequency response of the units is shown in Figures C-2 through C-4. The larger speakers exhibited a higher output at the lower frequency and, in general, had more output across the band than the transducers and the 1.5-inch speaker. The notch in the responses at approximately 2000 Hz is a result of taking the measurements at five inches from the device where a null that is a function of signal wavelength occurs.

The voice quality tests were run with the phonetically balanced word lists and sentences, as previously, except the simulated system filter was used. The quality was rated in increments from 1 to 5, with 1 representing the highest quality. The significant findings in the quality test were:

1 The 1.75-inch speaker provided the same level of quality as the larger 2-inch speakers when the input signal is band-limited by the system filter.

2 The 1.5-inch speaker and two transducers exhibited significantly poorer voice quality than the other units and also sounded distorted.

Furthermore, when listening to voice through the devices, the loudness of the transducers appeared to be even less, compared to the speakers, than the SPL indicated. This was judged to be caused by the inherently poor, low-frequency response of transducers, which results in "tinny" and weak sounds to the human ear. Even though the transducers were as intelligible

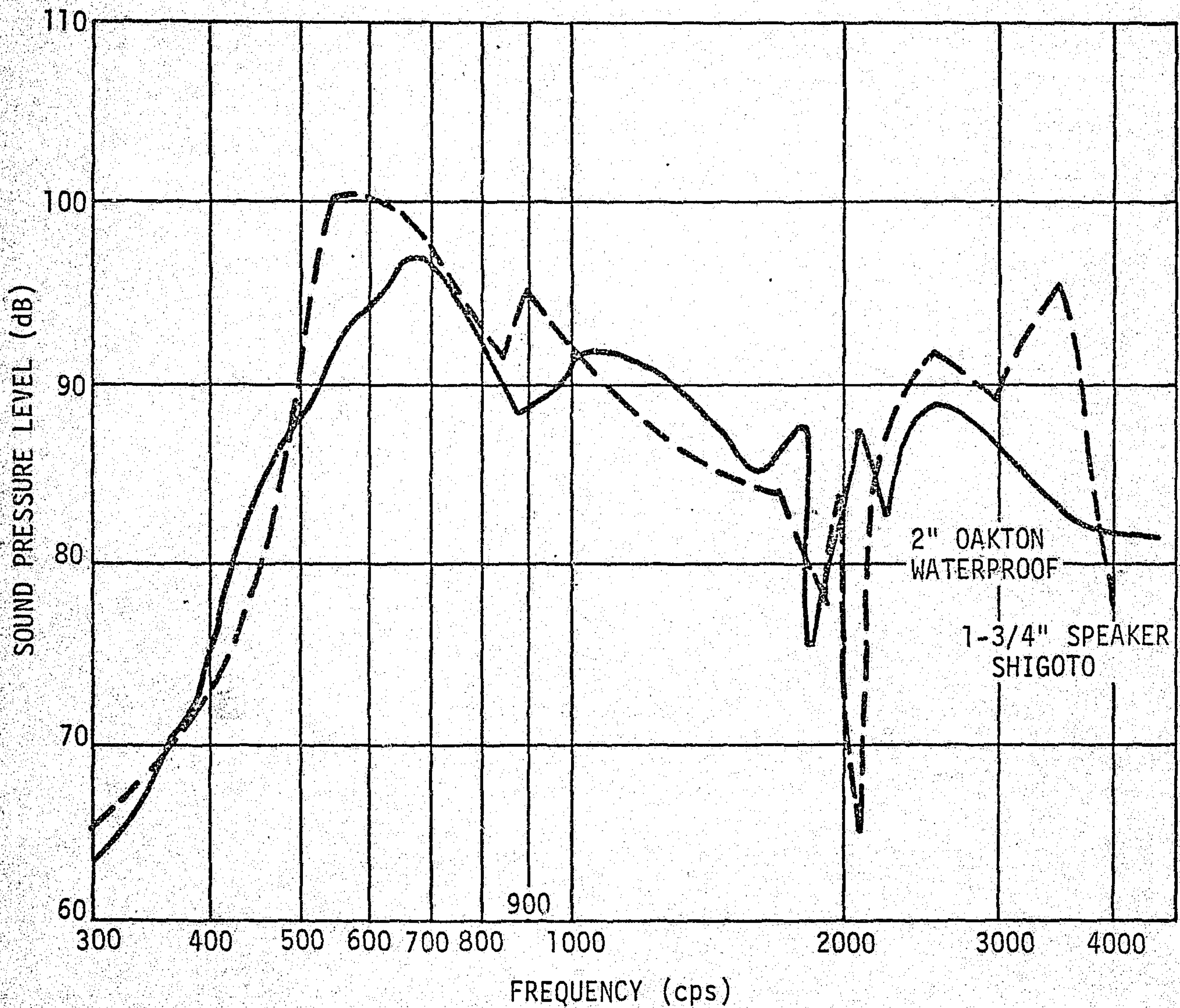

Figure C-2. Sound Pressure Level Versus Frequency

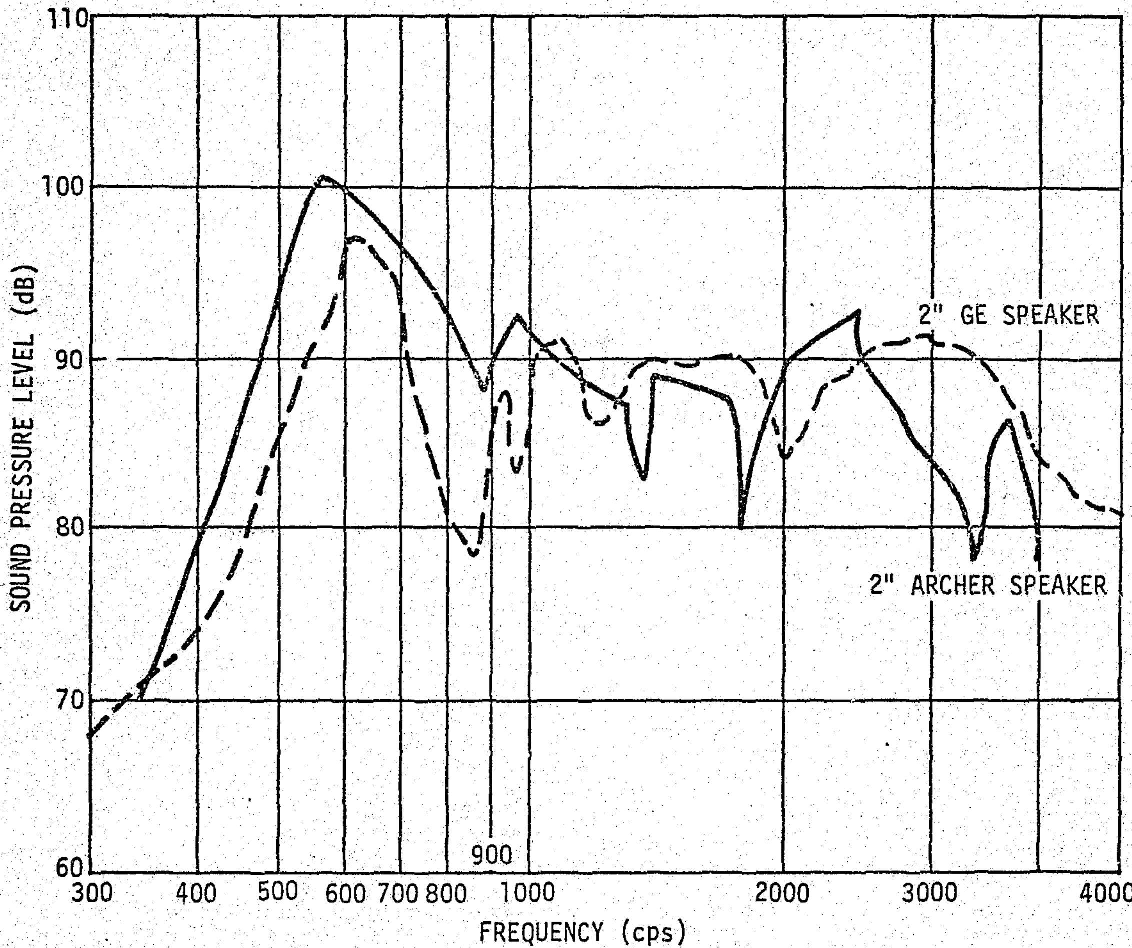

Figure C-3. Sound Pressure Level Versus Frequency

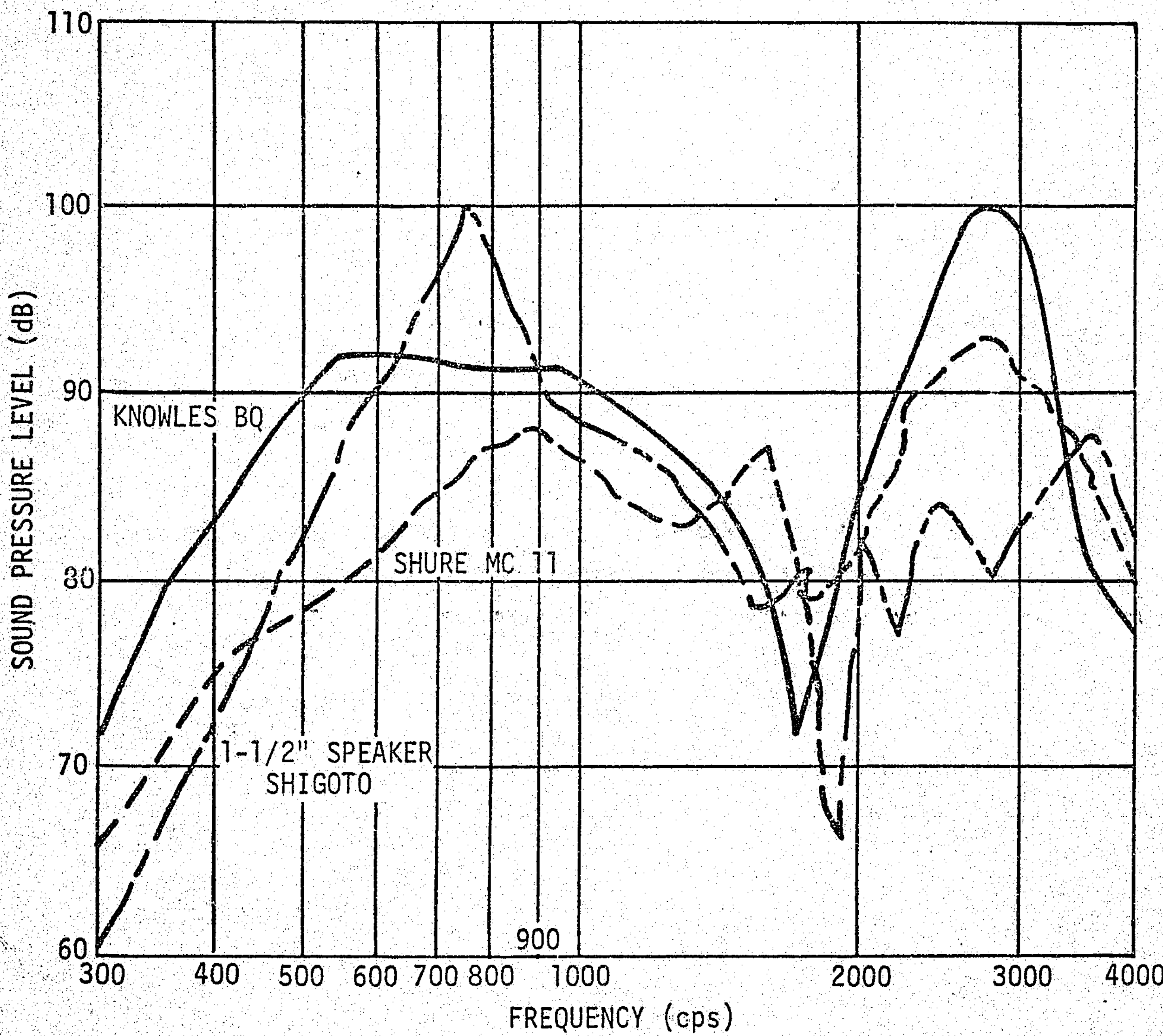

Figure C-4. Sound Pressure Level Versus Frequency

as the speakers, the latter sound louder to the human ears, exhibit better "fidelity" and are much more pleasing to the ear. For instance, listeners in the test program comparing a transducer and a speaker (each producing the same SPL) would, without hesitation, judge the speaker better in quality and loudness. Due to the poor apparent quality and loudness of the transducers, combined with unsuccessful attempts to significantly amplify the output, these devices were eliminated as practical candidates for use in a small portable transceiver where the cavity is required to be an integral part of the transceiver housing.

On the basis of good voice quality, high SPL, and small volume required relative to the units tested, the 1.75-inch Shigoto speaker was selected as the optimum unit for the transceiver. Additional tests were then conducted with the 1.75-inch speaker to determine if improvements in SPL could be obtained. First, three additional 1.75-inch speakers were obtained for comparison, but all were inferior to the Shigoto speaker in either volume, SPL, or distortion, or a combination of these three. The Shigoto speaker was tested with various cavity configurations at the rear of the speaker and with various baffles in the front of the cone without any noticeable improvements in SPL. Output responses for input levels of 80, 160, 320 and 640 milliwatts were measured with the results shown in Figure C-5. The output versus input response was linear, with approximately 1-dB increase in output SPL produced for every dB increase in input power. Consequently, about 650 milliwatts of input power would be required to produce 105 dB at five inches from the speaker. An additional test was conducted to determine SPL as a function of distance from the speaker. Figure C-6 shows that an approximate 6-dB increase is obtained each time the distance to the speaker is halved. The test also confirmed that the null at 2000 cycles was either a function of wavelength from the speaker or a reflection in the measurement process, and did not represent the true response of the speaker, since a null did not occur in the 1- and 2-inch tests.

To determine the response that could be expected at a user's ear when the transceiver is shoulder mounted, an SPL versus angle test on a 5-inch radius was made in the horizontal plane from -90 to +90 degrees. The results are given in Table C-III where, again, the null at 2000 Hz is prominent. No degradation in SPL is experienced over an angle of ± degrees, and a 3-dB reduction in SPL occurs at ±90 degrees. Since the plane of the speaker will be a 45 to 60 degree angle from the user's ear when mounted at shoulder level, a loss of 1 to 2 dB of SPL would be experienced.

After the transceiver cases were built, two speaker grills were tested, using 1.75-inch Shigoto speaker by determining SPL versus vertical angle. The preferred design was with the grill grooved to prevent rain from entering the speaker enclosure when the transceiver was in an upright position. This design was compared to a grill with wider grooves cut directly through the case, perpendicular to the surface of the front of the case and horizontal in direction. The test data in Table C-IV indicates that no significant difference in SPL was measured between the two configurations, and a reduction of 1 to 1.5 dB in SPL would be experienced at the ear, which confirmed the preliminary data. Consequently, the preferred groove design with rain protection was selected and incorporated into all transceivers.

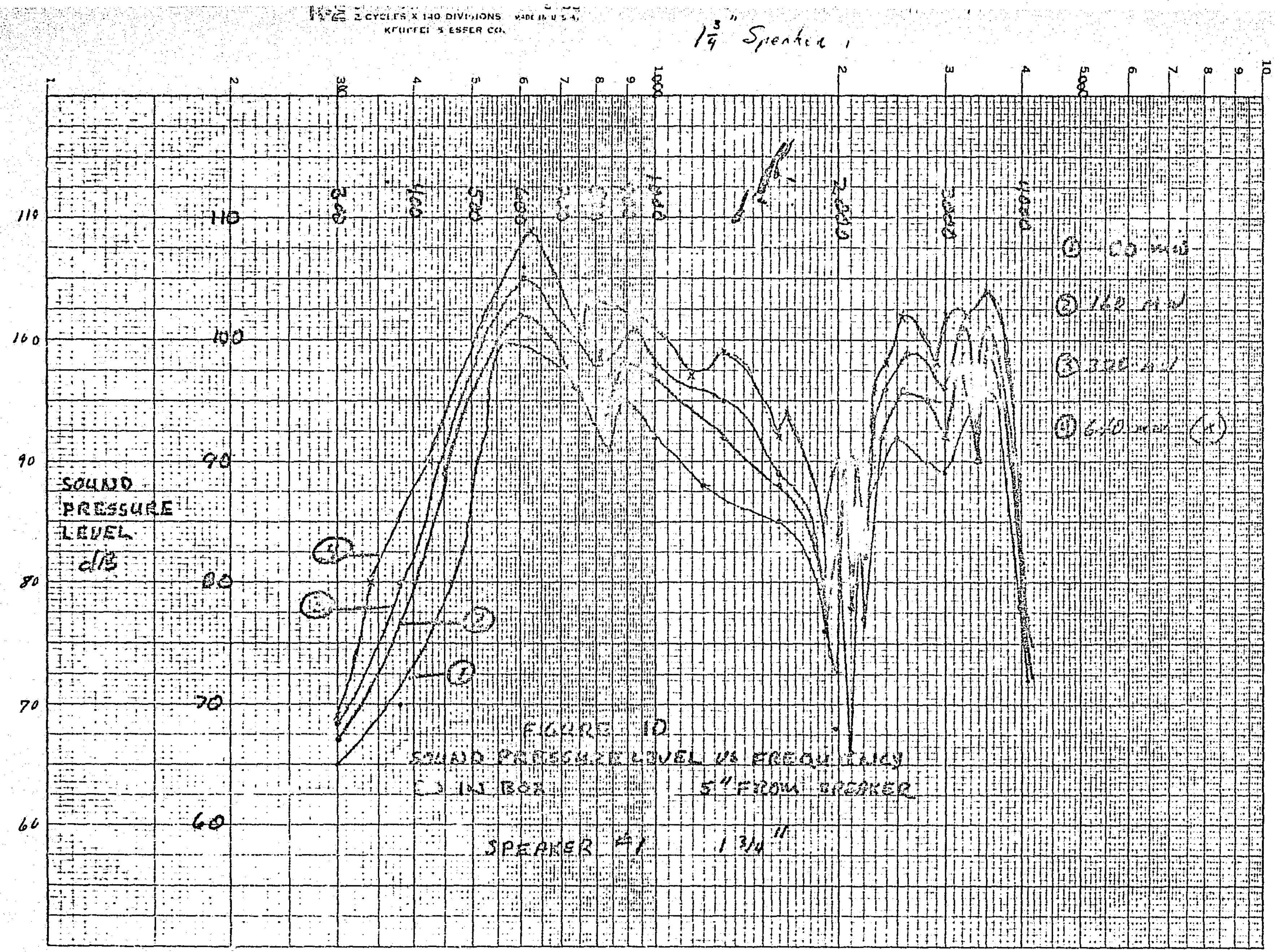

Figure C-5. Sound Pressure Level Versus Frequency

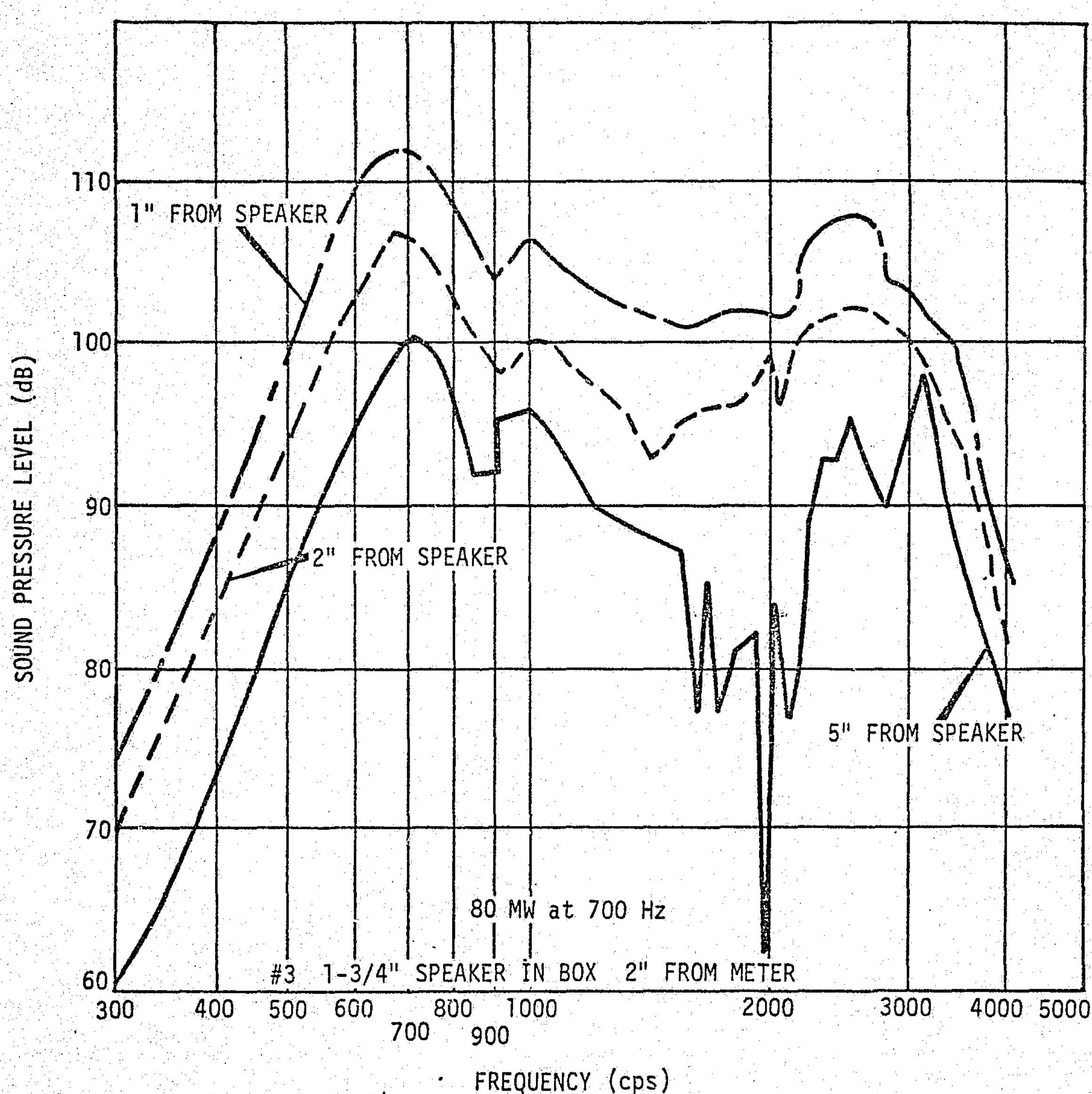

Figure C-6. Sound Pressure Level Versus Frequency

TABLE C-III

SPL Versus Angle in Horizontal Plane

Degrees Off Center	SPL dB 700 dB	SPL dB 200 dB	SPL dB 3000 dB
-90°	97	82	90
-75°	78	80	91
-60°	99	78	91
-45°	99.5	78	91
-30°	100.5	82	92
-15°	101	83	92.5
0°	101	83	93
+15°	101	83	92.6
+30°	100.5	83.5	92.5
+45°	100	83	92
+60°	99	78	90.5
+75°	98	77	91.0
+90°	97	80	90.1

TABLE C-IV

Speaker SPL in Vertical Plane

Transceiver Speaker Grill Configuration	Vertical Angle (Degrees Relative to Horizontal Plane)	SPL with 80-mW Input (dB)
Wide Horizontal Slots	+90	89.5
	+45	91.0
	0	92.0
	-45	91.5
	-90	89.0
Narrow Angled Slots for Maximum Protection from Rain	+90	89.0
	+45	90.5
	0	92.0
	-45	91.5
	-90	89.5

Initially, a preamplifier and compensating filter module was made to enable the speaker to also be used as a microphone. However, the concept was later improved in both performance and cost by using a transducer as a microphone and eliminating the preamp/filter module.

After conducting the speaker/transducer evaluation program, the conclusion was made that significant advances would have to be made in transducer performance before the devices would meet SPL specifications required in this program and could be considered for use as speakers in small portable transceivers. Meanwhile, the sound reproducing function should be performed by a speaker selected for an optimum combination of volume, SPL, and battery drain; this has been done for the personal VHF/UHF transceiver. In retrospect, producing 105 dB of SPL from 80 milliwatts in approximately two cubic inches or less appears to be beyond the capability of present technology. If 105 dB is required with a low input drive, a large cavity unit with a transducer external to the transceiver case should be provided. A unit capable of 105 dB of SPL should only be required for special applications, since 95 dB is a respectable loudness for most needs; in addition, the requirement appears out of perspective, relative to the needed volume in a transceiver developed with miniature techniques to obtain a minimum size goal. The selection of the 1.75-inch speaker for the personal transceiver appears to be an optimum choice for the application.

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3. ABSTRACT

This report describes the personal VHF/UHF transceiver prototype development effort and the five different versions of the transceiver that were produced during the program. The program involved the development of state-of-the-art microelectronic modules, miniature parts, and modular packaging techniques to meet the design objects of a small, lightweight, easy-to-maintain personal transceiver to satisfy requirements for municipal law enforcement agencies and Air Force Security Police. The requirements were met by using a combination of thick-film hybrid substrate modules, miniature discrete component modules, and custom development of miniature electrical parts and mechanical hardware.

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