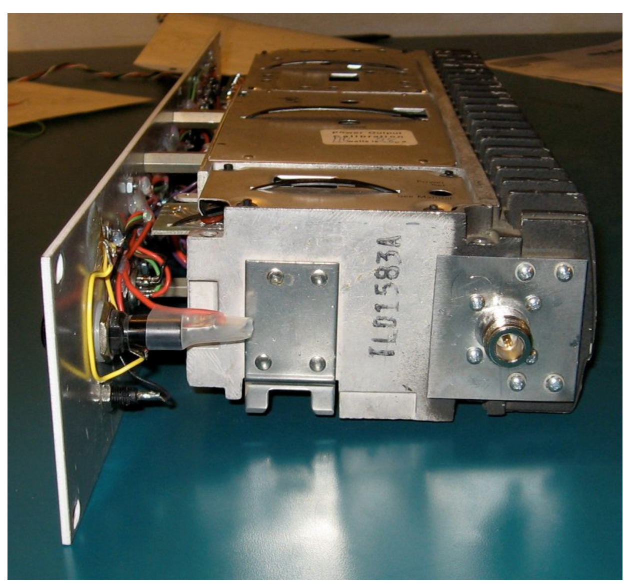
Motorola Micor transmitter for repeater use
By Karl Shoemaker

Introduction:

This document is written to include interested people in serious construction of a quality product. Its rather technical, however, if you have a basic electronics background with some repeater building experience this should not be an issue. Some of it's dry reading however, you need to spend time on this to better understand advanced circuits, later on. Understanding schematic drawings is required. If you are new at the repeater operation you might want to seek experienced help. Allow plenty of time to construct each radio, especially the first one. No free technical support is available however, some printed documents are available on an occasional bases, for a modest cost for P & H. The project is designed for amateur radio (not commercial) and is open for discussing, changes and improvements without notice. Should you feel qualified you are welcome to deviate from the Author's design. Images in this document may be used to illustrate a point only and may have been taken at different stages of research and development therefore, may not show the end "product" in some cases.

Overview:

Motorola made a "Micor" series of radios; both base station and mobile. This discussion is mainly on the mobile which was manufactured in the 1970's. Its a very rugged, heavy mobile radio unit (drawer unit, if you will) that works with an "accessory group" consisting of a power cable, speaker, control head and microphone. The basic ordering option was 1, 2, 3, or 4-frequency channels controlled with the head.



Acronyms, Definitions, semantics and Theory basics for Telecommunications:

Some of this material may not be popular reading for hobbyist however, is necessary to maintain a complete understanding of the project at hand. To be very clear on this philosophy, we will start with the basics. Humans wish to communicate since the cave-man days with grunts. A few million years later with smoke signals. A hundred years or so ago with wired telegraph (1800's) and wireless telegraph (1900's). In the 20th century voice finally was realized. In the 21st century better sounding, analog voice, then data and digital voice was realized. Only analog communications/transmission for Land Mobile Radio (LMR) will be covered in this document.

Radio systems send intelligence (voice, data, etc.) by modulating the originating transmitter and decoding (detecting) this modulation at the far end receiver back to something usable to be understood. How well this is understood depends greatly on how well the system is set up. Just about anyone can "throw" a system together to make it work, somewhat.

Amateur radio can develop the art of radio and improving operating practices in this area. This can set a good example for others, including the commercial industry, to what some amateur radio systems are capable of doing and to provide public service communications in time of need. This includes the technical side, to produce a high performance repeater and/or link.

A "repeater" is a generic term for user's signals to be received (input) and retransmitted (output). This greatly increases radio coverage, for a single-site, conventional repeater. Extended (user) coverage can be realized by linking several repeaters together. Further user coverage can be realized with a voter system and simulcasting as well in analog systems.

Most radio systems in the VHF, UHF (and microwave) are line-of-site for the radio paths. On the ground a path has limited range because of obstructions which attenuate signals. From high (remote) sites greatly increase this because most of the obstructions are gone.

A "link" is a one-way transport method for repeater support, such as the remote receivers on a voting system. For example, a repeater's (input) receiver may need to be "downlinked" to a central control point, such as a voter or connection to the outside world (telephone, internet, etc.). From this control point the system output can be "uplinked" back up to a high transmitter (output) for the users to enjoy wide coverage of such a system. In this case would be a multiple site repeater (system of links, etc.) In conclusion, three factors improve a conventional analog radio system:

- Repeater; to "relay" user signals.
- High location; get away from obstructions.
- Voter system; easy user access, especially with portable-low power subscriber units (users).

A typical (commercial) system uses the audio portion 300Hz~3KHz for repeaters and links. With several links this produces "tinny" and distorted audio. In some cases squelch and signaling circuits produce signals that are annoying and fatiguing to listen to. Because of user tolerance and ignorance this sets a (bad) precedence of what a system is expected to be. This document covering system performance will be somewhat different. The Author's design and specifications call for a better way, and is practiced in all SRG projects such as this one. For example, "flat" audio, better squelch and other signaling practices are utilized. This keeps a large system nice to listen and operate and may set examples for other groups to improve their systems. It also calls for good technical management.

For one, technician organization and discipline is necessary. Plan on what you want to do for a system design and stick to it. Force yourself to keep good practices. One good practice is to establish level references. Some call these "benchmarks" or "baselines". While old methods used linear (microvolts, watts, etc) units of measure, design of this project and document uses logarithmic units. Once accustomed, it's easier to see the entire picture this way, when designing a system or checking system performance and keeps the guesswork out of troubleshooting a subtle level problem. References can be expressed with a few acronyms.

Note: In this document, any font in blue indicates a guess and/or not verified at the time of publication.

<u>Test Tone Level</u>   and   <u>Test Level Point:</u>

Test Tone Level (TTL) is referenced to tone that modulates a channel or path 100%. For a testing or aligning a LMR transmitter, receiver or path this would be a 1 KHz (1004 Hz for telephone work) for a FM (frequency modulation) system. Test Level Point (TLP) refers to a measurement point (normally on equipment) in reference to TTL. TLP provides easy reference to any parts of the system for measurement and alignment. 0 dbm is referenced to 1 milliwatt at 600 ohms. A 6-dB drop in (voltage) level would reduce the modulation in half, and so on.

Levels are stated in transmit-receive (Tx-Rx) order. Therefore, an audio (Voice Frequency) "drop" TLP of 0/0 would mean a Tx TLP of 0-dbm, Rx TLP of 0-dbm. For example, a transmitter AF input with a TLP of 0 dbm, with a TTL of 0 dbm tone input, would fully modulate the system. If the far end receiver was set up the same, its output would be a 0-dbm tone as well.

Absolute levels are specific-measured (operating) levels, not to be confused with TTLs. Sometimes operating levels are not at TTL. In this case, a level would be so many db "down" from TTL, or just called "xx down". For example, CTCSS (sub-audible) tones normally are 18 db down. (1/8 deviation from voice, or 18 db down from maximum voice and/or TTL).

To avoid technician confusion two sets of numbers are sometime used in diagrams and on the physical equipment's ports or I/O connections. Non-parenthesis figures are (absolute/actual) fixed operating levels, and as mentioned before, may be at different levels from the TTLs. Figures in parenthesis are the TLPs, which is explained below.

Levels below 0 dbm are negative, while above are positive. Take this into consideration when working with system gains or losses. Normally, the negative levels have a minus in front of the number, while positive (optionally) have a plus sign. This is also true for absolute levels (as opposed to TTLs). This method is used for most any AC frequency (audio or RF). For example, many transmitters run a +42 dbm while most receivers' sensitivity run a -117 dbm for 20 dB quieting.

<u>Other terms:</u>

RF or AF ports at the **T**op **O**f **R**ack are considered "TOR". This is all equipment in/on the station's cabinet or rack. External equipment from TOR is later figured for a system performance (losses or gains). This may be RF lines, a combiner system or tower antenna(s). TOR levels are referred in the order of the transmitter and receiver (Tx and Rx, respectively).

Single digit numbers of "1" and "0" in brackets (" [ ] "), are not to be confused with TLPs. In this case these 1s and 0s identify the logic state of a gate, or other TTL/CMOS I/O driver circuit, and so forth. Another aid to avoid confusion between logic states and a TLP is that the latter normally would have a " + " or " - " before the number (as earlier mentioned). For example, a TLP of -14.8 is the audio input controlled by a logic gate of [1], being a normal logic "high". One last word on the logic state; The brackets indicate a state in normal standby/no activity condition. As a side note, "TTL" mentioned above has nothing to do with "TTL logic", a type of IC series.

Most "TIMM"s and AC voltmeter scales are in "dbm". When measuring across a circuit you may need to have the meter in bridge mode, being medium impedance as not to load down what you are measuring. In such cases a more accurate term of level would be "dBu". Having said this, dbm reading in bridge mode is still understood by most, for a specific (absolute) level measurement using log10 based numbers.

The term "COR" came from the old tube days of "Carrier Operated Relay" whereas, a tube receiver had a point, when its squelch opened, a tube (switch/valve) drew current through a relay's coil, to give some contact closure, to key the associated repeater's transmitter. Repeater stations in the early years were called "Relays" whereas, the station would "relay" a signal rather than "repeat" a signal.

As the solid state technology came in the later 1960's the COR term stayed with repeater operation. In addition, most modern equipment no longer had a mechanical "relay" used. Perhaps a more accurate term would be "Carried Operated Squelch" , "Carrier Operated System" (COS) or CAS in the case of the older GE receivers.

Both terms are correct and this gets down to semantics or content of a discussion:

- Modern technology used in the LMR field by amateurs and professionals alike.
- Recent repeater product terminology and it's manuals.
- To avoid reader confusion; since they may expect the term of "COR".

After careful consideration it was decided to stay with the term "COR". Therefore, this and other SRG documentation will reflect this decision.

"CS" will be reserved to describe "Carrier Squelch" as a receiver's mode of operation, verses "TS", "PL" or "CTCSS" to describe a "Tone Squelch", "Private Line" or "Continuous Tone Coded Squelch System".

"SDI" means Signaling Decode Indicator (or Input). It's also similar to a CTCSS line out of a tone decoder. "HUB" means Hang Up Box. Motorola's uses a "closed loop" for mobiles and base station control. "AND squelch" means it takes both carrier + tone to activate a COR board, transmitter or system. AND squelch is also referred as a variable sensitivity squelch whereas, the squelch setting affects activity threshold. An "OR" squelch does not; whereas, it "bypasses" whatever squelch setting, using only tone to keep it active (once the squelch is open on startup reception). More is discussed, later in this document.

Operational Note: Tone "protection" (CTCSS) is only to avoid a squelch from opening undesirable signals. Ignoring RFI does little or nothing to correct it from competing with weak, desirable signals. Hence, the words "protection" in this context is almost a misnomer and does not "fix" the RFI problem.

<u>Push To Talk:</u>

The term "PTT" came from a button on a radio's microphone. For this documentation PTT will describe an active going "low" for DC functions, such as transmitter keying ("PTT Input"). It also will describe a receiver's COR line driving a NPN transistor, with the open collector being "Receiver PTT Out", or just "PTT Out". "PTT 1" will describe this function however, with a buffer, such as the output of the cor/af board, which changes state for user signal change of status. This function would be used for audio switching, such as auto-patch audio routing. "PTT 2" will describe a buffered, and "hangtime/tail" output of the cor/af board, to keep a repeater's transmitter keyed up (AKA tail) for normal back-and-forth conversations of the users of such system(s). One or both types of PTTs may be time-out controlled.

<u>PM/FM:</u> (for a transmitter)

Frequency modulation is the common way to send intelligence in the LMR analog world. FM is also referred to "deviation" (of the carrier, at an audio rate). There are two ways to frequency modulate a transmitter, phase modulation (PM), AKA indirect, or (direct or true) FM (frequency modulation). PM is the easiest design with good frequency stability however, lacks audio response. PM has "natural" pre-emphasis which works well for LMR standard. On the other hand, (direct) FM has much better response (flat audio) at the cost of more complex engineering to keep stability. Also, FM needs additional pre-emphasis. With modern synthesized/PLL transmitters this is major consideration. However, later technology-design has allowed direct FM to perform well in LMR systems.

The MI (modulation Index) for a PM signal is always changing, especially for voice traffic. MI is mentioned because FM causes side bands to be created above and below the carrier and takes up bandwidth on a particular frequency, or sometimes called a "channel". Modulation and deviation are the same results when talking about FM. Maximum deviation of 5 KHz means 5 KHz above the center frequency and 5 KHz below the center frequency, making a total bandwidth of 10 KHz possibly including side bands.

Radio technologies have different bandwidth standards (for maximum deviation) such as:

- FM radio broadcast of 75 KHz
- TV (analog) aural of 25 KHz
- Legacy cellular of 12.5 KHz
- Legacy commercial/government (LMR) VHF-UHF of 5 KHz (and most amateur).
- Current commercial LMR of 2.5 KHz
- Point-point microwave using (legacy) frequency division multiplexing about 5 MHz, in many cases.

While its good to be aware of these different bandwidth standards only amateur radio standards will be covered in this document. Crowded parts of the U.S. and abroad may use the “narrow band” standard of +- 2.5 KHz. It’s believed the reasoning behind the narrow band is less adjacent channel interference at the cost of lower performance in some cases. The Pacific Northwest VHF bands are still blessed with the 5 +- KHz standard and is the standard for SRG projects such as this one.

A quartz crystal is normally used to control the frequency of an oscillator. A variable capacitor across the crystal can fine-adjust the frequency in the form of “warping” it. The fundamental crystal frequency will be converted by multiplying its frequency to obtain the (final) operating frequency. For example, a typical LMR VHF transmitter would be 12 times; or a tripler, driving another doubler, driving a final doubler. (Fc=12 MHz x 3 x 2 x 2 =144 MHz). It’s then amplified to a usable level for transmitting over the air.

Transistors and diodes have a P-N junction inside the case. The former can be used as an amplifier or switch with a potential (voltage) applied to create current flowing in the forward direction (against the schematic diagram arrow).

They also can be used as a variable capacitor. The P-N junction on either device has a “space” in the middle in the form of capacitance called the “depletion zone”. By applying a DC (reverse) voltage across this zone will affect it. This is also called “bias” across the zone. More reverse bias results in more space, thus, causing less capacitance. In a RF circuit this can mean higher frequency, in general.

By applying “intelligence” in the form of audio (AC/voice) across the zone will cause the RF circuit to change in frequency at the same rate, thus, creating frequency modulation. The bias is set up for a fixed value to keep the voice operating in the linear range of this device. This will create good symmetry (waveform) on a frequency modulated RF carrier. This is especially true (no pun) for true/direct FM.

Special diodes are made for this purpose, called a varactor diode or “veri-cap”. They come in various specs, for capacitor ranging 5 ~ 100 pf. Typical is 10 ~ 13 pf for LMR.

Most PM transmitters have the veri-cap diode in series with the crystal causing a phase difference on the fundamental frequency, while most FM transmitters have the diode in parallel to the crystal causing a (direct) frequency change on the fundamental frequency. For FM transmitters, most have the anode to (common) ground.

FM is also used for compensation against frequency drift from temperature changes of an oscillator circuit. In some cases a transmitter uses both PM and FM for audio and compensation, respectively, or two stages of FM, for both reasons as well. Sometimes both circuits are contained (with the crystal) in one module, as in the case of the GE Mastr-II transmitter’s “ICOM”. This way the channel device (element) can be set up (compensated) for each crystal for best performance.

Frequency multiplication also multiples the modulation of the fundamental frequency. Since this arraignment multiples the crystal frequency 12 times it won’t take much capacitance change to obtain 5 KHz modulation (deviation) or temperature/frequency compensation, at the operating frequency.

Flat audio – The long explanation:

As previously discussed, most stock/conventional two-way radios are designed for single path operation, with it's own pre-emphasis, deviation limiting (clipping) and receiver de-emphasis, and "forgiving" squelch operation. Each time a repeated signal occurs some reduction in signal quality happens. For multiple links (long haul) these stock radios can add gross problems, such as excessive distortion, audio frequency response being very poor and very long squelch bursts. All these conditions will cause a system to operate badly and be rather annoying and fatiguing to listen to. Fortunately, these conditions can be corrected.

Some of the problem is human ignorance, interpretation, perception and semantics when discussing audio processing (or not). To fully understand proper audio will take some careful thinking. The other point to keep in mind is the frequency range specification, such as 300 Hz ~ 3 KHz response for a conventional voice circuit, (which some would call “flat”) or 20 Hz ~ 5 KHz (which is more “flat”) or somewhere in between. Perhaps a better explanation to clear up this argument would be to call the latter “extended flat audio” (EFA). Also, there are ways to modify a PM transmitter to FM (true) as part of a flat system. Now, let’s go over some audio processing methods:

There are two types of audio frequency processing when it comes to FM radio equipment; which is conventional (emphasized) and flat (modified or specially designed). One of the standards for FM operation is to improve reception (audio) quality by improving the signal to noise ratio. Consider these two factors:

- Signal; meaning, the intelligence quality of voice or analog data reception.
- Noise, meaning noises from all other sources of this type of communication circuit.

Most of the noise is in the high end of a standard communication channel of 300 Hz ~ 3 KHz; also known as a voice channel. Therefore, by processing the high end of the voice channel can improve audio reception quality. This is normally done by emphasizing (increasing the level) of the high end at the originating source audio by 6 db per octave and de-emphasizing (decreasing the level) of the high end of the far end audio at the same slope.

This is a similar method to “Dolby B” technology used in stereo/hi-fi sound recordings for music listening; except its not companded (compression during recording and expansion during playback). For LMR, the far end listener will experience apparent noise reduction; thus, better S/N ratio. This method is for simplex operation and is done only in the subscriber units. While this may work for a single path, repeaters and multiple links will need further understanding to produce a quality audio path.

Repeater stations:

One could use the audio from the speaker of a receiver feeding a mic. input of a transmitter. Since amateur systems can be modified without violation of type acceptance better points can be used. For example, the (flat) DPL (channel element) input is used in the case of Motorola LMR equipment. For the receiver the discriminator output is used. All receiver's discriminators should have great low-end response however, (due to IF filtering restraints) the top end always rolls off too soon. There is also the impedance-loading and level issues to deal with in some receivers. This and other SRG documents address this.

Most amateurs refer to “flat audio” with methods for the equipment. The key point is both parts have to be the same type conditioning. A repeater station with a flat receiver driving a flat transmitter will result in a flat audio path going through that type of repeater. On the other hand, a repeater station with a properly de-emphasized receiver driving a properly emphasized transmitter will also result in a flat path through that type of repeater. For this discussion we using standard voice channel of 300Hz ~ 3KHz. A flat repeater means the path will be transparent and not alter the audio frequency response. While some conventional station curves may have sufficient response for a single path voice transmission, most are not precise enough to be called “flat”; hence, the misunderstanding. The other key point to remember is that the term “flat” should refer to path/circuit performance and not the method to obtain this.

One exception:

If a repeater is truly flat for subscriber Tx to Rx path (reception) there is one exception for processing within the repeater station for “drop and insert” applications. In the case of flat equipment being used, there is a special situation where pre and de-emphasis is used in addition, to properly interface with non-radio equipment, such as a controller, voice synthesizer or the PTSN (Public Switched Telephone Network), AKA a phone patch. These sources are flat in origination therefore, need emphasizing to properly interface with subscriber (user) radios for a compatible audio frequency response curve.

Deviation limiting or clipping:

Each time you limit deviation for each link in series will add more distortion. An alternative is passively repeating the audio 1:1. If you do have to limit, only do so at one point, such as the system's controller, user signals or system output transmitter (user receive). Another option would be to set the system limit at 6 KHz and let the system user's transmitters limit at 5 KHz deviation, to avoid (double) audio distortion. Passive mode requires system management and user responsibility with your adjacent “channel” neighbors. This may require some enforcement on the owner's part. There are ways to "punish" or filter over deviated (and modulated) users however, is beyond the scope of this document.

Squelch operation:

For squelch modifications, some theory is needed to be discussed. FM receivers have large IF gain. At the discriminator there is plenty of noise available during signal absence. This noise can be filtered above the standard voice channel near 8-10 KHz, amplified, rectified and DC amplified to usable DC levels. The higher audio frequency range is chosen so normal traffic (voice) won't affect the squelch operation. This is known as a noise operated squelch, used in the LMR-FM analog world. A signal into the receiver that is stronger than the noise will "quite" the discriminator audio output, which changes the DC levels in the squelch circuit and turns on the audio amplifier to drive the local speaker for listening. A squelch circuit can also be used to key an associated transmitter; thus, making a repeater.

Sub-audible tone:

Some FM systems use CTCSS (Continuous Tone Coded Squelch System). A carrier operated squelch can work together with a tone to make either an "AND" or "OR" squelch. Companies produce repeater controllers and use this acronym in many cases. Other types of signaling (digital, etc.) can also be used to control a circuit or System. Therefore, the general term used for SRG equipment is "SDI", for Signaling Decode Indication (or input). Other terms include "PL" "TPL" "CG" for various brands of equipment.

"AND" squelch means it takes both a valid carrier and valid tone decode to activate the squelch. "OR" squelch means a valid tone decode will keep the squelch open regardless of the carrier squelch setting; thus, bypassing the squelch setting. An OR squelch is not desirable for amateur use because of the (annoying) long burst of noise that occurs after the input signal stops. AND squelch is best for amateur to avoid this burst. "OR" squelch, "reverse burst" (squelch tail eliminator) and other theory of operation is discussed in another document on the SRG web site in greater detail.

Stock radio receivers have (carrier) squelch constants (time for squelch to close and mute the audio path) designed for both fixed (base station) and mobile (moving station) signals therefore, are a fairly long (200 msec.) time for squelch closure. This is noticed by a burst of noise at the end of a received transmission. For a single site this is tolerable however, for multiple links (hops) this can quickly add up to something annoying to listen to. It also slows down switching paths, causing user collisions. For links, this problem can be corrected by lowering the R/C constants in the squelch circuits; thus, shortening the squelch burst. However, if they are too low the circuits will be unstable therefore, require some careful selection, which is discussed in other documents concerning link receivers, on the SRG web site.

Links are not intended to receive mobile (moving) signals. Therefore, this squelch modification will be transparent to fixed (links) station use, which should be full quieting, strong signals. Only multiple "clicks" would be heard with this modification. The remote user (input) receivers will still have stock squelch components therefore, will provide for moving (mobile) signal changes, plus, "cover up" the multiple link clicks. The result will sound like a simple, small, single site System.

For flat audio processing there's a "cor/af board" design (by the Author) to work with most FM receivers. This board is "fixed" with soldered wires (or screws, such as the RF-IF board in the receiver). A "card" is removed simply by pulling it out, such as with the Spectra-Tac shelf. If the cor board is mounted on a card then the entire piece becomes a "card" thus, "cor card" (or module as the OEM manual calls them).

Other definitions, acronyms and other "shortcuts" are for practical reading and document space. For example, names may be truncated only after the **full name** is established. This avoids reader misunderstandings. For example, the parts list shows several manufacturers in truncated form, such as, Mouser Electronics (a major parts supplier) and may be later referred to as "Mouser" or "ME", etc.

Spokane Repeater Group:

The Author is the founder of SRG, which is a non-profit organization for the development of equipment, operation and enhancement for the benefit of other amateur radio operators doing Public Service (emergency traffic) and other hobby type discussions. http://www.srgclub.org

The project - - - Transmitter for repeater usage:

For repeater use will require a custom-build chassis. You are required to know the micor inside and out. This is especially true if you are converting a high range (150.8-174 MHz) transmitter to a low range for the amateur band. Repeater building experience is needed as well. One little component mistake can cause hours of frustration. If this is your first time seek help from a local repeater owner to avoid problems and equipment damage.

For repeater use will be a single frequency operation. The OEM mobile radio has several sections inside. Two of them are discussed here; the separate transmitter and receiver sections, each of can be easily removed and mounted on a 2RU 19" rack panel. The appropriate controls then can be installed on this panel, eliminating the need for separate cables and controls, both of which take up space and clutter in a repeater cabinet or rack. The rest of the mobile unit is discarded or otherwise used only for misc. parts. This unit is set up for negative ground.

This arrangement is similar to the "compa" station unified (or non-unified) chassis, without the control circuitry. However, one large advantage to using a mobile is each part can be installed at separate sites with minimal space. Therefore, each of the transmitter and receiver will be a covered on separate documents found on SRG's web site. For this document only the transmitter is covered. The first custom-built transmitter pre-1990 started the compact package. Shown above is serial #1.

Serial 2 changed to the white panel standard. Shown here is the front of a finished transmitter. Notice there's a switch function to "lock on" the PTT line for transmitter testing under load. It was decided a ON-Center OFF-ON switch is sometimes awkward to use; disable being in the "center" position; one may run the switch to the down position and keep the PTT on, so this was changed to a ON-ON switch as shown below.

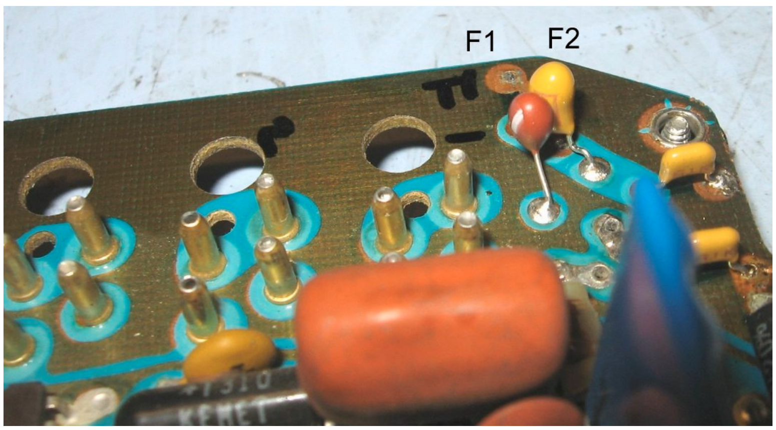
2014 redesign/updates: (Serial 4 and later)

A logical and standard layout needed to be realized. This includes additional indicators such as 12v, 9.6v, keyed 9.6, PA power and PTT activity in the appropriate colors. The correct terminal block placements were done for consideration of the exciter's I/O runs, etc. and short PA wires. The smaller, 4-pin mic connector is the new standard. Behind the panel, the chassis position was moved to the left for improved fuse and RF port clearance on the right side. The three switches on the panel are arraigned properly. The left is the main power, middle PTT control and right PTT lock-on test position. Both PTT switches have to be up for this test function to work. A red flashing light reminds you it's in this mode, for testing. The picture above (page 8) was taken during a load test and is the final layout.

Exciter:

The exciter board is the heart of the transmitter. It has the frequency determining element (channel element with the crystal), the modulation section and all the multiplier and amplifier stages to a usable level (of +26dbm) to drive the PA. The type of modulator is very important for a flat system therefore, only the 4-pin exciter board is used for this project (older versions with the 3-pin phase modular where modified for direct FM).

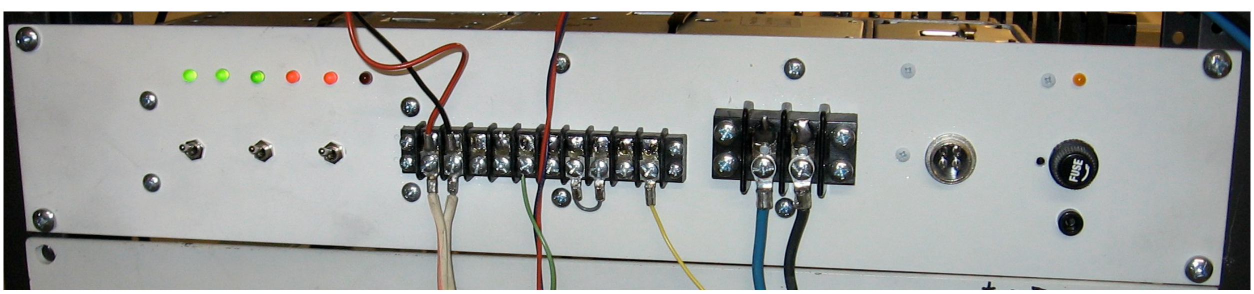
As of 2014 it's capable of 2-frequency operation. The F1 and F2 enable wires run out to TB1 for external control. For normal, single frequency operation (F1) there's a jumper in the front from "F1" to ground, typically, terminals 7 and 8. Terminal 10 is the fan control (discussed later).



Shown on the left are the two audio coupling capacitors that now use the (old) F4 line as the input (flat audio). TLP is about +3.2 dbm.

To start, remove C457 and replace that spot with a wire jumper (now called JU457). Also, jumper this point to the eyelet feeding P902 pin 5. This now functions as a ground run. Remove C410 and replace with a 4.7uf, 25 v electrolytic capacitor with positive lead going to P902 pin 7). This is a general filter for the regulator. Optionally (for general cleanup) you can remove JU401, JU402, JU403, JU404, C465, and C466. Remove C405; then remove C463 and install a new tantalum with the leads reversed; the positive lead going to CE1 pin 4 and the negative lead going to the F4 select line (where part of C405 was). For the second frequency option install the same value to with its positive lead going the CE2 pin 4. The other lead can be shared with the F1 cap's negative lead (going to the F4 select line). This is now the "Tx AF input" (P902, pin 18).

The board will need +12v (A+) and regulated +9.6 to operate. For OEM (mobile), the latter gets it from a regulator on the middle board (which is not used for this project). For this project the LM-7810 3-pin regulator is used. The output goes through a simple rectifier diode (6 tenths voltage drop) causing the output of 9.4v which is close enough to the stock "9.6" voltage.



Control:

To control the keyed circuits a TIP42 transistor is used with its associated parts. The physical location has been under research for several years. The left image is the older, obsolete mounting location for the 9.6 regulator (the PTT switch was located elsewhere). More recent versions (2009 and later) have the parts mounted on P401 which was the PL pins that are not being used. First, to make is the regulator with a very small "footprint". Then install a .22 uf cap on its output, which is required to filter noise at this point. Then add the dropping diode to get the 9.4v output. This "sub-assay" can be later mounted on the P401 pins.

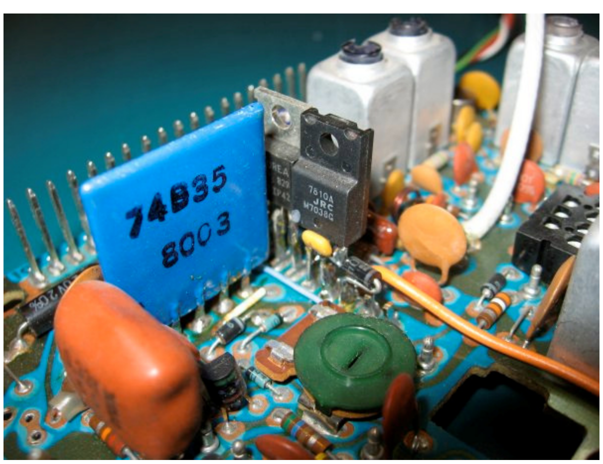
Next, remove P401 pin 1 and cut the rest of the pins down in length, so the top of the installed parts will clear the chassis and tin them. Install the 10v regulator and PTT switch on the pins, per the diagram for the interconnect and these pictures. Install a diode (cathode) on pin 1 with a 1K resistor in series near the PTT input with its cathode facing there. The diode isolates the 9.6v to (outside) 12v equipment’s PTT and other (LED) circuits on the front panel. Remove JU405 and install a 2.2K resistor in its place. (2.7K is okay for a substitute.)

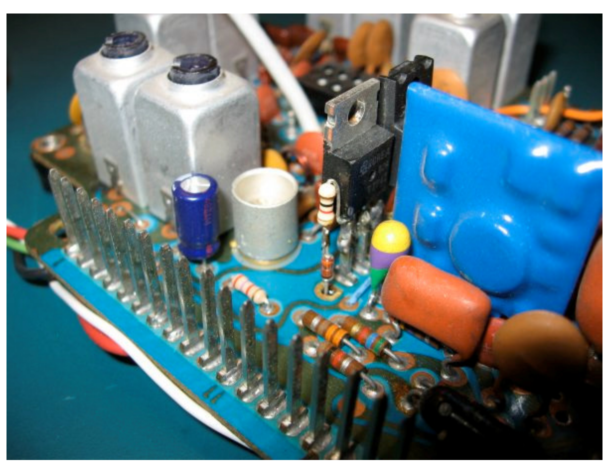
In the event the components needed replacement is an easy task working with the pins as solder mounts. In the picture below notice the blue capacitor (C410) next to Q406. If its larger in size move it slightly inward (angled leads) so it clears the chassis (rail) when installed.

Note: For this project, when the “9.4v” unit is discussed, is the same as OEM “9.6” (or even 9v).

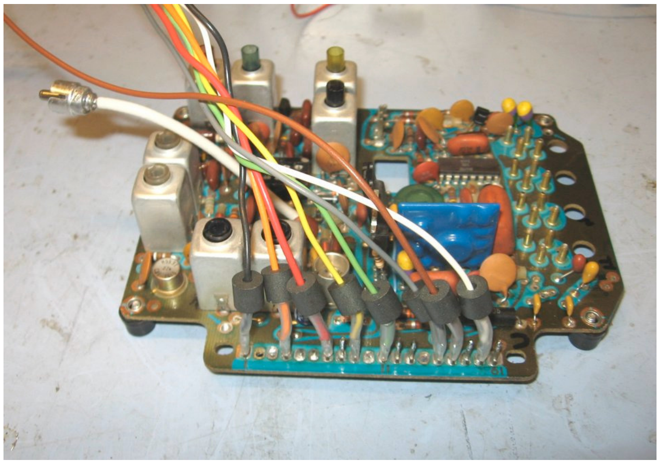
Shown are several units being made as a production “line” to produce several transmitters with their regulators.

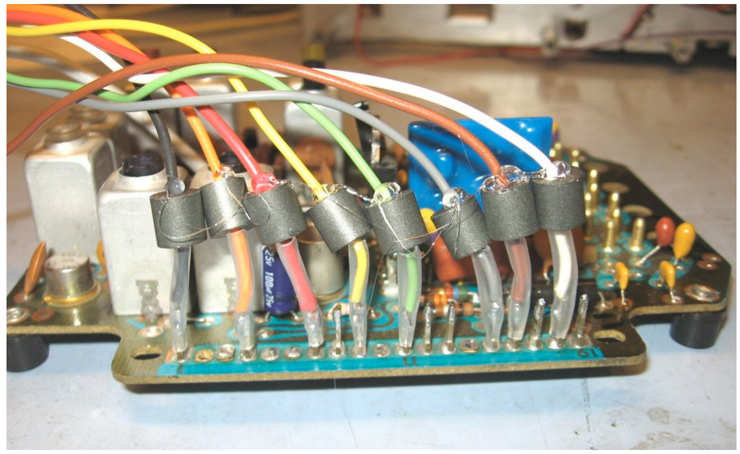
The lower images show the completed task of this regulator and switch.





Here's the modified exciter board to the extent wires are soldered to the P902 (I/O) pins with heat shrink to increase reliability. Some of the unused pins are removed to assist the ferrite bead clearance (some others are left). The beads can reduce RFI on the lines if the site is (RF) hostile.





A drop of glue will keep them in place. The unused pins that were removed are 2,3,5,6,10 and 14.

Control versions:

To control the transmitter some 9.6v stages are "hot" during standby, while latter 9.6v stages are "cold" (mainly the multiplier stages). When keyed they become "hot", causing the transmitter to output RF. Also, the OEM arraignment has Q406, the last output stage, (Q408 in the compa style) "live" all the time from the 12v (A+) source. Being a class C device; it only has output when the earlier stages are "hot". For this project this section is kept as OEM.

There were several different SRG versions of exciter boards developed. This involves the control method, such as what circuits are "hot" during standby and which ones are "switched" (to key the transmitter). These versions were developed in September 2009, based on research from 2000, using the TLD5132A exciter board. There are several versions; "A" from the 1990's and recently, September 2009 version "B" was developed however, not proven in service. Version "C" appears to be the best method and is the version to be used for all SRG transmitters. All versions are reviewed here:

Version **A** ; Only the channel element is running full time:

This version keeps the crystal and channel element running full time via the continuous 9.6v line. This improves stability. The other circuits after the CE are off during standby condition; that would include pulse amplified IC401, mic audio IC402, CE buffer Q401, pulse amplifier Q402, and the multiplier stages of Q403, Q404, and Q405, via the keyed 9.6v line.

For this version, cut the PCB run between IC401, pin 9 and CE4, pin 2 and C406 area. There's a straight run at IC401; right near it's pin 16 is a good place to make the cut. This isolates the continuous and keyed 9.6v lines. Jumper P902, pin 4 to pin 8. This feeds the voltage input of the PTT switch and other continuous 9.6v circuits. Jumper P902, pin 9 to pin 13. This feeds the keyed 9.6v circuits and components such as the IC and multiplier stages. Jumper the eyelet near P401, pin 7 to the area of the cut, just before C406. There are two eyelets that work great for this; one next to the pin 7 and the other above C406. This completes continuous 9.6v to feed only the channel element continuously, during standby state.

Version **B** ; The channel element, some transistors and IC are running full time:

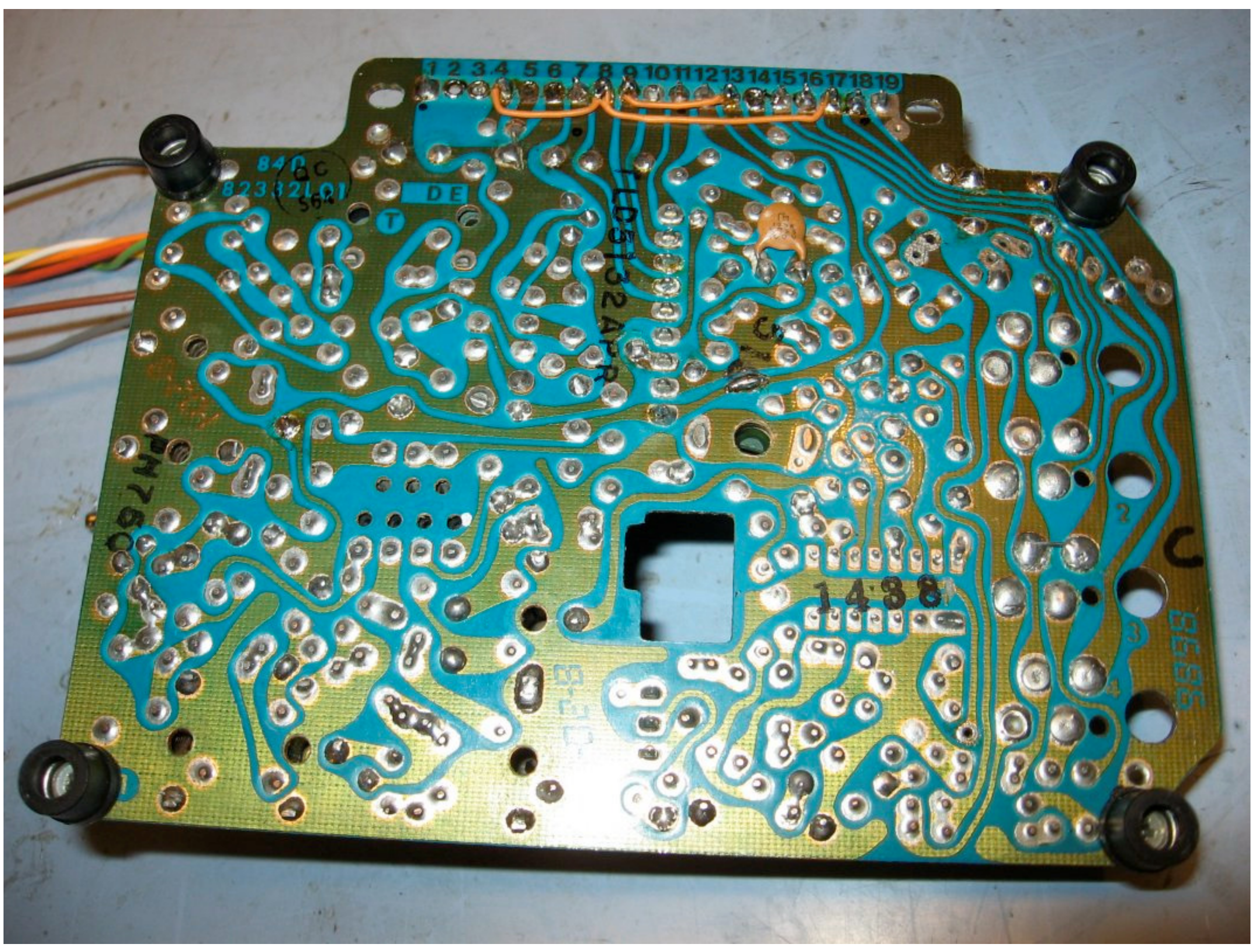
This version keeps the crystal and channel element running full time via the continuous 9.6v line. This improves stability. Some of the other circuits after the CE are also running during standby condition via the continuous 9.6v line; that would include pulse amplifier IC401, mic audio IC402, CE buffer Q401 and pulse amplifier Q402. The multiplier stages of Q403, Q404, and Q405 are off during standby state, via the

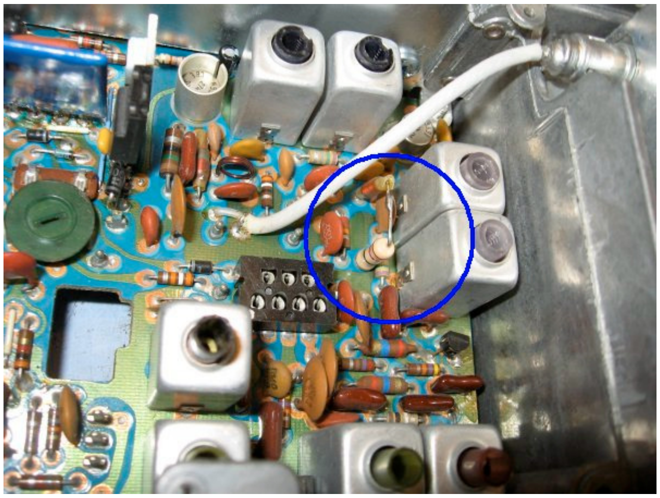
9.6v keyed line. For this version, cut the PCB run between P401 pin 9 and Q402 emitter. There's a straight run closer to the former to make the cut. This isolates the continuous and keyed 9.6v lines. Jumper P902 pin 13 to P902 pin 8 and pin 4. This completes the continuous 9.6v line. Jumper P401 pin 3 to pin 9. This completes the keyed 9.6v line. This version has not been tested/proven in actual service.

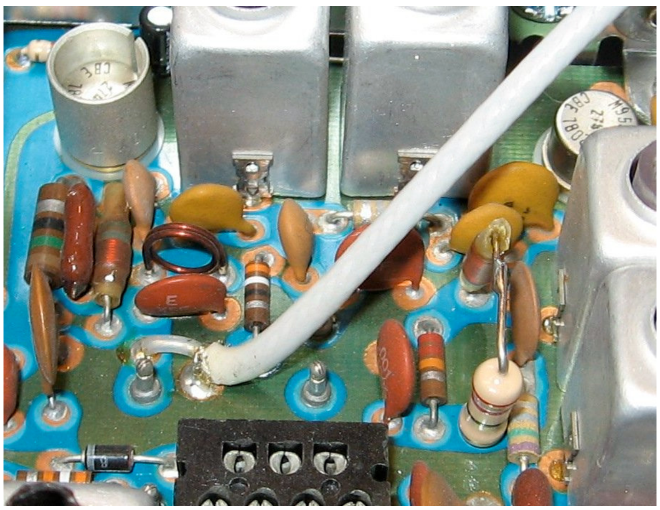
Version **C** ; The exciter's (last) output transistor is "hot" all the time with 12v. It's class-C therefore, no significant current drain is realized. The channel element is running full time with 9.6v supplied. The multiplier stages are "cold". When keyed 9.6v supplies these stages causing RF to output. The version is the same as version A except two shorter jumpers take the place of that one long one running over to the C406 area (for the continuous 9.6v); it looks cleaner. To recap, the procedure for version C:

Cut the PCB run between IC401, pin 9 and CE4, pin 2 and C406 area. There's a straight run at IC401; right near it's pin 16 is a good place to make the cut. This isolates the continuous and keyed 9.6v lines. Next, jumper P902 pin 4 to pin 8 and pin 17. Then, jumper CE3 pin 1 (old F3 line) to pin 2. This feeds the continuous 9.6v to the channel elements and PTT switch. Then jumper P902, pin 9 to pin 13. This feeds the keyed 9.6v to the audio circuits, IC, Q401 and the multiplier stages. Shown here is the exciter board with the completed version C modifications. This is SRG's new standard as of 2014.

If you are using the exciter TLD513x observe note 409 on the schematic of manual # 68P81008E40-L. It says to bypass R431 (33 ohm) for 1-4 frequency operation. It's located on the input of IC401, pin 14. Other radio versions don't have this. Also, some (compa) types don't use the IC401.



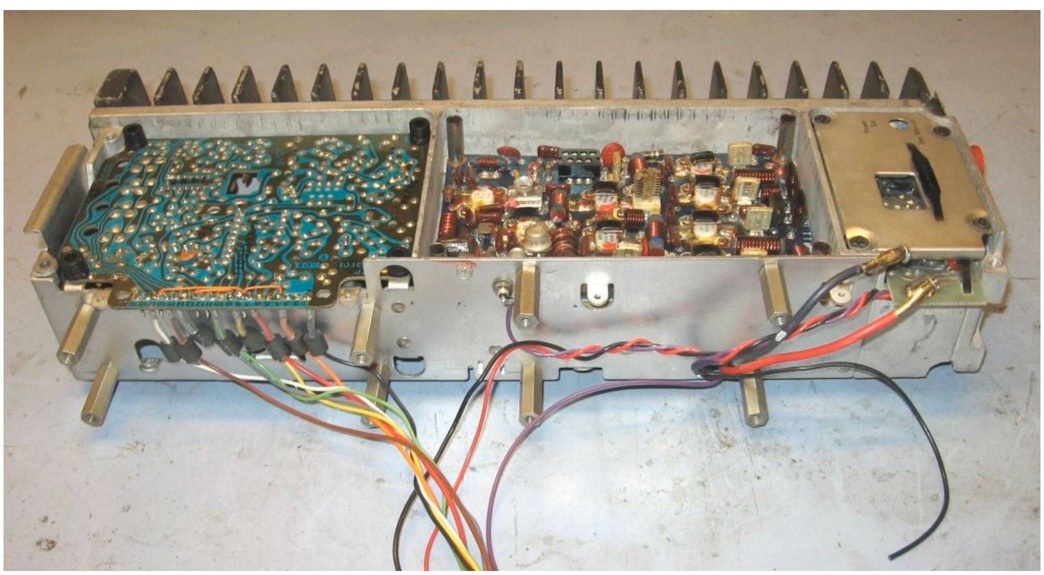




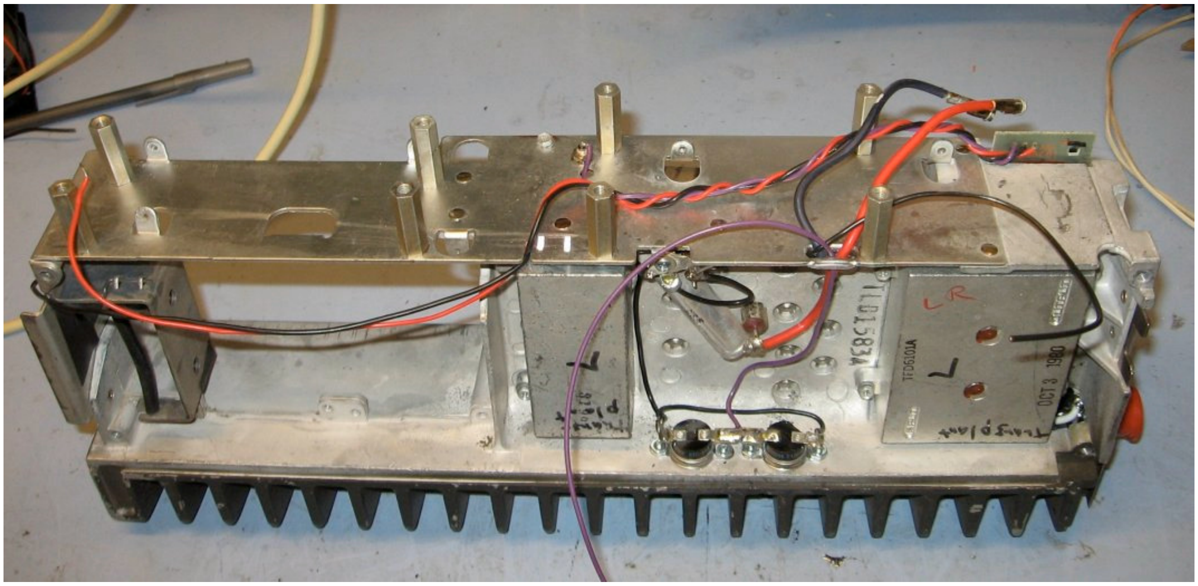
Sometimes there's a slight heat issue problem with some boards. The second to the last RF stage (Q405) may run a little too hot during long transmissions. In this case you will need to reduce the heat, but still provide enough RF drive to the PA. The RF stage of Q405's collector voltage is lowered a little by adding a 27 ohm (1watt) resistor in series with L413. (circled in the left image.) First, check to see if the transistor gets hot before you do this modification because you will loose about ¼ db output on some boards which could be a consideration.

This equipment is old and subject to wear. The (floppy) RF output coax is no exception. During normal mobile use, plus modification handling can cause most or the entire wire shield to break off which would cause level and interference problems. The coax is just long enough to reach the filter it plugs into so cutting it is not an option.

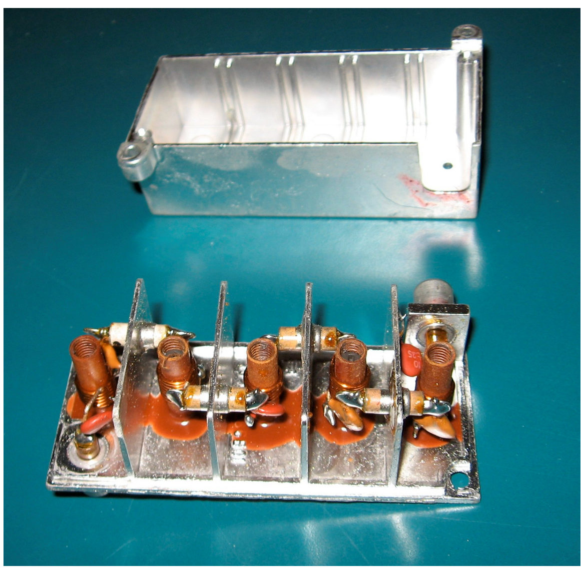
If this is the case with your board, remove the broken parts of the coax and board's eyelets. With a new piece of shield from a spare piece of coax and solder-wrap around the damaged shield to extend it to a point it can be soldered back to the board as shown here; a repaired shield on the coax output. Also, the "shorty" RCA plug's ground fingers get loose over time. It's a good idea to press all four in slightly for a tight fit on the filter module. Be careful not to slip and bend them in too far, when doing this.



Now, you can install the exciter board in the chassis as show here. Then install the wiring for the power control board; 3 wires; ground, A+ and control voltage. The latter connects to the PA control transistor. In this view a feed-though cap was used however, OEM just has the wire go through a hole in the chassis.



The picture above is before the exciter is installed. Did you notice the two silver “boxes”? They are filters for the transmitter. The one on the left is a band pass filter (Z501) for the exciter board’s output.



Z501 comes in two band ranges. Model TFD6111 is the (L) 132~150.8Mhz range and the TFD6112 is the (M,H) 150.8~174 range. As shown above, the “ L “ range won’t need any tuning or modifications for the 144~148 MHz amateur radio band (2-meters).

If you have the M range it will need tuning which can be done only while the cover is in place. However, you can modify the cover by drilling 5 holes as shown here. Keep them small to not affect the properties but enough to get a slim tuning tool inside. 3/32” is suggested. Take care to line up the holes right over the coil forms. Then re-assemble and install the filter for tuning. Be aware that some filters were built in the factory with excessive sealer and if you cannot break the seal it may have to be discarded for another one. The completed filter should look like the image on the left.

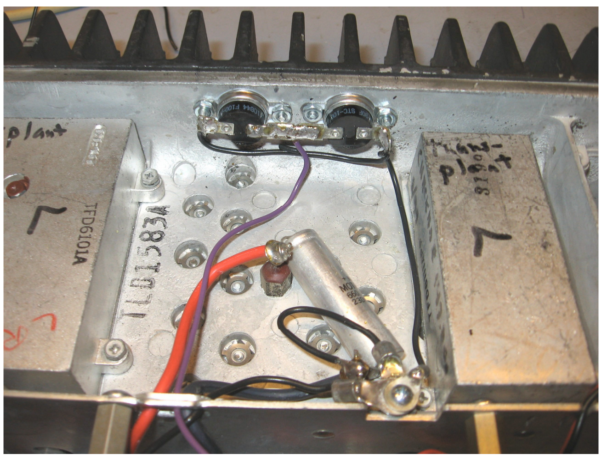
The filter output appears not to be 50 ohms. It’s best to tune the filter with a spectrum analyzer however; peaking it with a power meter works in most cases.

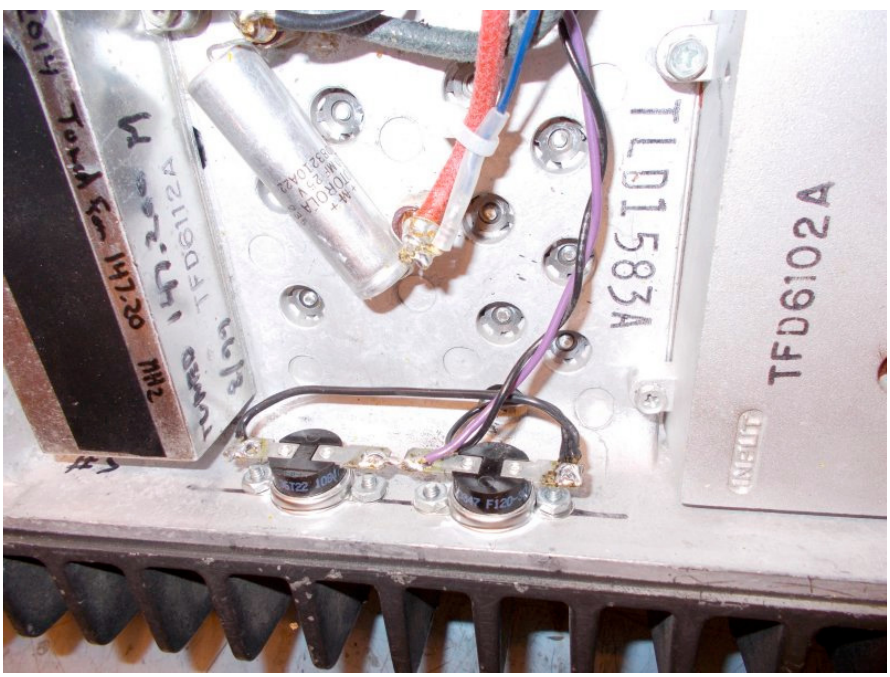
For final tuning this filter needs to be in the OEM circuit arraignment (driving the PA) and observing the RF level at transmitter output port.

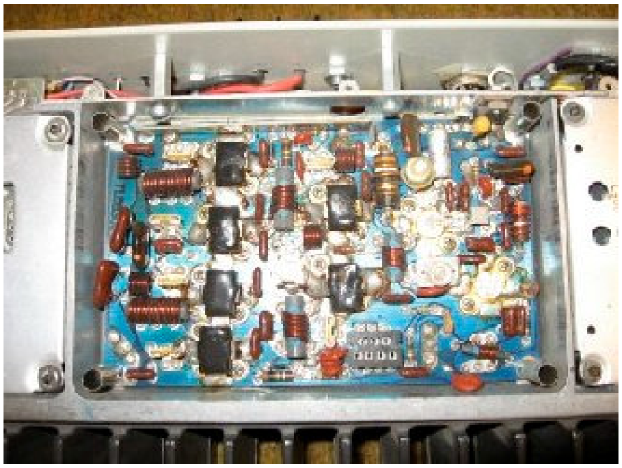
The other is a harmonic filter (Z502) on the output of the PA section. Z502 is not tunable but should be broad enough to make it to the top end of the amateur 2-meter band. For the lower portion (145 MHz there may be some challenges or suffer a little insertion loss.

The next area of discussion is the PA (high power) section. It's "hot" all the time however, not significant current drain (and no RF) is realized beause it's a class-C device. Keyed power from the exciter board drives this PA to produce an output. OEM specification for intermittent duty is +50dbm however, for repeater use this should be lowered by 2 db (at least). Even with the low (10v) voltage PA operation it gets hot during long transmissions. For example, some SRG traffic will keep the repeater keyed (transmitting) for several hours. Obviously, forcing some air across the heat sinks with a fan is a "fair" idea. The Author designed and built FCUs (Fan Cooling Unit) for the sites with this type of transmitter. Running the fans 24/7 wears it out. A better choice is have it come on only when needed, controlled by a set of thermo switches. Two are installed in parallel for redundancy. They are normally open, then close at 120° F. In the past 100° switches were used however, it was found they did not open back up at some sites that don't go below 90° in the summer. This is because of the 30° hysteresis (spec) on the switches. With the higher rating the FCUs can cycle properly.

When Installing them use a good layer of heat sink compound under each switch. 4-40 x 5/8" screws work well for the install. In the event you cannot find that length you can countersink them as shown in the lower right image.

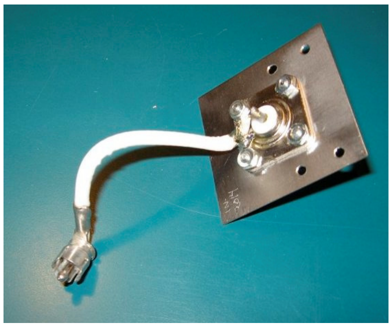


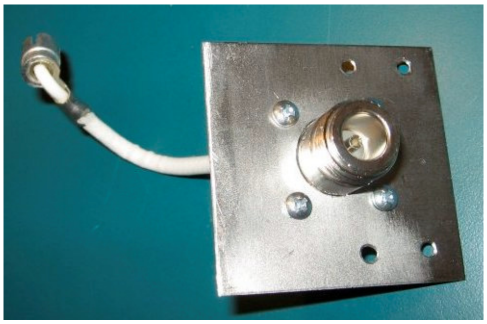


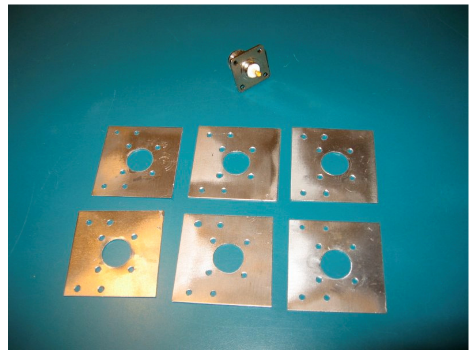


The last area of discussion is the RF output section. An interface plate had to be built to mount the connector and give more shielding on that end of the chassis. Steel plates were chosen and several being built as shown here for the connector. The 8 holes will be 7/64 and the one center 5/8”. In the event the holes don’t line up perfectly you can enlarge the small ones with a 1/8” bit.

The (old) OEM coax with a RCA connector at one end was used to plug into the power control board. The other end was cut off and prepped for soldering directly onto the new N connector. Shown here is the completed subassembly (back and front) ready for the radio

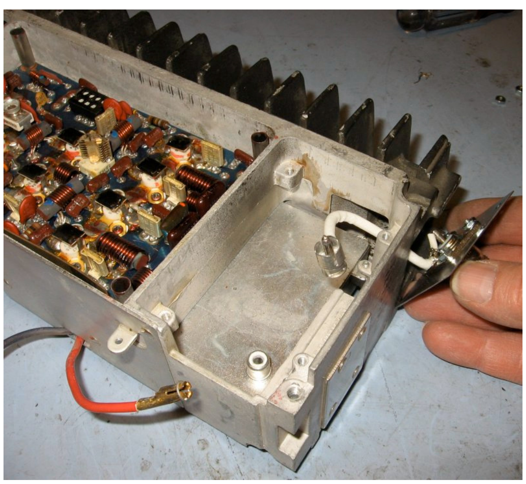


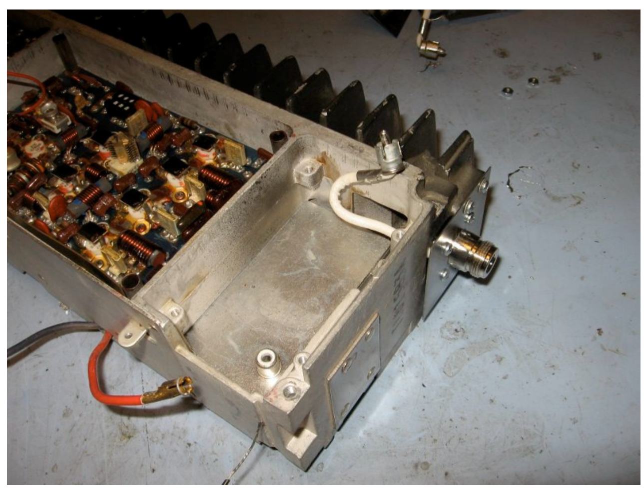




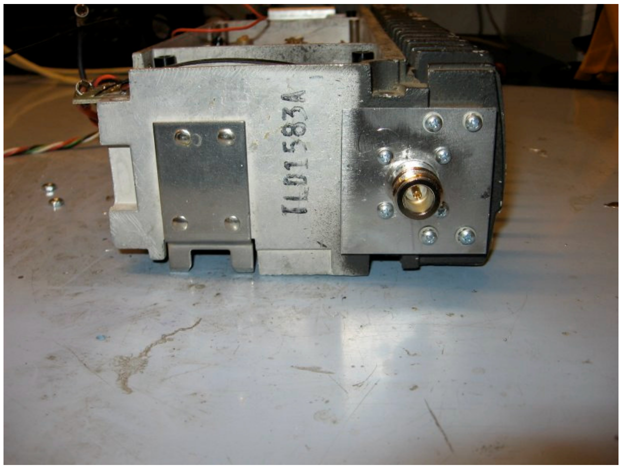
Now, mount the subassembly to the radio’s chassis. There are four 4-40 type holes already there for this. The 1/2” screws are too long, so either cut them, use washers or find 3/8” ones.

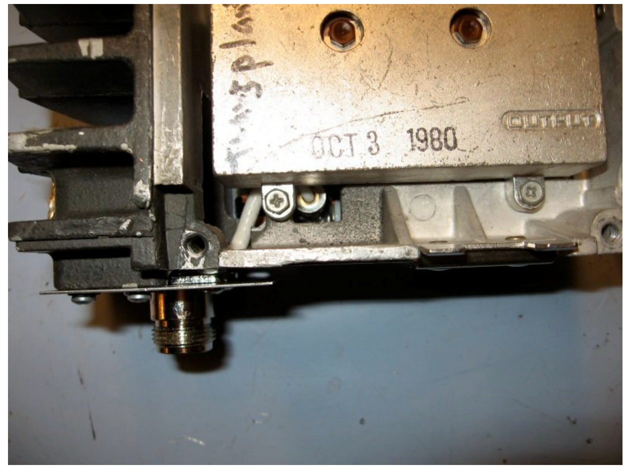
You’ll need to make two notches for the PA shield to clear the (mounting) screw heads.





Shown here is the completed task for the antenna port.





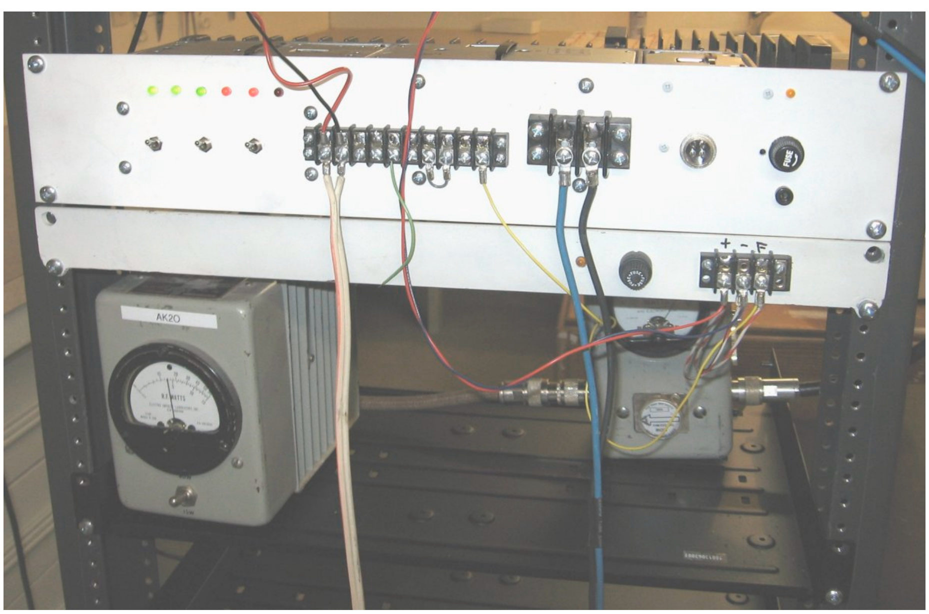
Without any of the front panel being built, this may be a good time to run the transmitter though its paces to look for any problems overlooked. In an extreme (bad) case you could stop here and start building a new one. Just clip the needed wires for power/control and put a load on the RF port, etc.

<u>Mechanical:</u>

The mechanical part of the project is working with the panel, drilling, mounting the standoffs and fastening with screws and bolts. Most of the bolts are 8-32 with phillips head. Phillips head (with a pan head) make it much easier to work with, especially in an angle, such as securing inside a cabinet. Even the terminal blocks, TB-1 and TB-2 have these types of screws to hold the wires and lugs.

TB-1 is Cinch-Jones "140" series size; **.**375" in holes, using a 6-32 machine screw. Molex brand has the equivalent in the phillips screws. ME part is 538-38770-0110 is for the 10-terminal. For the wires crimp them with #6 spade lug for 22-18 gauge wire, ME part 517-2232.

For the PA power, TB-2 is also available from the same vender, "142" series size; **.**563" holes, using 8-32 machine screws. ME part is 538-38211-0102 for the 2-terminal, rated at 30 amps. For the wires you can crimp them with #8 spade lug for 12-10 gauge wire, part is BS-33-8. For best (high current) contact area, use full rings instead, for 12-10 gauge wire, ME part is 517-1217. In any case, the Author prefers to crimp, then solder all lugs.



Keep in mind these vender part numbers are subject to change or discontinued.

Shown here is a typical set for testing the transmitter for endurance and stability. The front panel labels have not been installed at this point. The FCU below the unit is of an earlier version.

Tuning and checkout:

Install the appropriate channel element for your frequency. The formula is carrier frequency divided by 12 for the crystal frequency (inside the channel element). You might consider sending the entire channel element for crystallization so it can be compensated as well. Doing this also has the advantage of the crystal company being responsible for the proper formula; all you need to supply is the carrier frequency for the model of this radio. Next, tune the exciter board as usual per the service manual. In the event its not available you can use the following procedure (running the PA at 10 volts):

The meter socket pins 1~7 are functional either with a stock test set or a simple meter. If using the latter, typical voltages are as follows (when properly tuned): (a RS22-204C meter was used for tuning).

Pin 1 is IDC-audio level (no tuning here).
Pin 2 is channel element output; typical + .865v (no tuning here).
Pin 3 is the pulse amplifier output of Q402; peak L401 and L402. Typical voltage is -1.877v.
Pin 4 is Q403 output, or Q404 input; peak L403, L404. Typical voltage is -1.174.
Pin 5 is Q404 output, or Q405 input; peak L405, L406. Typical voltage is -.529v.
Pin 6 & 7 is ground.
Peak L407, L408 for power out using a power meter or spec analyzer. Minimum level is a +26 dbm to properly drive the P.A. section. Typical level is +28.451 dbm (700 mW for math challenged folks).

On the power control board turn R611 fully CCW (min resistance). R610 will be your power control setting. For transmitter output levels, (intermittent duty) rating is +50dbm (100w), +49.5 is 89.13w, +49 is 79.43w, +48.5 is 70.8w and +48 is 63.1w. As you can see "watts" change is overrated when comparing to with log scale.

Most conventional amateur stations that use this radio (and perhaps these modifications) normally run the entire station on one 12v power supply. For the SRG stations are configured differently. For example, the exciter section runs on conventional 12v while the transmitter's PA section is on a separate, 10v supply to keep IR losses to a reasonable level. It might be useful to know what the current draws are as shown here.

Micor transmitter study for power figures, both conventional and K-SRG arraignment

Status	DC input in volts		DC draw in amps		Remarks
	Excitor	PA	Excitor	PA	
Standby	13.80	10.00	0.165	0.00	
Keyed **	13.80	10.00	0.384	19.50	
NOTES:	All test are with transmit port out set to +48				
**	K-SRG arraignment with separate 12v & 10 v supplies; the latter for the PA onl				
	All figures are typical however, may vary				

PA heat:

Setting the power out to +48 dbm will draw about 16 amps from the KPS-20 supply. Using the FCU mentioned earlier will keep the heat issue to reasonable control. Typical time for heat-up to signal the fan is 6 minutes, while cool-down to turn the fan off about 13 minutes, with the 100°F past switches, in a cool environment. Using the 120°F has not been timed as of printing of this document.

However, there is another trade-off. As you may know, power factor (PF) ranges from 0 to 1, or an efficiency of 0 to 100%. Running the transmitter at this level the PF (power factor), AKA power transfer efficiency (x10), is about 35%. By lowering the RF output to +47 decreases it to 34%. Let's take a look at the formula on the next page.

NOTE: For this discussion, you'll need to convert (back to old school) RF levels to linear.

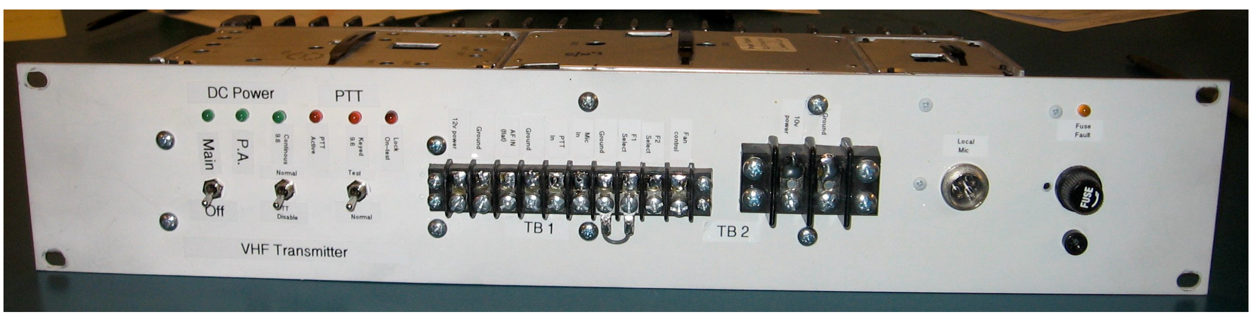
RF output of 72 watts draws 176 watts from the supply; @10v x 17 amps = 176. Take the RF output (72w) divided by the 176 from the supply = PF of .3845 or an efficiency of 38%.

RF output of 50 watts draws 147 watts from the supply; 10.5v x 14 amps = 147. Take the RF output (50w) divided by the 147 from the supply = PF of .339 or an efficiency of 34%.

RF output of 30 watts draws 114.5 watts from the supply; 10.8v x 10.6 amps = 114.5. Take the RF output (30w) divided by the 114.5w from the supply = PF of .2621 or an efficiency of 26%.

If you study the (rounded off) figures you will see the lower RF power levels causes the supply's voltage to increase. This slightly offsets the PF however, for this discussion will do. Obviously, the efficiency (PF) decreases pretty much directly with the RF power out. Heat loss reduction is more important than efficiency in the case for the SRG stations therefore, are set to run the lower power level of +47 dbm (in log10) or lower. That's "50 watts" for math challenged folks.

Shown here is the completed project with labeling on the front panel; serial number 4, ready for service.



Parts Listing: For front panel & chassis:

1 Panel, 19" rack type, Bud radio: PA-1102-WH
16 Screws, 8-32 x 1/2" for mounting the panel to the chassis
8 standoffs, 1", 8-32 thread, female-female, All Elect: SP-284 ($.35 each) for the panel mount
1 terminal block, "140" size, 10-position. Mouser Elect: 538-38770-0110 (TB1)
4 Screws, 6-32 x ½" for TB1
4 Nuts, 6-32 for above
1 terminal block, "142" size, 2-position. Mouser Elect: 538-38211-0102 (TB2)
4 Screws, 10-32 x ¾" for TB2
4 Nuts, 10-32 for TB2
2 Switchs, SPDT, miniature, Mouser 10TC320 (DPDT okay).
1 Switch, DPDT, miniature, Mouser 108-0010-EVX (or use this number for all three switches)
1 Jack, 4-pin, Hosfelt Elect: 4PMCS (for panel mic jack) (or MCM electronics 27-7977)
1 Fuse holder, 3AG, All Elect: FHPM-31 (or Mouser 576-03420004H)
3 LED, green defused, T1 ¾ - (for power indicators)
2 LED, red defused, T1 ¾ - (for PTT, keyed v, indication)
1 LED, red defused, blinking, T1 ¾ (for PTT lock-on indication)

1 LED, yellow (or orange) defused, T1 ¾ (for fuse indication)
7 Resistors, 1K (for the LEDs) (one is mounted in the PA section)
1 Pin jack, black

For the 9.6v regulator:

1 IC, regulator, LM7810, 220 case
1 Capacitor, tantalum, .22uf, 25v (mylar substitute is ok)
1 Capacitor, electrolytic, 4.7uf, 25v (this may not be needed in some cases)
1 Diode, common rectifier type, 1 amp, 100 piv (for the 6/10 voltage drop from the regulator)

For the 9.6v switch (keyed 9.6v)

1 Transistor, TIP 42, 220 case
1 Resistor, 2.2K, ¼ watt 10 % (2.7K okay)
1 Resistor, 1 K, ¼ watt 10 %
1 Diode, 1N4148/914 type (to isolate the internal 9.6v reference to the outside (12v) PTT equipment)
Note: this device may be located away from the switch.

For the PA section:

2 Switchs, thermo. type, normally open, closes at 120° F, Mouser # 802-STC-120.
4 Screws 4-40 x 5/8" (for thermo. switch)
4 Nuts, 4-40 (for thermo. switch)
Some heat sink compound for the switches

For the ground buss:

1 6-32 x 3/8" screw (longer ok, if you use many lugs)
2 lugs, #6 ring for AWG 14-16 (more lugs if you wish more ground wires)

For the antenna port:

1 RF connector, N type, female, chassis (4 hole flange) Ampenol "RFX"
1 Coax jumper, teflon type, 50 ohms (from OEM power control board)
1 steel plate gu 16-18, 2 x 2". (8 7/64" and one 5/8" holes to be drilled)
4 4-40 x 1/4"screws to mount the connector to the plate
4 4-40 nuts for above
4 4-40 x 3/8" to mount the plate to the chassis

For the modulation section (channel element pin 4)
2 Capacitors, tantalum, 4.7uf, 25v (2-freq operation) Mouser Elec part # 80-T354C475K025AT

Other needs:
Shop with tools and test equipment, well lighted; 40 hours typical time for this project
Glue; hot and epoxy (for holding LEDs, wires, etc in place on chassis & panel)
Labeling tape or marker (for labeling the front panel)
Misc., wire, AWG 20, 22, or 24; black, brown, red, orange, yellow, green, violet and other colors as needed and a few lugs. Some solid wire for board jumpers (CAT-5 orange wire is good).

K7SRG