Motorola MX radio for link 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. Understanding schematic drawings is required. Allow plenty of time to construct each unit, 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, Inc. made several models of LMR transceivers. Some of them were built with transmitter and receiver units put together as a single unit, either in portable or (base) station configuration. One was the "MX350" built around the 1980's. They performed with excellence and would last many years in commercial service. Even though they are 20 years old they are still in service. With the exception of an occasional (dried) electrolytic capacitor needing replacement they continue to work well for amateur service. This for two main reasons; one, they are very cheap (or free) to obtain for amateur service and two, they are set up for the "normal" +- 5 KHz channel deviation/modulation, while current commercial systems have migrated to the "narrow" band of half of this. Although there may be some unknown "SP" receivers and other sub-bands and chassis types, this document is focused on the more commonly known models in the UHF 450 ~ 470 MHz band and the VHF “Hi-Band” 132 ~ 174 MHz.

For this project the Motorola MX-series portable radio in the 2-meter and 70cm amateur band is used. For 70cm this project is support equipment for Spokane Repeater Group. This equipment works in the "background" for managing user signals (links) to a control point of the System. The VHF transmitter is not practical for link/repeater use. A VHF receiver and UHF transmitter can make a nice little user remote package (access point) running low power demand. From OEM specifications, no performance or reliability degradation was observed from the modifications discussed in this document.

Because the MX Tx and Rx units are one unit they cannot be separated for full-duplex operation. They can however, be used as a receiver-only or transmitter-only unit for up and downlinks respectively. For a same-band duplex unit two MXs are used in the same package.

This receiver uses a (noise) type squelch circuit to keep the speaker and/or line (AF) output silent during no activity. During activity the audio path needs to turn on thus, providing activity to a controller or associate transmitter’s audio circuit. The squelch also needs to signal such a controller or transmitter for its PTT input. These and other factors are address in this document.

The purpose of this project is to promote good communications audio, starting with repeater/systems. Better practices are used for all SRG projects. Some of these will be covered in this document.

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.

Test Tone Level and Test Level Point:

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.

Other terms:

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 a sufficient 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.

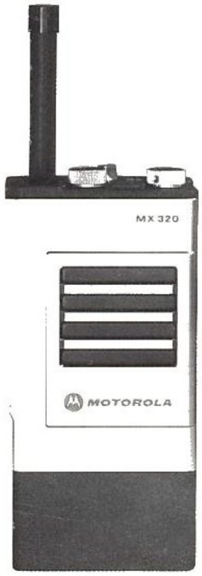
For flat audio processing there's a "cor/af board" design (by the Author) to work with most FM receivers. This board is "fixed" with soldered wires (or screws, such as the RF-IF board in the receiver). A "card" is removed simply by pulling it out, such as with the Spectra-Tac shelf. If the cor board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

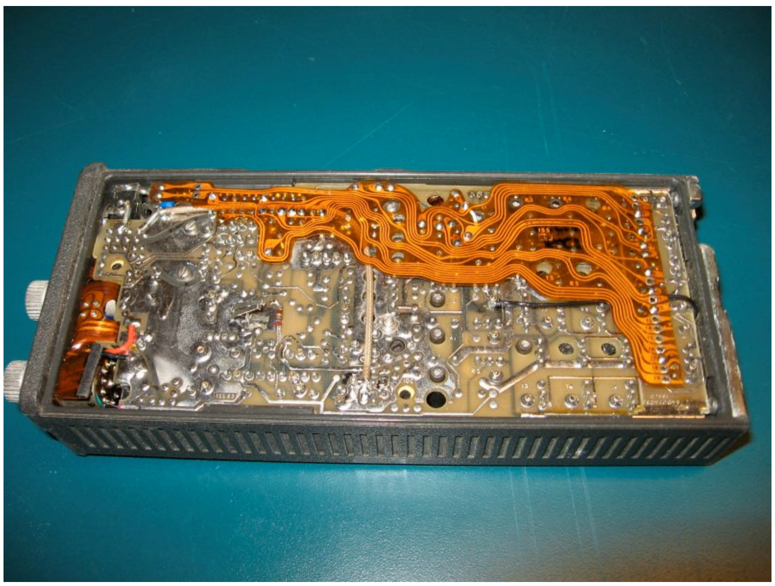
The Author is the founder of SRG, which is a non-profit organization for the development of equipment, operation and enhancement for the benefit of other amateur radio operators doing Public Service (emergency traffic) and other hobby type discussions. http://www.srgclub.org

K7SRG

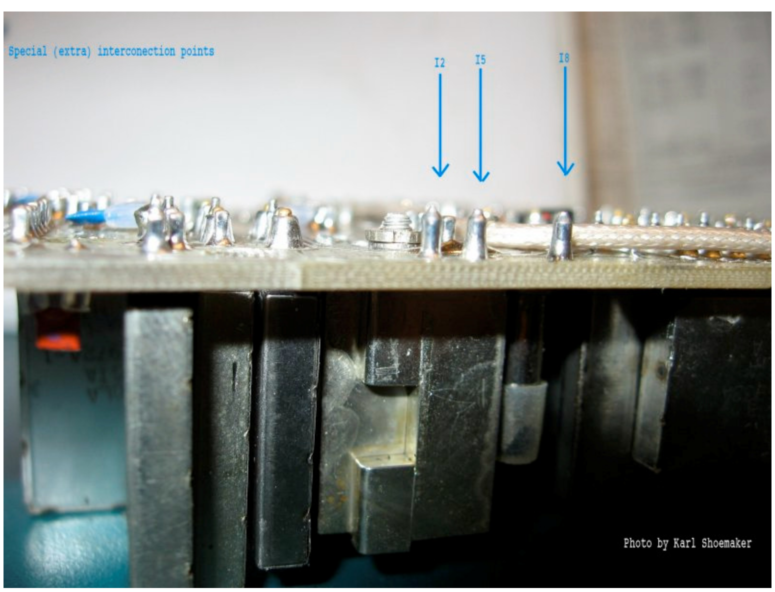


The radio:

The Motorola MX-350 (35x) radios were produced in the 1980's and performed very well as portable units in the 150, 450 and 800 MHz bands (VHF-UHF) for commercial and government services. One distinct feature of this radio is modular (units) inside, plugged into a motherboard. The radio came in the "2W" or "5W" version, with 1-8 channel, PL or DPL, or even "DVP/DES" encryption. Both transmitter and receiver performance is good and (basic) frequency response is very good as well. The transmitter does not need any audio frequency compensation, only the receiver, which is minimal. The receiver's a single conversion with an I.F. of 21.4 MHz. Since this project is about the 70cm band we will be covering the UHF model however, a few points with the VHF model, too. Most of them are the “5W” and 8-channel version. It easily tunes down to the amateur 70-centimer band. The radio will duplex however, the receiver will have degradation with the loss of effective sensitivity of 10-12 db therefore, not recommend. For a duplex link you should use two radios. If this is your first project on this radio its best to study both sides of the main board and the accessories that may go with it. This would include the (OEM) manual’s diagrams.



With the rear covered removed you can see the special “flex” circuit board. This one is for the multiple PL feature. There are others like this one in the radio for functions such as volume, squelch, power input (from the battery) and channel selection. The multiple frequency board has a diode matrix to control which transmit offsets are used for the channel position. For example, channel one may be “talk-around” (simplex) and enables CE101 (zero offset), while channel 2 may enable CE102 for the +5 MHz offset to use this portable radio to access a repeater. In this case CE1 would be used for the Transmit and receive of both channels. For this project only CE1 and CE102 will be used. This example is a UHF model.



Here’s a side view where some of the “I” connection points are soldered to the multiple PL flex board. Some of these points can be use for the modifications such as the SDI wire to be installed, later.

These points (no pun intended) are brought up to further understand how the (OEM) radio works, should you run into a problem, such as a shorted (or open) circuit run or other possible damage because of the used equipment’s condition that may be found for your project.

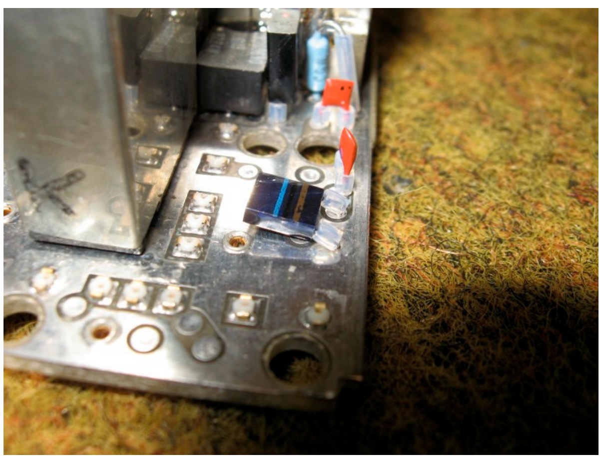
For the project, remove the radio main board out of the (plastic) OEM housing, discarding all the top controls, front and rear covers and ending up just with the main board as shown.

The coax shown is for the receiver and will be relocated at a later stage of the project.

In addition, the (mechanical) T-R relay, K101 will be removed.

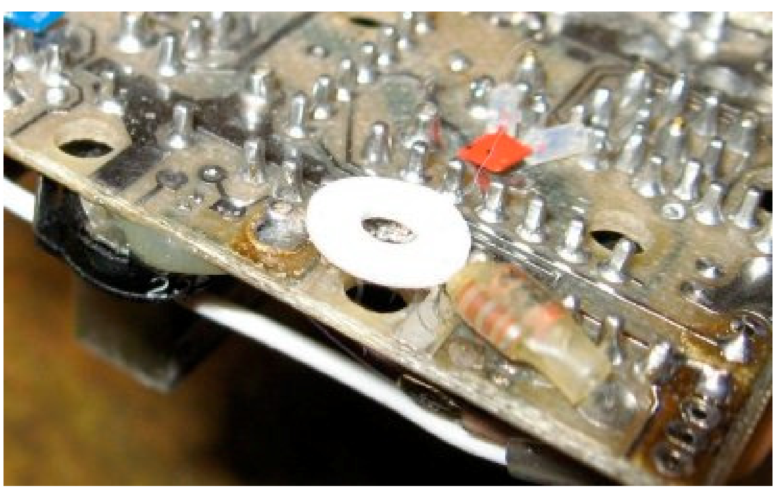
RF and power routing considerations are covered later in this document.

Another interesting point to note is that the two diodes near the top and right of the image. A (custom) arrangement can be had by installing "steering" diodes to the PL disable lines, This would allow automatic squelch mode when the user changes channels. In this image channel 5 selected puts "P" voltage on CE5 and also the PL decoder/control circuits to put the radio on carrier squelch on this channel only.



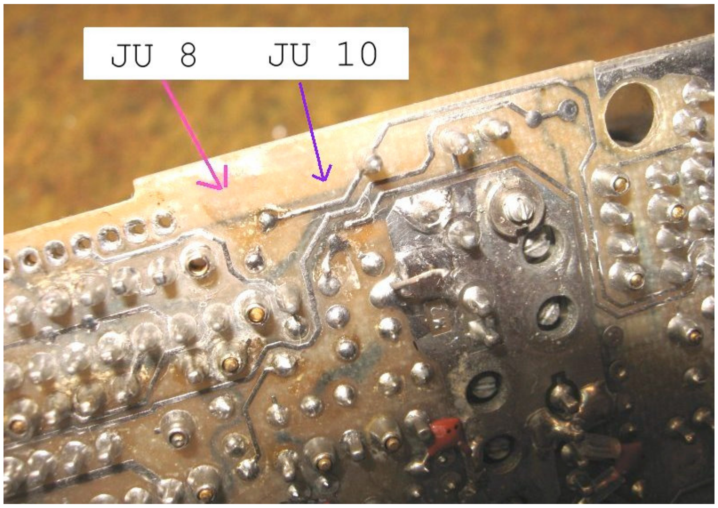
Occasionally, components get bent over on the main board as shown here. To protect the leads just leave them as is, unless it's interfering with a module.

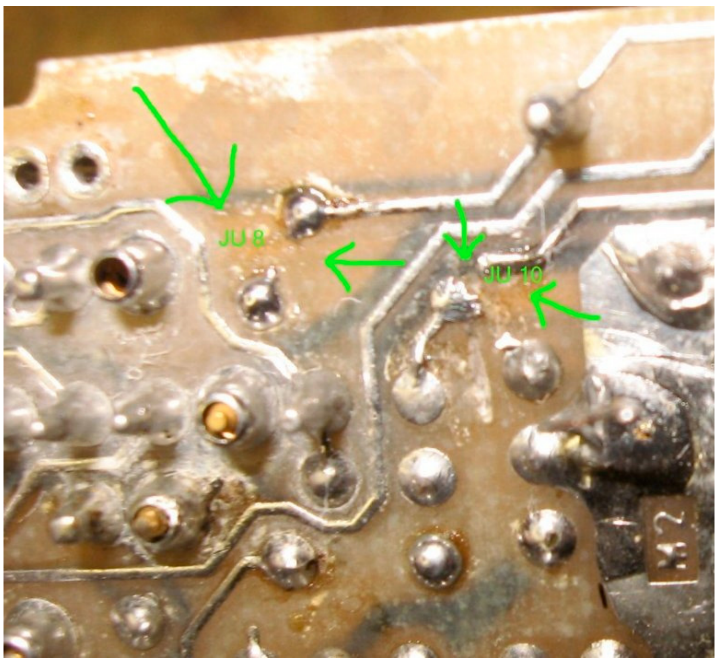
The "lost" controls will be mounted with new parts on the front panel of the chassis. This would include the volume parts of R308,and squelch parts of R311. The associated capacitors will be located on the interface board; C304 and C301 for the volume and squelch feeds, respectively.

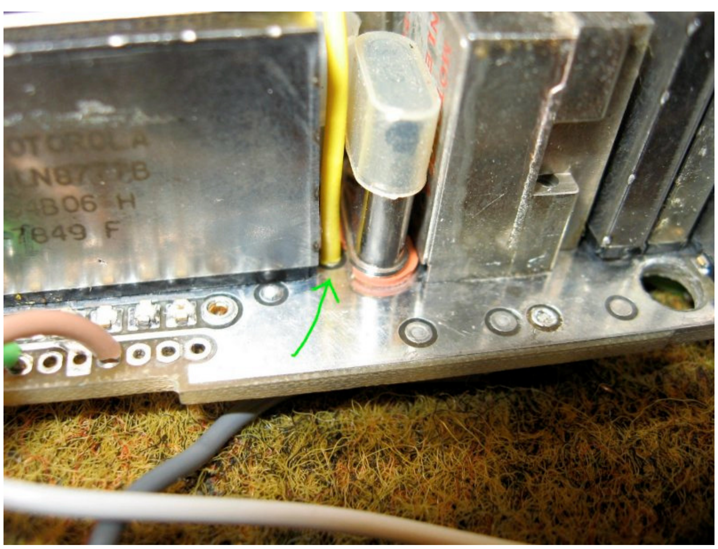


The volume swap resistor, R309 was left out. This is a circuit to prevent the speaker volume from being turned completely down, for portable use and not base station use.

The main board will be mounted on a chassis, right side up, with standoffs. There will be considerations on the standoff locations so no board run shorts occur when the 4-40 screws are tightened down on the main board. . One way is a nylon washer over some runs that cannot be removed. During testing expect some instabilities. The other holes won't need the washer, thus providing a good ground connection to the chassis, which is needed, for a stable operation.







For a good connection for the "COS" is a hole, part of JU10 (towards pin 4 of U9 side, next to a crystal filter, shown on left image).

For the "SDI" (OEM PL indicate) point, I-5 makes a good one so install the violet wire to that point. It's a "high" output during standby and goes low during a valid tone decode.

Connecting the COR and SDI to the (separate) COR/AF board will create the AND squelch for the (separate) cor/audio board. More on this later. Next, cut JU 10. There is more discussion on this later on page 15.

A side note for U7; JU11 is IN. (is out for selective call units, in portable service). This U7 also regulates the +4.6 ("F") for other modules therefore, is important it's functioning correctly.

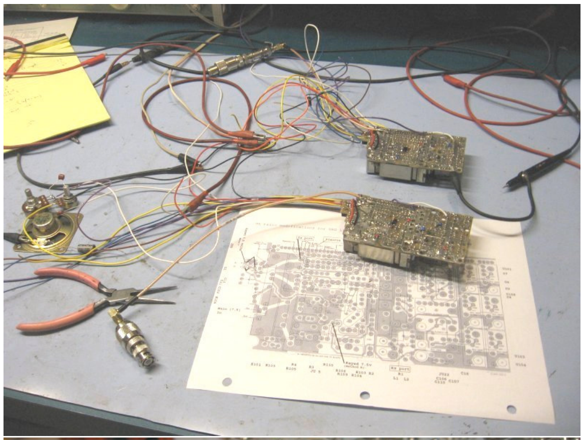
JU 8 was cut as well. After further investigation it was determined this was unnecessary. JU 8 is used to override the portable's PL mode switch S303, from line "P". For the replacement project, of course, this feature is not used nor is S303. For the first unit it was left cut, to save time.

Earlier production had all the wires installed on both the transmitter and receiver, thus tucking the unused ones. However, this was found to be a source of slight confusion and created a bulky install. Therefore, that idea was dumped and only required wires for each radio were installed.

Per the SRG block and level drawing (separate document), the transmitter has 2 control (7.5v) lines, (flat) AF in, mic in, 7.5v main power and ground for a total of six wires. For the receiver, has 2 speaker wires, volume & squelch hi point, volume and squelch wipers, COR, SDI, 7.5 power and ground for a total of ten wires.

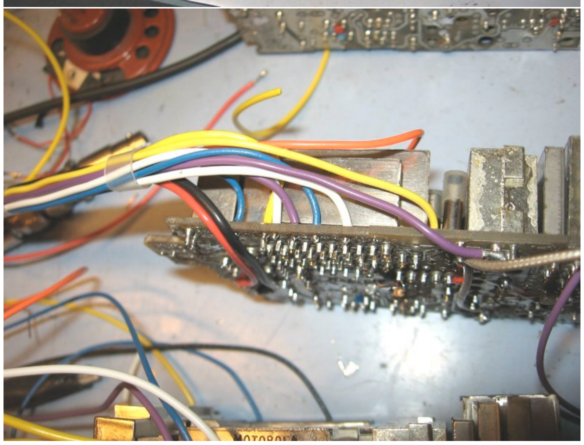
A full set of plug-in modules are left in both the transmitter and receiver which provides a handy "storage" place for any unused ones, in case trouble shooting (swapping modules) is needed at the remote site. The only exception is for off-grid stations whereas, the "spare" modules are not included because some of them still draw excessive standby current. Off-grid stations need to draw as little power as possible.

Wire colors were chosen for association from previous repeater projects by the Author.



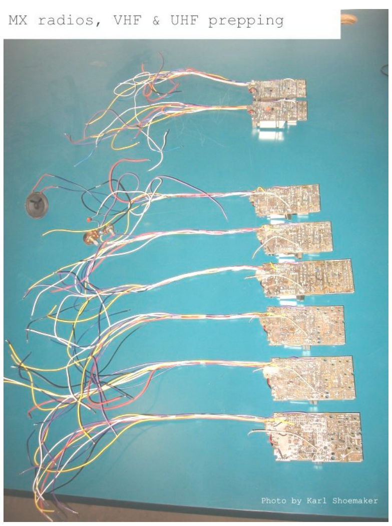
You can bench test the radio before finding a permanent box to mount it in. Be aware you might have some RF issues with the squelch circuit, while out of a shielded box, with long wires, such as shown here. Once it's inside the box and bonded, it should be quite stable.

The board can be mounted in a shallow box, such as the Bud CU-247. The wiring shown is in "rough" state, being this is a prototype in the working. When you clean up the wiring, and perhaps using ties, making a "umbilical cord" leave enough length to allow easy flip out of the board for maintenance.



This photo was taken before the new (amateur) frequency was installed in the CE. When you get the new crystal you can align the radio on the new frequency. In the past you could send in the entire channel element for the new crystal installation, proper compensation and testing. The Author has been using ICM since 1977. However, they closed in 2016. Therefore, you will have to do your own compensation until a proper vender can be found.

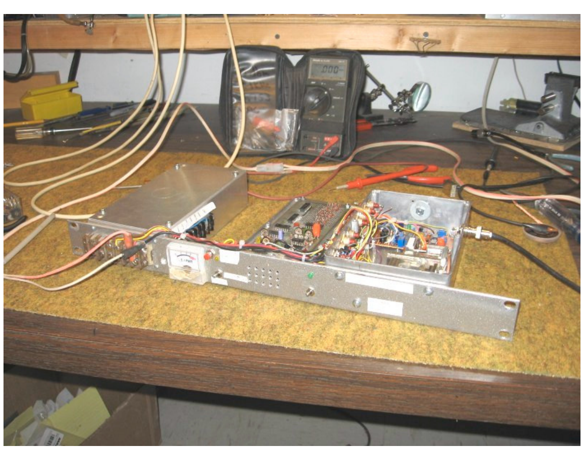
Shown here are several UHF units being prepped for links. The VHF units are being built for remote user receivers. They have been removed from the OEM case, relay removed, runs cleaned up, JU9, JU10 cut, all the wires installed, stripped and tinned on the far end, ready for testing. The 6th one in the back already has the temporary controls at the end of these wires. The last two in the background are more UHF ones to be tested as well. It’s more efficient doing several (assembly line type) rather than a “onez-twoz”.



During preliminary tests, the receiver for UHF and VHF performed the best for any brand of receiver for basic frequency response, audio detector distortion, and sensitivity. Only minimal equalization was needed for SRG's specifications. That procedure can be found on the COR/AF board document; version 5.4 and 5.5.

The UHF receiver has excellent rejection. RF sensitivity into the box measures about -115 dbm for 20 dbq. With an additional band pass cavity it should provide a good uplink at a mountain top site.

This shows the completed unit uplink for the 20-Omak Tx project that’s been tested and aligned. The IDer is also mounted in the link box on the lid. ID audio runs into the COS/AF board's aux input. Its PTT line is paralleled with the COS/AF board's PTT-2 line. The cor/AF board provides the transmitter tail. The AF output drives the VHF (Micor) transmitter with a TLP of +3 dbm.



For the 80-Omak project (and other current units) the electronics is house inside a commercially made chassis. It’s a 1 RU chassis that is 12” deep. With the finished unit with controls on the front and ports on the rear increases this to 13 3/8” for the depth. Take this into consideration if you are mounting the unit inside a cabinet. There are pictures of this new chassis later on in this document. Since then a better 1RU chassis has been found as discussed on page 15.

<u>The Channel element</u> (crystal) situation:

For UHF radios the channel elements, CE1 and CE102 is used for a transmitter. Part numbers are KXN1039A and NLE6972A respectively. CE1 is referred to as the “LO” (Local Oscillator). CE102 is referred to as the “offset”. For receive only radios, CE1 is used. Further explanation may be in order here:

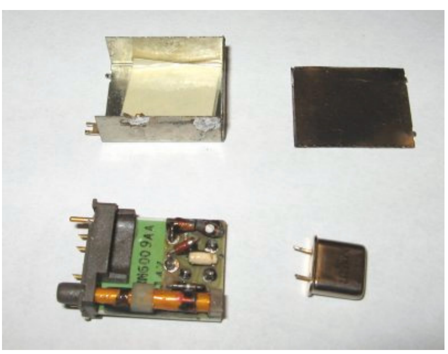
CE1 controls both transmit and receive frequency. It’s energized in either status. It contains the (base) crystal, plus other components, which triples the crystal frequency. Then it’s doubled in the A1 module coming out 21.4 MHz <u>below</u> the receiver’s operating frequency. This is also called “low side injection”. The difference is the receiver’s IF of 21.4, of course.

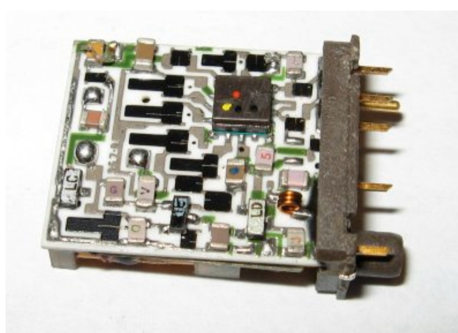
Therefore, the crystal formula is Fo – 21.4 / 6 = Fc. Whereas, Fo is frequency of operation and Fc is frequency of the crystal. Some OEM’s use different meanings so it’s recommended to pay close attention to that. However, when ordering a new crystal it is best to give the vender only your <u>operating frequency</u> and let them figure out the rest. If a mistake is made by them they should correct it.

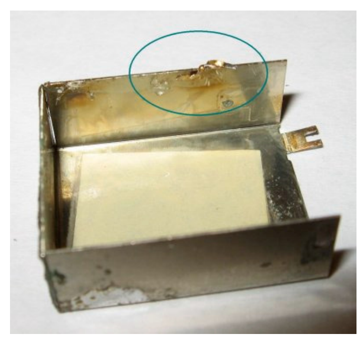
For transmit simplex (talk-around) you would mix CE1 (21.4 MHz below Fo) and CE101 (21.4 MHz) thus, coming out on Fo (no offset). For transmit to work a (Hub) repeater you would mix CE1 and CE102 (now being 26.4 MHz) thus, coming out with an offset of 5 MHz above CE1. Since this is for the latter, CE101 is not used and it left out of the unit. Only CE1 and CE102 are used.

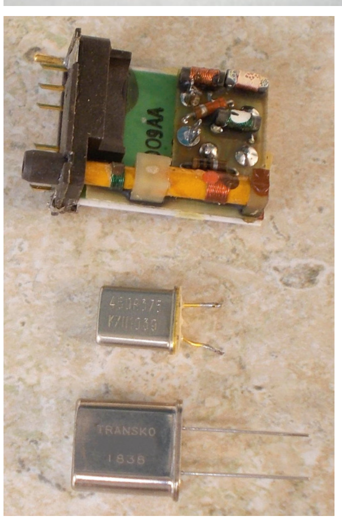
For the VHF radio; the formula for the crystal is Fo –21.4 / 2. For example, SRG on 147.800 has a (base) crystal frequency of 63.200 MHz.

For the MX radio the crystal should be AT cut, in series resonant +- 10PPM (or better) 0-70C in third overtone mode, in a HC25-short holder; 0.364” would be best. The UM-1 holder of a height if .303” is best. Otherwise, you need to drill out the bottom of the element (lower image). Your results will vary. The lower right image shows the upper can is OEM (KXN6212) while the lower is a .430” may be acceptable. The other images show the stages of disassembly of the element. Note the two tiny ground straps to the case. The case can be soldered for reassembly. It’s a very tricky process.









- **Control and current draw:**

A 7808 voltage regulator (U10) was added so the package to be powered directly from a station supply, typically, 12 or 24v, negative ground. This is close enough, since most MX portable batteries run 8v just after a charge. You also will need to be familiar with all the DC voltages the OEM manual refers as “T1”, “T2”, “R1”, “P”, “F”, etc. The (mechanical) T-R relay, K101, switches both the antenna (RF) path and some the DC voltages for both transmit and receive sections of the MX radio. To increase reliability it’s removed. Therefore, some considerations will need to be made, with jumpers and RF routing.

The T1 line draws 65 ma, while U103, pin 4 draws 52 ma, so, both of them draw 117ma. The OEM manual says U101 draws 10ma, CEs draw 6ma and U102 draws 70ma. Switching is done with a PNP transistor, pulling the base low (in respect to 7.5 line) now called Q1. A 2N3906 may not carry the entire T1 line, while a (bigger) TIP42 will. Consider this when deciding on a transistor for the keying method.

The 7808 regulator is rating about 1-amp. The unit’s transmitter PA section draws anywhere from 2-5 amps, depending on the power setting. Therefore, an additional 2N3055-pass transistor supplies the power for U105 and U106 amplifiers via the A2 line. The 7808 regular and the PNP switch drives this pass transistor, and low-current sections of the transmitter plus the entire receiver. During keyup draw is about 200 ma, which is well within the regulator’s rating.

U108 controls the transmitter RF level out with ALC (voltage) line from pin 5 which varies 1~1.7 v DC. In many cases the power out cannot be turned all the way down. To improve adjustment range change R106 to a 2.2 K. The PO now can be adjusted from +26.6 to +38 dbm PO. SRG spec calls for unit’s port output of +27 dbm however, the PA still gets hot during long key-up (hour). No solution was found on this issue at this time. Downlinks however, have less duty cycle (user transmissions).

Duplex:

When the transmitter is keyed it causes 10-12 db of receiver desense. Research lead to the output of U3. During receive it has an internal injection point to Z6, Z7, then onto the mixer, U2. U3 also has an output on pin 7 going to U102, pin 12, which is the transmitter’s PLL. It’s output is 21.4 MHz below the receiver’s operating frequency. When the radio is keyed the level increases by 20 db. As a test, R103 was removed thus, removing voltage on U3, pin 7 and U102, pin 12. All the degradation disappeared and the transmitter continued to work, but on an intermitted basis. Based on these observations it appears that the higher level is needed to properly drive the PLL circuit. Lowering the level 20 db is too close to the cut-off point for it. However, the real issue is believed that the higher level of 21.4 desenses the receiver’s IF, being on that frequency. No solution was found at that point. Therefore, it’s recommended using two (separate) radios for a duplex station/link.

- **For transmit only arrangement:** (downlink)

Install a jumper from pin 7 of CE5 to Y1 and X2. This will provide the F voltage to enable both CE1 and CE102. Next, connect a small coax cable from pin 8 of U107 to an (outside) BNC connector on the chassis (like the receive operation, unless you are using an internal duplexer in the chassis).

Because you won’t need the receiver operational you can remove many modules including U4, U5, U6, U8, U9, U121, U122 and U123. This will reduce current drain for an off-grid site. A1 and U7 need to be left in; for the LO’s injection to work with the offset frequency and providing the +4.6v, respectively.

Because LMR transmitters are (normally) FM most of the sections can be class C devices, which means power can be left on these devices. Without input RF drive there is no current draw or RF output. Control is done by leaving one or two devices off. When keyed these are switched on to cause the transmitter to be energized with a modulated RF output at the antenna port. This is done with a switching transistor.

There is a situation to be aware of when choosing your keying method. In the case of not using an isolator for the transmitter and another nearby signal is strong enough to get into the PA section will generate IM products, being voltage is applied to any class C devices. By switching all of the transmitter components will render the sections “dead”. Even though these devices still maintain non-linearity characteristics there may a reduced chance of IM being generated.

If the complaint on a PIM problem is only when keyed there's a good possibly it's your (project) transmitter is the cause. However, if you keep some sections "live" with voltage an IM problem may occur all the time. The point is knowing your station's configuration to help locate an RFI source. Of course (in any key method) the best way is preventive measure (with a populated site) by using an isolator (and the required LP/cavity filter as well) on your station's transmitter.

As indicated in the above paragraphs there are 2 ways to key the modified transmitter. Either keep half of the sections "live", the other half "dead". When keyed all sections will be live, causing RF energy. The other method is all the sections are "dead". When keyed all the sections come "live" with the same results.

<u>Key methods:</u>

The earlier method for "A" was to install a jumper from pins 6 to 1 of K101 and supply keyed voltage to pin 4 of U103. However, due to (used equipment) K101 eyelet damage this was abandoned.

For the current method for either "A" or "B" provides an easy wiring change for the keyed voltage, even at the remote site. Remove R110. Install an orange wire in each hole. One wire will be control for the T1-T2 lines, while the other will control pin 4 of U103, calling the (control) wires T1 and T4, respectively. Both have to be powered to create transmitter power out (keyed condition).

Q1 and U10 (and other components) are part of the additional components (modifications) for this package. All of these are external to the (OEM) radio PCB. Refer to the (separate) block and level diagram created by the Author available on SRG's web site.

- Method **A**: Connect both wires to the output of Q1, plus the "main" power (red lead). This is good for an off-grid site. because next to no draw occurs during standby. However, there is a minor issue that the VCO "zips" across the band during PLL lock. The RF level is 20 db down from primary carrier and lasts about 100 mSec, so this may not be a problem, especially if there's no other systems at the site. (This is the part where a portable radio may not be FCC type accepted for commercial base station operation.)

  (Note: Continuous power to T4 only does not appear to draw any current (to key with T1) however, for best control the Author chose not to perform method A this way.)

- Method **B**: Connect the T1 wire to continuous 7.5v (from regulator U10) and the "main" power (red lead) (from Q2 collector) and T4 wire to the output of Q1 (switched B+). This corrects the zip issue. However, there will be a constant draw of 62 mA on the T1 line. Take this into consideration if it's at an off-grid, powered site.

- **For receive only arrangement:** (uplink)

The discriminator, U6, pin 7 (through R4) (otherwise tie-point E8) feeds the top of squelch pot, R311, the LPF, U123, the local speaker's audio module, U7 and now, the cor/AF board input. The TLP is - 7 dbm. Connect the white wire to E8.

Connect a small coax cable to the input of the A1 module to an (outside) BNC connector on the chassis. Install a jumper from pins 7 to 8 of the (removed) K101. This will provide (7.5v) power to all of the receiver modules. Some transmitter modules will be energized and some not, but no transmitting will occur. Next, install a jumper from Y1 to pin 7 of CE5. This will provide the F voltage to enable CE1. Note: for receive operation both CE's can be enabled for convenience-pin 7 to Y1 and X2 (like for a transmit only mode).

The receiver's COR voltage will operate PTT line out to key an associated transmitter (with the cor/af board) or other device. For downlinks using a MX VHF receiver it may be on carrier squelch. The path would be linked back to a control point for further processing, such as (PL) tone decode.

For uplinks (controlling a system 2-meter transmitter) they need to be PL capable to prevent annoying RFI being heard on the system. Tone decode slows down audio path opening causing possible first word being heard by a user. To correct this issue the audio path needs to be on carrier squelch, but the PTT (control) needs to be on tone. Also, the (stock) MX in tone squelch (PL) controls the local speaker. It's best to have the local speaker on carrier for monitoring and testing at the site. For these reasons you will need to separate the COR and PL signaling outputs of the MX radio.

To do this, cut jumper JU 10. Install a wire in the hole towards pin 4 of U9, which will be the COR. Install a wire towards pin 4 of U122 (I5 point), which will be the PLI.

The JU 10 points originally were a source and path for the OEM “AND” squelch control. Cutting the jumper now makes them separate sources of signaling. Both of them is a source for the COR/AF board Feed both wires to this board which will process both signals. The result will be the PTT output will be an “AND” squelch (carrier + tone for activity to happen) while the audio will be on carrier. The COR board will also provide a “tail” for the associated 2-meter transmitter. This will provide a quick, but protected path for user reception on 2-meters.

When putting the station in service, the squelch setting normally will be set somewhere between the break point and maximum. At maximum it would open near the 20 db quieting point, only needed in the case of moderate RFI. The only exception if a MX radio in VHF is being used for user access. In that case the squelch would be near threashold and tone protected.

Typical sensitivity is –113 (20dbq) at the (OEM) 460 MHz range however, at 441 MHz area -115 has been found on some radios. However, this may be due to higher LO injection level. Something to keep in mind. When tuning the receiver from 460 MHz area to 441 takes only about a turn on the slugs of A1.

The receiver’s tone decoder-encoder U122, has a (low side) PTT input on pin 10 with delayed PTT output on pin 8 (for the reverse burst function) that goes back to the low side of the K101. For tone receive (PL) the OEM manual says JU9 is out. If you are converting a MX receiver section from carrier to PL (installing U122) be sure to do this. Otherwise, U122’s in and outputs may be “confused” causing tone decode failure.

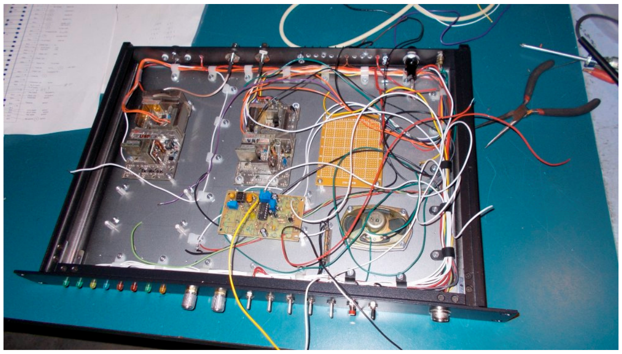
Also, since K101 and the flex boards are removed there’s no “pull-up” resistor to keep U122’s input (pin 10) “happy”. In most cases this should not be a problem however, to be “safe” install a 10K resistor from E2 to E1 (E2 is 7.5v source and E1 goes to pin 10).

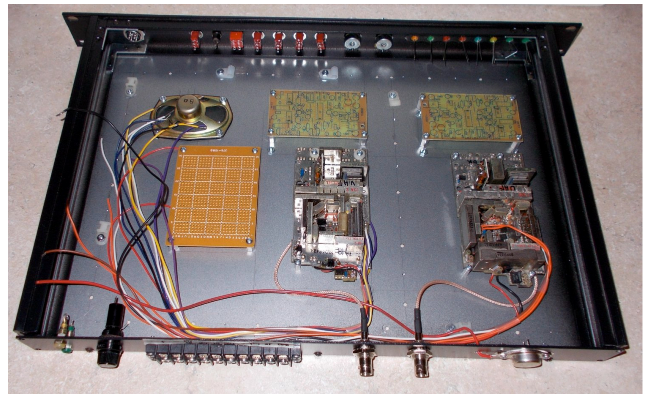
“Robbing" is possible for the CE1 for a method of troubleshooting or emergency repair of another radio since either uplink or downlink radios use the same CE1 frequency. This arrangement is similar to the UHF Micor mobile arrangement for Tx and Rx frequency control. CE102 normally comes with the radio and does not need any changes. CE101 also comes with the radio, but is not used and can be removed.

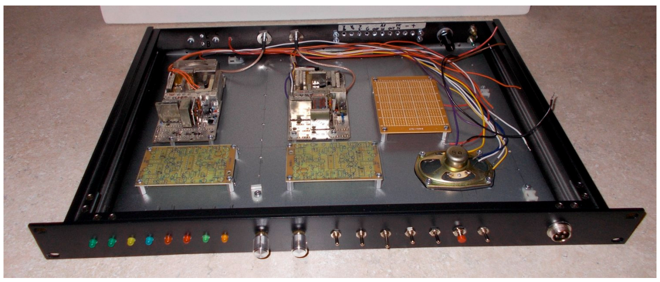
At a later (engineering) date the receiver’s IF signal could be rectified to be used as an AGC line to drive a meter circuit for front panel viewing of present/calculated R.S.L.

First, the front panel the holes are drilled and cleaned up for the indicators and controls. Next, the bottom chassis holes are drilled and cleaned up for the components to be mounted. There are several holes for the speaker audio to come out of the chassis plus some holes in the rear panel, later.

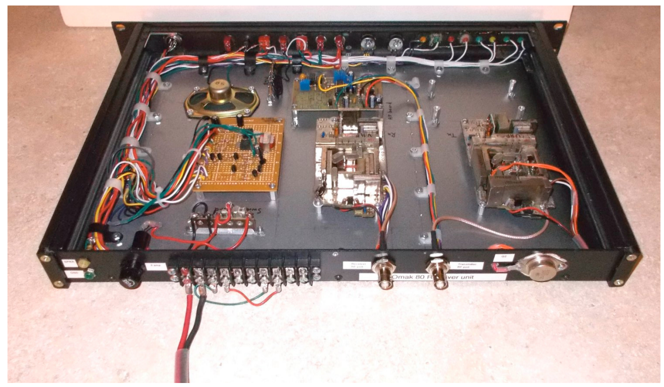
Next, the wiring between the components:

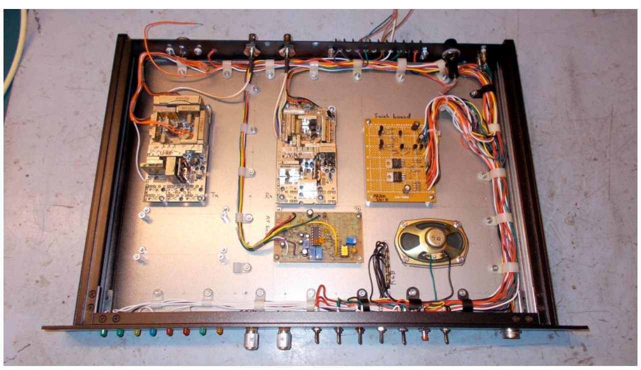


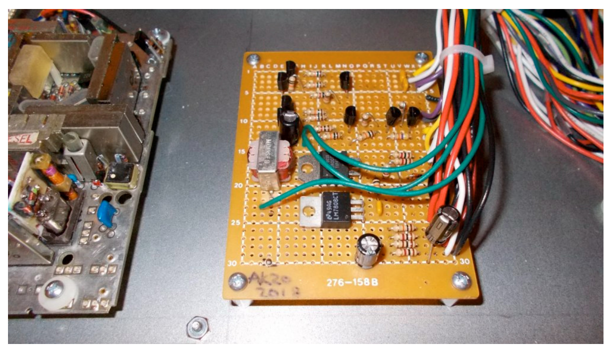




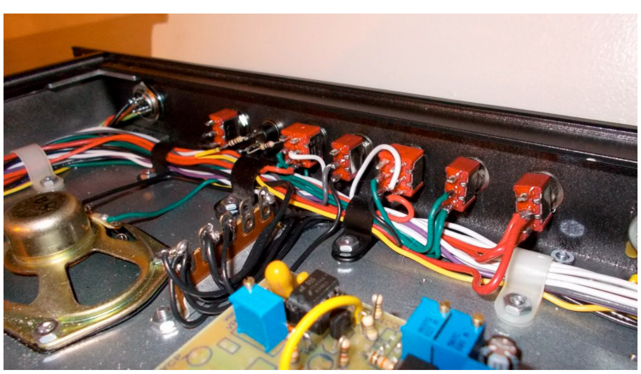
Most of the wiring is completed here. On the right is the switchboard; for voltage regulation and DC switching.



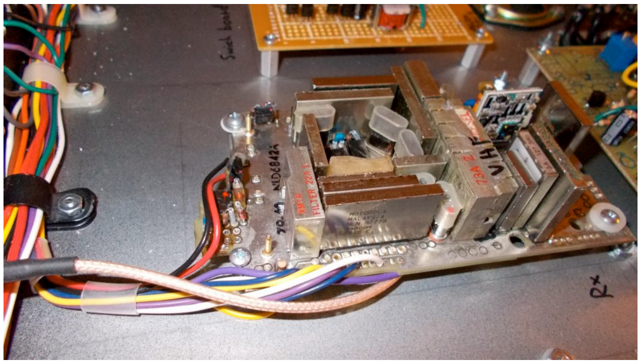


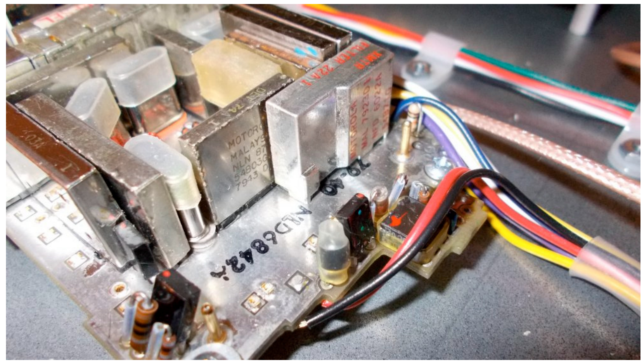


Shown here is an inside view of the controls on the left and indicators on the right.

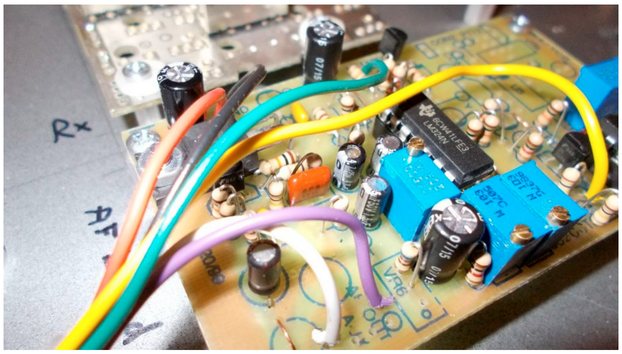


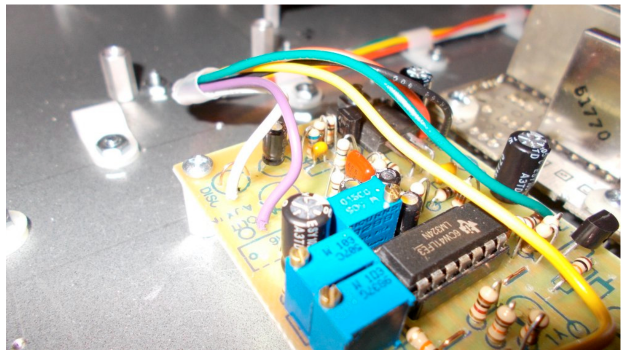
Shown here is the VHF (input) receiver from two different angles. The UHF (downlink) transmitter is pretty much the same as the previous units and earlier pictures in this document.



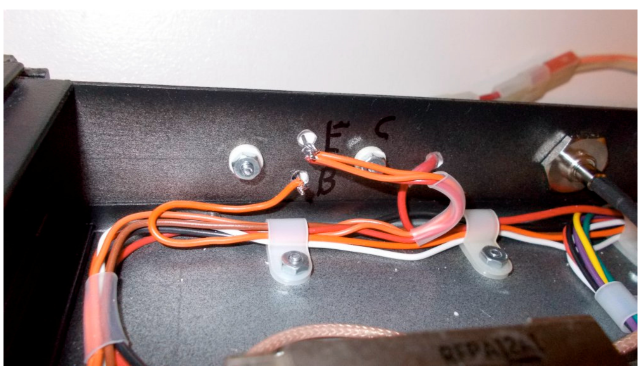


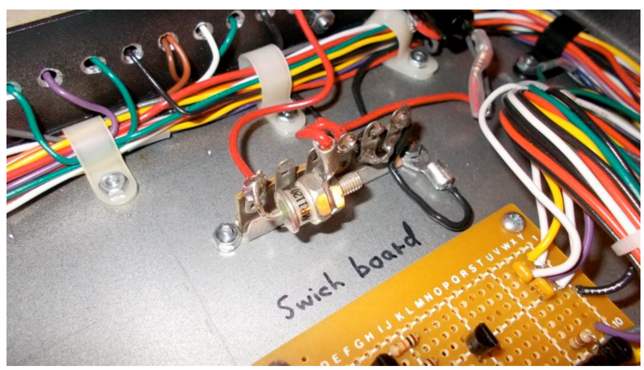
Here's some close ups of the COR / AF board for the receiver audio processing. It's set up as version 5.4 for downlink use. There's a separate document on this board on the SRG web site.





As discussed on page 13, the 8v regular is rated about 1 amp, which is about the draw for the downlink transmitter. Therefore, the regular drives an external 2N3055 transistor (shown on the lower left) to power the transmitter. On the lower right is a terminal strip available to add power protection devices. For example, the stud diode is in series with the DC power entering from the rear barrier strip. This prevents damage in the event the unit is connected with reversed polarity from the outside power source. The traditional voltage drop a silicone diode has is not a factor when regulating down to 8 volts as in the case here. A shunt would work as well, however, would blow the fuse causing a trip to the remote site for repairs. The reason for the strip is to give you some flexibility on these protection options.



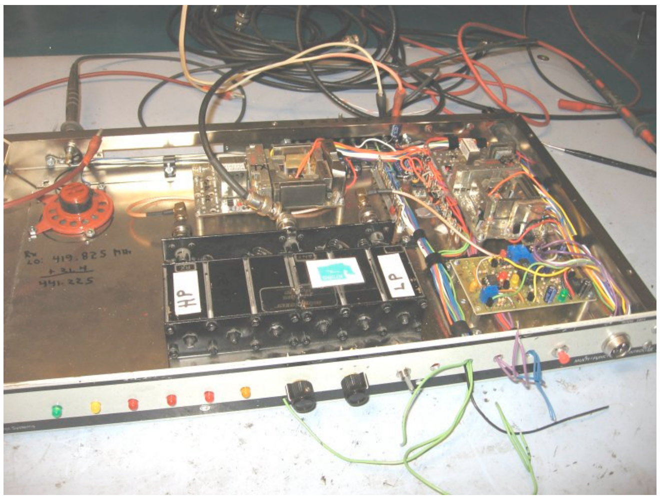


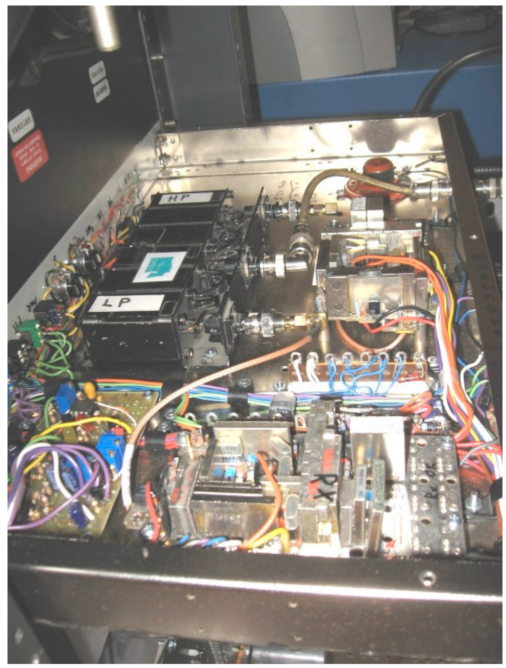
The pictures here are for the Omak downlink version (2.0).

Here’s a project where two UHF radios make up a complete (duplex) link package), including the duplexer, because of limited cabinet space. The bottom image is the complete unit, installed at an actual working site, in service in 2016. Future link packages are planned for an external duplexer, because modular system design is practical for repair (swap-out) efforts at remote sites. This would also allow one to install RFI protection devices on the transmit side, such as an isolator and band-pass cavity.

The chassis found from a vender was used for this project is about 13 ½”. Some of the deep cabinets should accommodate this depth are the GE Mstr-II and Motorola later, deeper (15”) ones. Depending on the (adjustable) rail position the Motorola cabinet may provide depth up to 18 ½”.

Below is a chassis found out of a junk box, which has a different depth than the chassis just described. Take this into consideration if mounting inside a cabinet. Obviously, open rack mounting with work for most any chassis depth.





Here’s a typical station with the unit. The chassis found was used from old equipment. The 1 RU is a nice feature for installations whereas, the cabinet is full of equipment. Since then, new chassis have been found (as previously mentioned). The only issue (for the Author) its painted in black, which makes visible troubleshooting more challenging.

Jumper Chart:

Mode:	JU-A	JU-B	JU-C	JU-D
For receive operation	IN	OUT	IN	OUT
For transmit operation	OUT	IN	OUT	IN
For both	IN	IN	IN	IN

(JU-B is no longer being used (reference only).

Strapping:

JU-A For Rx, K101 area, hole 7 to 8
JU-B For Tx, K101 area, hole 6 to 1 (not done; for reference only)
JU-C For Rx, CE5, area, pin 7 to Y1
JU-D For Tx, CE5, area, pin 7 to X2

Tx audio:

Research found a couple audio inputs (other than the mic input) for good frequency response. These are the two inputs on CE102, pins 1 and 2, for the TPL/DPL and voice modulation, respectively.

CE102	Pin 1 (TPL/DPL input)	Pin 2 (voice mod. input)
TLP	+9.5 dbm	+4.3 dbm
Test reference (2/3 mod)	+5.3	-.2
Coupling cap(for test)?	No	Yes, 10 uf
DC voltage on this pin	Static of .02	3
@ 10 Hz	-.2	-5.9
@ 20 Hz	-.1	-2.3
@ 30 Hz	0	-1.1
@ 100 Hz	0	0
@ 1 KHz	0	0
@ 2 KHz	-.2	-.1
@ 3 KHz	-.7	-.3
@ 4 KHz	-.3	-.7
@ 5 KHz	-.1	-1.0
@ 6 KHz	-.1	-1.4
@ 7 KHz	-.1	-2.0
@ 8 KHz	-.5	-2.6
@ 9 KHz	-.6	-3.0
@ 10 KHz	-.8	-3.6

As you can see by the figures pin 1 is flatter, by far. The little “bump” at 3 KHz is not explained, but will have to be used. The test was done a 3 KHz deviation to insure the transmitter modulation was in a linear range and the monitor’s response as well. Monitor was put in wide for this test. The input (from the panel) may need a heavy coupling cap, such as a 100 uf. Therefore, pin 1 will be the Tx AF input.

Because of the very high TLP on pin 1, an optional audio amp can be installed to drive pin 1, thus creating a more reasonable TLP, for example, 0 dbm. However, this was not done on any SRG projects.

Connection	Wire color	for: Tx or Rx	Function	Remarks
X2-Y1-CE5-7	(any)	Tx	enable +4.6 ("F") to CEs	
K101-7-8		Rx	enables "R1" "R2" voltage runs	
Cut JU10		Rx	allows separate PL control, and/or a PLI.	
Cut JU 8		Rx	enables local audio CS (later found to be optional).	
JU10 U9 side	YEL	Rx	Pickoff point for COS	+4v sq.; goes low on open
E4	BLU	Rx	local speaker audio	
E12	BLU	Rx	local speaker audio	
E10	VIO	Rx	volume wiper	
E15	WHT	Rx	volume hi	
E7	YEL	Rx	squelch wiper	
E8	WHT	Rx	squelch hi	also discrim. TLP -7dbm
I5	VIO	Rx	PL indicator	

Typical levels:

T1 B+ line draws 53.8 mA, T4 B+ line draws 97.9 mA, “main” (A+) only draws 19.36 mA on standby.

Keyed (RF out): +30 dbm @ 0.65 amps, +32 @ 0.83 amps, +35 @ 1.22mps, +37.2 (max) @ 2.0 amps. For entire unit operation allow for switching, receiver and the transmitter for total draw.

NOTE: For transmitter key method:

- Omak is A
- TC is B

A good crystal vendor for the crystals is Transko. However they don’t compensate elements – like no one does anymore (search continues). The Author’s contact is below, otherwise, just visit their web site of www.transko.com

Shannon Jacobs, Account Executive, Phone: (714) 528-8000 Ext. 206
Email: shannonj@transko.com

They do: Crystals, Oscillators, VCXO, TCXO, OCXO, VCO, SAW Filters, Crystal Filters, Ceramic Filter, Resonators, Inductors

K7SRG