GE Mastr II Station interfacing for repeater / 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:

For this project the GE Mastr II station in the amateur 2-meter band is used. This project is an access repeater for Spokane Repeater Group users. This equipment works in the "foreground" for providing local coverage for the users to enjoy. It’s interfaced with external linking equipment for positive and full-time connection with the rest of the system. From OEM specifications, performance or reliability was not affected by the modifications discussed in this document.

General Electric (GE) made several models of LMR transceivers. Some of them were built with transmitter and receiver units put together as a single unit, either in mobile or (base) station configuration. One was the "Mstr-II" (correct spelling) built around the 1970's through the 1980's. They performed with excellence and would last many years in commercial service. Even though they are 30 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 (transmitter modulation), while current commercial systems have migrated to the "narrow" band of half of this. Although there may be some unknown special production units and other sub-bands and chassis types, this document is focused on the more commonly known models in the VHF “Hi-Band” 132~174 MHz.

Because the GE Tx and Rx units can be taken apart and configured for separate units, this is ideal for SRG’s repeater design. However, for this project they are kept intact for the chassis/station. This is because this radio is used for only one site/project therefore, is unique. This is mainly due to the difficulty to resolve issues with transmitter modulation and frequency response. The receiver however, is much easier for amateur use because it will tune the entire band without sub-band component changes.

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 addressed 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.

<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 since this processing 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 a single transmitter or a single receiver to obtain quality. The key point is both components of the repeater station have to be the same of one type or the other; you cannot mix types within the same station and expect the (throughput) audio path to be flat. 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 a 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 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 (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 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.

A twist:

Some FM systems use a sub-audible squelch system, better known as CTCSS (Continuous Tone Coded Squelch System). A carrier operated squelch can work together with a CTCSS 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 here is "SDI", for Signaling Decode Indication (or input).

"AND" squelch means it takes both a valid carrier and valid SDI (decode) to activate the squelch. "OR" squelch means a valid SDI (tone in most cases) 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.

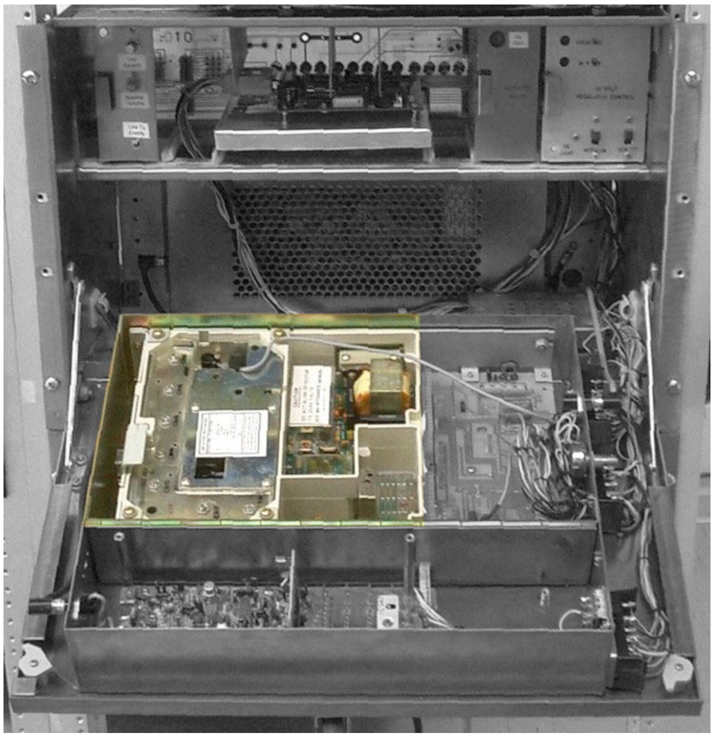
Spokane Repeater Group:

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 project:

The GE Mastr II Station is housed in chassis taking up 7 RUs (12 ¼”). The transmitter-receiver (drawer/door unit) is in a separate box with 3 I/O connectors, plus the two RF ports. It duplexes just fine even with the top cover removed. Note: there will be some comparisons with the Motorola’s “micor”.



Two types of transmitter-exciters were produced; the old type, using a conventional crystal inside a plug-in module called an ICOM. The transmitter tuned stages were multipliers and amplifiers.

The newer type was a PLL for frequency control. The (voltage controlled) oscillator is capable of anywhere in the designed frequency band, in this case, 136 ~ 174 MHz. It “sees” the ICOM’s LO and locks on to it in a very short time. This type requires only one tuning adjustment which is the VCO’s range (coil). The nominal RF output is +24 dbm. This drives the external RF PA that has a gain of 26 db.

GE does their voltage distribution slightly different over Motorola’s “Compa Station”. The stations’ power supply is a rough 15v semi-regulated only to the point of the ferro-resonant AC transformer, rectified and DC filtered. The rough, 15 DC volts is routed to two places, the PA and the control shelf’s 10v-regulator/control card. That card has a regulator/filter to run all the station’s circuits. It also controls the transmitter’s PTT and audio.

Semantics:

The OEM says there are “boards” on the control shelf however; the Author prefers to call them “cards”. The Author feels calling them "cards" (pullout devices) helps identify the item to the newcomer to this radio. Fix (mounted) ones can be called boards. The receiver’s boards are interfaced with what GE calls the “system board”, not to be confused with the control shelf’s’ back plan board (that Motorola calls theirs) which GE calls the “motherboard”. The exciter control is simple. Most of its circuits are “hot”. The control card on the station shelf inputs (low going) PTT and outputs keyed 10v that goes to the exciter’s P902-12 to key the station. This makes the system amateur “friendly” and easy to troubleshoot (Motorola’s way is rather complicated for the compa). The receiver is conventional, with an ICOM-LO, mixer and front-end tuned stages. When bringing the unit out of commercial service you have to carefully tune its stages. You may need the OEM service manual and test set to do this effectively since the receiver is very selective. Just cramming a high level signal in the RF port for tuning won’t do in this case.

Interfacing:

Being the repeater is on a single frequency, other “F” select lines may be used for other functions in this project. The rear connections on the motherboard will be used for I/O to external equipment, involving P1, P2 and TB1201 on the rear. The first two use the larger molex type pins. This avoids some additional wires running around the chassis for a “clean” installation.

Flat audio:

For multiple links you need a flat system to sound decent. This station is conventional therefore, the stock circuit is not flat. While the receiver is easy to set up for flat audio, the transmitter is more difficult (but doable) because OEM design is phase modulated (PM) for several functions.

The acronym ICOM stands for **I**ntegrated **C**ircuit **O**scillator **M**odule. The operating frequency determining element is the quartz crystal inside the ICOM. Shown here is the Tx "2C" ICOM circuitry with a crystal, compensator, oscillator and two frequency modulators; phase and direct. The latter is used as the compensator.

A temperature change causes the crystal to change in frequency, such as in a mobile environment. To keep it on frequency in this situation a compensation circuit consisting of two thermistors and some resistors are set up in a voltage divider arrangement with supply from pin 1. With temperature changes they switch in or out changing the voltage across a varactor diode (reverse bias if you will), which is paralleled across the crystal, making it a "direct" frequency changer, AKA direct FM. However, this is not an audio circuit in stock configuration.

All 5Cs and 2C have compensation built-in. Only the 5C's compensation voltage goes out on pin 4. ECs do not have any compensation therefore, depend on compensation voltage from a 5C ICOM via its pin 4. Besides stability, if there's no compensation voltage they won't net on frequency (5-7 KHz low).

Note: the OEM drawing is a little vague to say a 2C's compensation voltage does not connect to pin 4 (except during factory testing). However, the 5C does, and this line on pin 4 is what drives the other ECs. For the 2C you will need to reconnect the pin 4 run. However, the OEM manual does not address this.

2C

Stock

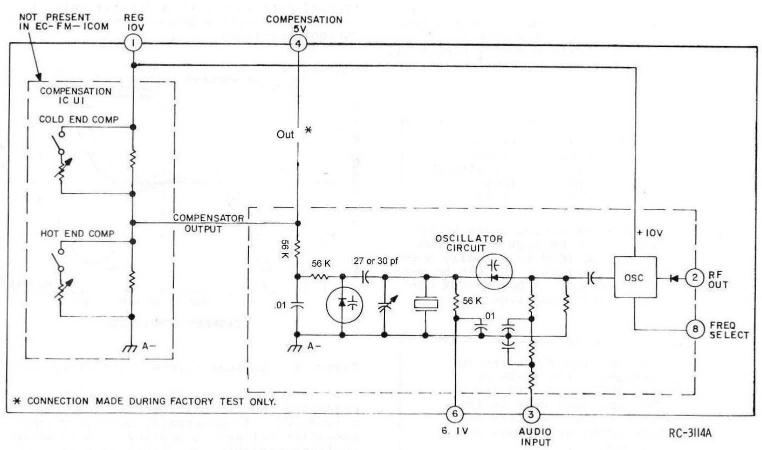


Figure 3 - Equivalent FM-ICOM Circuit

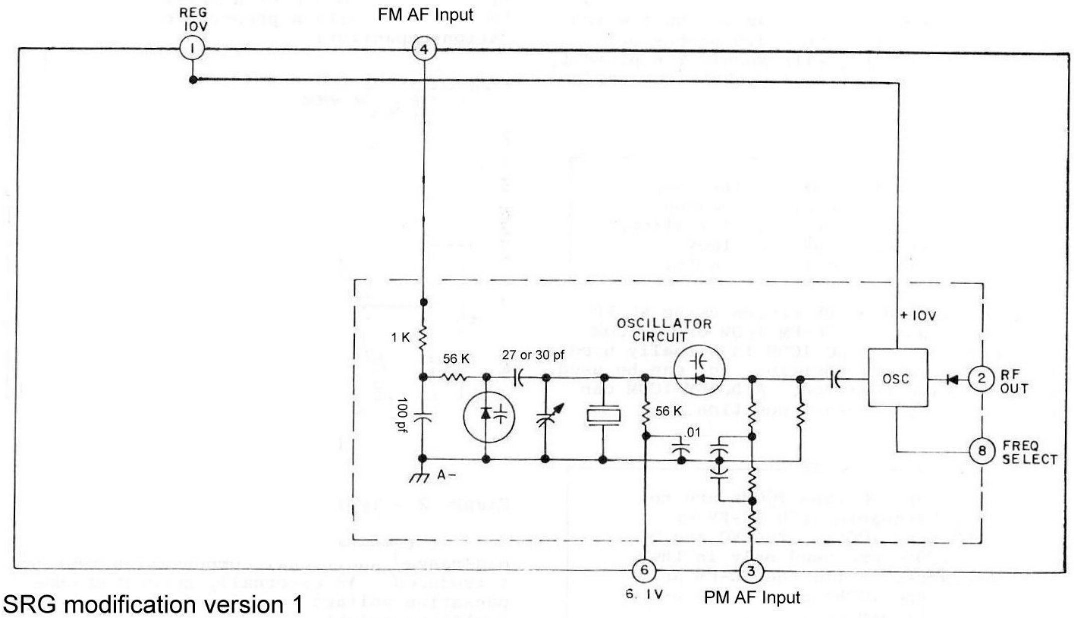
The audio input on pin 3 phase modulates the (first varactor diode, which is in series with the crystal and oscillator transistor. Since it's PM, won't be good for flat audio. The FM will, with some modifications.

The (FM) compensation circuit can interfere with good (linear) audio so should be to be removed. There are reputable people that will differ with this practice, so take this into consideration for your own project. Most SRG stations are located at a temperature controlled site, so compensation is not a major concern especially, if you add the appropriate temperature compensation capacitor to keep the crystal on frequency within the 5 PPM spec. (that's **.**0005 %).

There were three versions researched to modify the ICOM for direct FM however, only version **one** is the most successful and covered here. For 5C and 2C ICOMs remove the separate (little) daughter board inside the ICOM. To greatly improve the FM-AF TLP change out the input resistor from the 56K to 1K. Change out the RF filter cap from .01uf to 100 pf to prevent top end roll-off.

EC

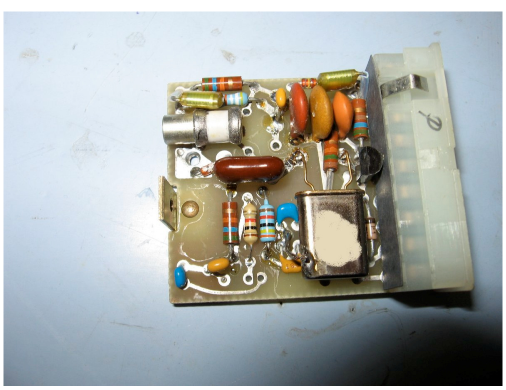
v1

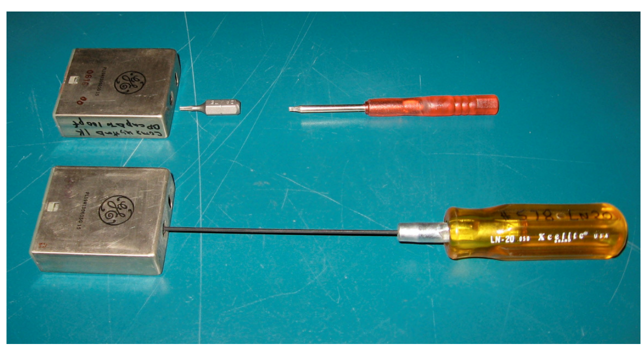


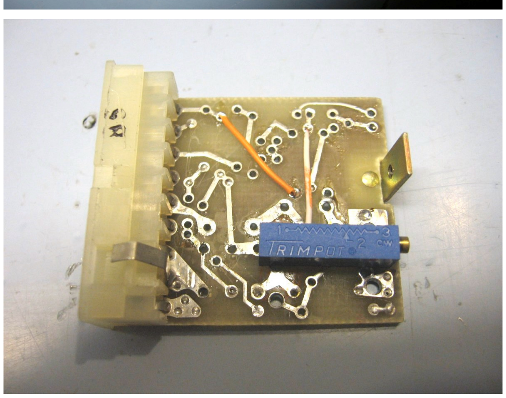
SRG modification version 1
Change input resistor to 1K
Change bypass cap to 100 pf
Change coupling cap to 22 pf

Compensation / Bias source:

Next, you will need a “bias” source to run the EC. If you have a spare transmitter ICOM (EC, 5C, 2C, etc.) remove the screw on top and pry open tabs on the bottom edges of the ICOM. Note: The screw will be either a Torx-6 or a “allen” (hex) type; size of .050” (about 3/64). The Torx bit (or Torx driver (red handle) as shown in the image, can be found on the Internet as well as the .050” hex driver (yellow handle). Shown is the Xcelite part LN-20; 050 (Mouser Elect # 578-LN20).



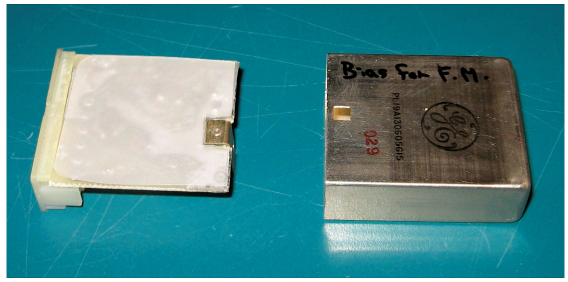




The PCB has several components including the (fundamental) oscillator, crystal, modulation and compensation circuits. Strip the necessary components off it to isolate pins 1, 4 and 5. The Author chose to remove all components for display and research reasons as shown here.

Next, install a 10K trim pot. 10 or 20 turn type is best. The holes used that line up with the pot’s leads put it in a great spot for a tool to access through the top of the can, when completed. You also will need two jumpers on the ICOMs board; pin 1 to the top of pot (10v) and pin 4 to the wiper. The low side of the pot goes to ground.

One (minor) twist; the adjustment will be reversed; CCW to increase the bias voltage. We will now call this the “bias ICOM” (AKA, compensation voltage).



The reverse side of the bias ICOM shown here. The Author was concerned about the PCB pins touching the can. Using a piece of laminate plastic prevents this. Make a notch for the rivet area.

Assemble the bias ICOM can and screw. Note the nice access hole on the top for easy bias adjustment with an alignment tool. Shown here is the EC ICOM in position one and the bias ICOM in eight.

Inject a test tone (to fully deviate the transmitter) (in the amateur world this is 5 KHz). Tune the bias for best symmetry. You will have to adjust the input test tone to verify its good at TTL. Typical bias will be 3.41v. The response should make 8Hz ~ 10 KHz.

The modulation line needs to be connected to the outside world via pin 4 and 9 of the exciter board. To avoid outside DC competing with the bias use a capacitor (and load resistor) for the jumper.

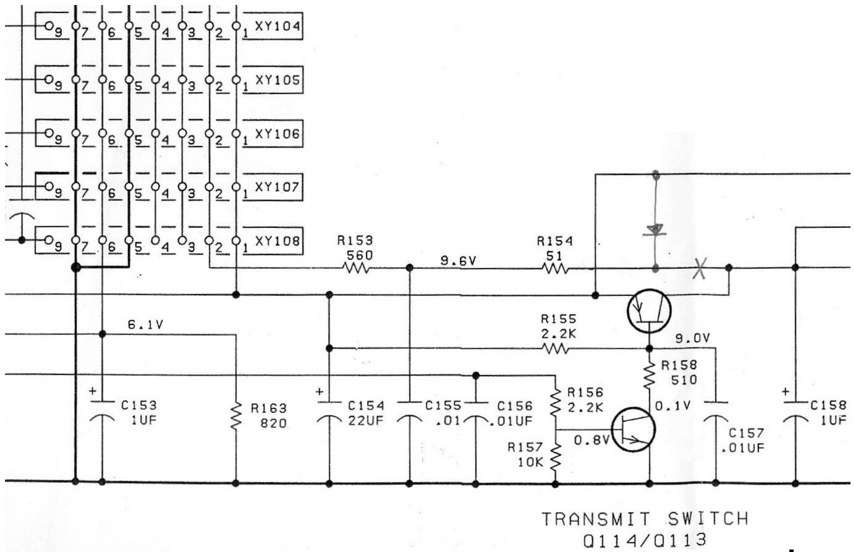
<u>Transmitter control option:</u>

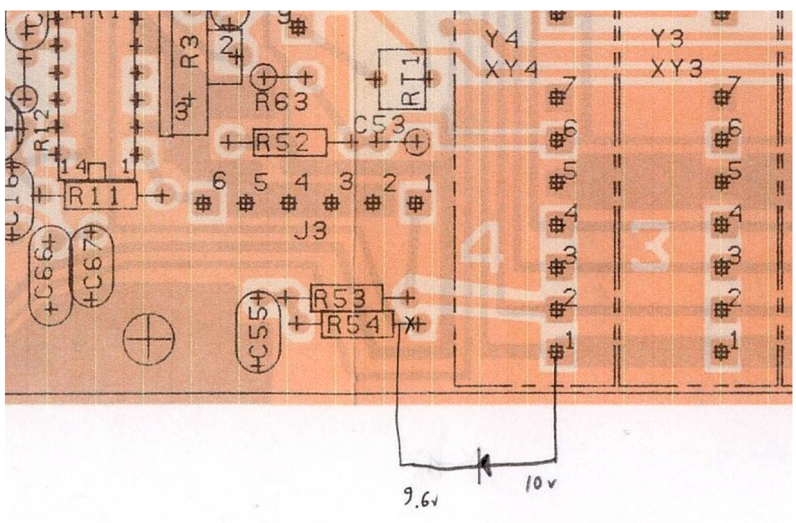
The OEM drawings can cause some confusion with parts identification. For example, on the exciter board, Q114/Q113 ID is grouped together (with the slash) on the schematic diagram. Also, on the board layout drawing, the first significant digit of these parts is deleted. For example “Q114” becomes Q14. SRG will use the latter part identification.

The receiver’s ICOM “runs” continuous but the transmitter does not, causing the latter crystal aging to be longer. This can be changed. The Station control card on the shelf provides both continuos and keyed 10v. On the exciter board the continuos 10v appears on pin 7 of P902, while the keyed 10v appears on pin 12. Continuos 10v supply inputs Q13 at its emitter. Keyed 10v to R56 turns on Q13; its collector goes low and turns on Q14. Q14’s collector is the (switched) output which goes to a 5v regular and also filter/divider R54, C55 and R59. This goes to the Tx ICOM’s pin 2; activating RF out on the same pin and paralleled to the RF filter, FL101, then to the multiplier stages.

To make the transmitter’s ICOM run continuously, lift one side of R54 (lead towards ICOM pins) and install a common diode in series with its anode on pin 1 of Y4. The diode lowers the supply on pin 1 “close” to what the OEM circuit did (9.6v). Q13 and the 5v regulator will be isolated from this and still function as a keyed circuit, allowing normal transmitter control while keeping the ICOM live all the time.

The Author choose not to do this option as of 2014.



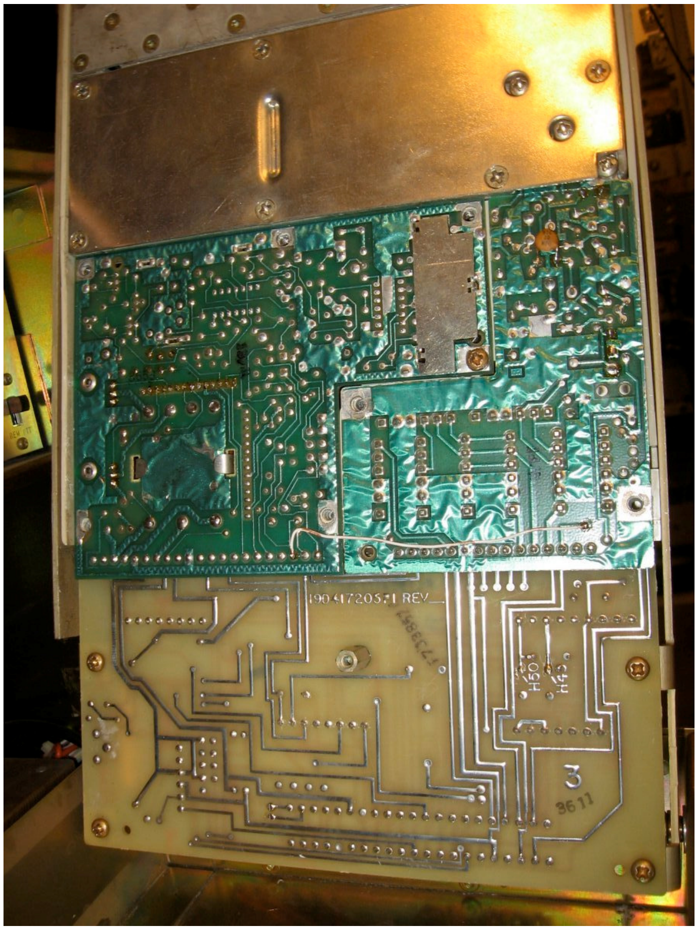


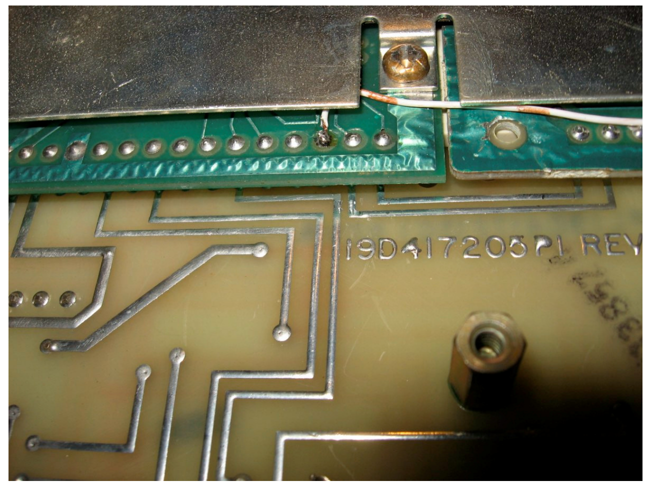
Receiver:

The receiver is easier for flat audio. For start, the audio will be picked off the discriminator of U602. There are active components (such as Q601) to bring the level up however, complicates maintenance. For example, adjusting R608 would change the TLP. To simplify, the “FM DET MTR” audio is used, which is from the discriminator, going through a few connections then appearing on P904-3. There’s no outside connection from this point, so a jumper was installed from the IF/audio board’s P904-3 to the oscillator-multiplier board’s P903-3 (old Rx F3 select line). From this point it goes out the (old) F3 Rx line and ends up at J2-3 on the back of the chassis. The Rx F3 line is not planned to be used, plus there appears no components on this line to affect the audio, making this an ideal circuit for audio output. Optionally, remove the bottom cover and shield to gain better access to the points to the jumper.

The (stock) TLP for this point was found to be too low (around –25) therefore, R607 value is changed from the 180K to 1K. This brings the TLP up to a (typical) –16 which the (external) cor/af board can handle this level (see separate document on that device).

Next, the receiver's cor (signaling) can be obtained from the (stock) CAS from U603 that appears on P904-9 and ends up at J1-13 on the back of the chassis. Using unused lines is a "cleaner" way instead of the audio and cor wires running through the chassis.

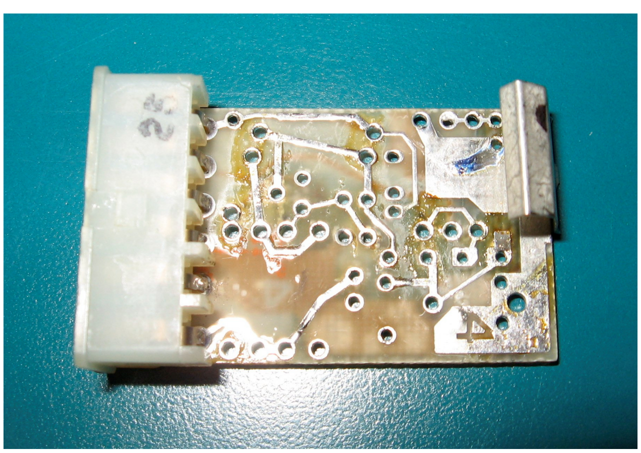


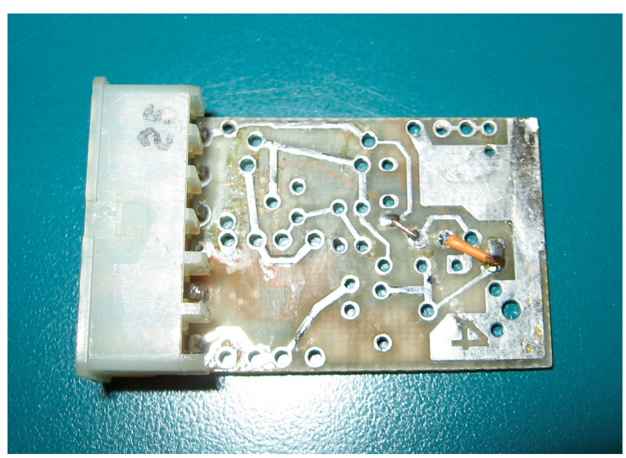


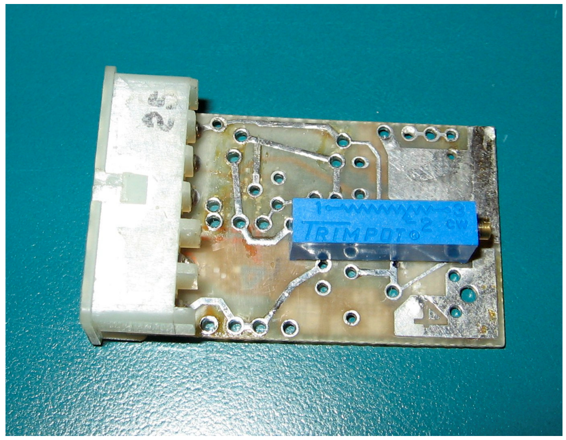
Below is a close-up of that jumper showing it from the discriminator point. One nice feature (over the Motorola) is the little shield is not soldered to the board, making removal a snap.

Receiver ICOMs:

The receiver 2C and 5C ICOMs provide their own bias (OEM compensation voltage) to keep the crystal on frequency. However, the ECs do not. Like the transmitter side, the receiver side EC ICOMs will need bias voltage to be on frequency. The two main differences is the bias in on pin 2 and it will be 5.0v instead. From a spare, old receiver ICOM, strip the parts, add two jumpers and the trim pot as shown. Adjust the pot for the 5v output on pin 2 which will feed the working ICOM's pin 2.







Receiver signaling options: There are two thoughts to the process:

- Conventional, stand alone repeater with linking. This would be the configuration most amateur repeaters are set up, with its receiver audio & PTT going into a (on site) repeater controller and it's output going to the associated (on site) transmitter, including any IDer audio. This would be a single-site station, with possible linking into another repeater, group or service. Also, both the repeater control and repeater audio cards would be used on the station shelf.

- Flat audio, 4-wire drop-in station, with full-time link support. This is the normal configuration for SRG, with its receiver audio & PTT downlinked to another station, typically a (distant) HUB (repeater) or MCP, with the uplink (return) audio & PTT from that HUB or the MCP. Therefore, the 2-meter station is not stand-alone; the audio (and carrier) path goes through the distance end. Only the regulator card would be used in this case. Many of the OEM circuits and ideas are discarded and bypassed.

Local monitor audio: (for conventional stations)

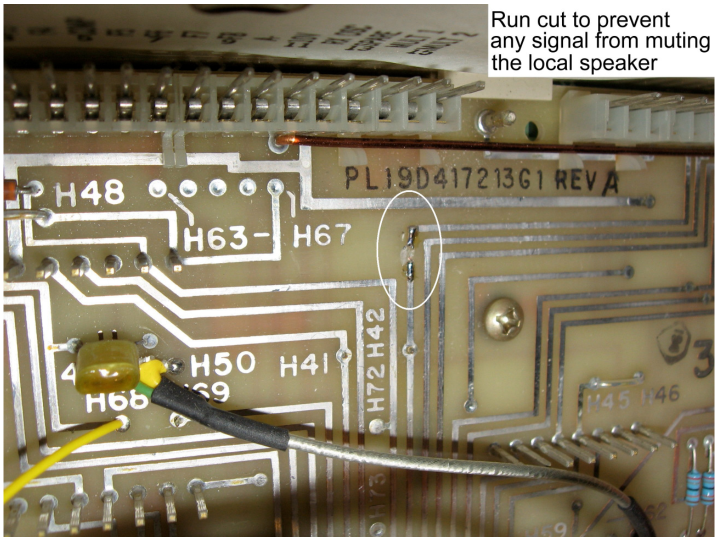
For SRG packages much of the audio, COR, PL decoder and PLI paths are custom set up, ignoring most of the OEM circuits used in the station. However, for a conventional station (not flat audio) it would be helpful for you to know some points. For remote site receivers, you need to have three outputs:

- Audio, to feed a conventional controller and finally the associated transmitter.
- "COR" (RUS) to signal the controller and/or repeater control card, etc.
- "SDI"; (CG decode output) an indication there is a valid tone (CTCSS) on frequency to control the station's audio and PTT circuits. Obviously, for receivers on carrier squelch this last item won't apply.

This modification allows the on-site technician to hear the receiver's local audio (speaker) for checking interference and/or dynamic sensitivity checks, while not affecting the normal station's operation (i.e. keying the station's transmitter to check for receiver desense.

For stations that don't use the repeater control card take out the jumper H41-H42. This prevents the CG output (signal) from providing a "low" at the receiver's P904-7 line (which controls U603 and U604 there).

For stations that do use the repeater control card the above cut won't work. This is because the SDI (CG output) goes into the control card on pin A3. This signal goes back out of the control card on A6, to mute the receiver's COR and local audio. The best place (found) to change this was to make a cut on the run from J904-7 and H42 on the System board. This prevents any CG signal, local or remote PTT from the regulator card (H18 area) from muting the local speaker audio. Therefore, the local speaker will always be on carrier squelch. The OEM local squelch is still in effect in this case as well. U603-7 output (Rx mute) which, now, only goes to U604-1 to squelch the output audio of this device. The run cut made is after this local squelch circuit. The run-cuts were tinned in this image for easy identification only. However, there still is another issue with the repeat audio.



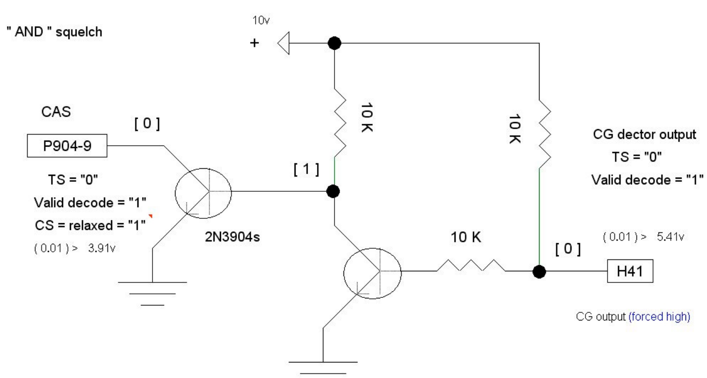
Repeat audio "AND" Squelch:

In times of carrier squelch operation (no interference) is simple to operate a repeater. In times of interference (or other reasons) tone control will complicate the repeater's control however, is doable.

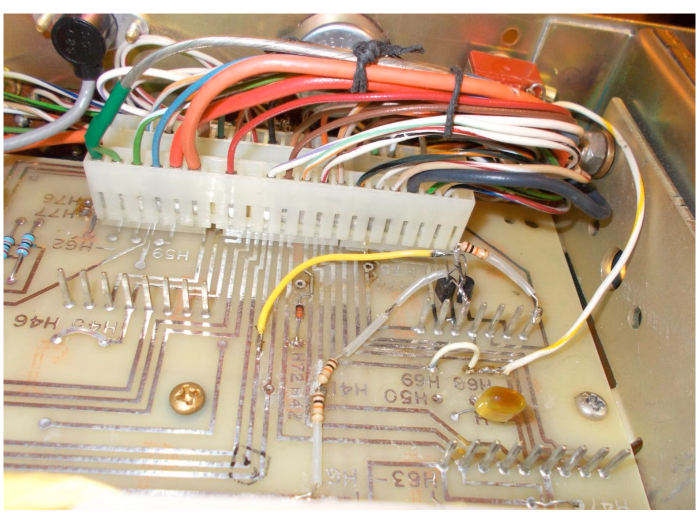
The repeater PTT can be an "AND squelch" via the repeater control card's "OR" gate of CR12 and CR8 from the inputs of RUS and CG detector voltage, respectively. However, the (conventional) repeat audio will still be on carrier squelch (via Q13 on the repeater audio card). For a repeater with a significant long tail and having some RFI this can be rather annoying to listen (until the PTT/carrier line drops out the transmitter).

To fix this issue, the repeat audio also needs to be an AND squelch. Some explanation may help you with this next task. The RUS is an open collector line with a pull-up; same as the CG decoder line. The latter gets its (10K) pull-up from R24 on the repeater control board. Therefore, you can't tie the line lines coming into the board otherwise, the R24 will raise the RUS line enough to keep the transmitter keyed continuously.

The solution is a buffer / isolation circuit from the CG line to the CAS line. It's believed this line is an open collector. This allows the CAS to be "0" during standby and to a "1" during activity with the CG decoder only controlling the "0" state, thus, creating an "AND squelch". Both lines have to go high to activate the PTT circuits. A simple transistor buffer will provide the solution. It was installed on the System board's P935, which provided 4 spots; a good power source of 10 volts (pin 1), a ground (pin 5), a CG decoder signal (H41) and a place to control the RUS line.



Shown here is the actual circuit installed on the system board. Some of the connections are "flying tie" but should be satisfactory for most amateur service. The yellow wire is the buffer/AND gate output, putting a (low) shunt to the CAS line. When a carrier AND a valid CTCSS (tone) is decoded this output relaxes to allow it to go to a logic high to provide an "AND" squelch RUS signal to the controller.



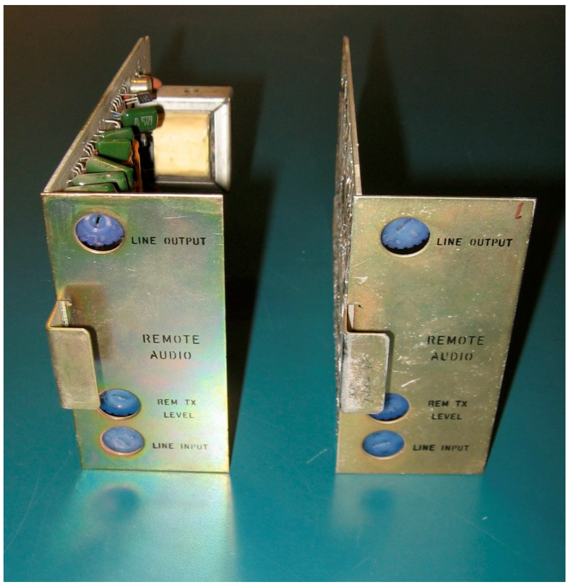
For stations that don't use the repeater control board point H41 won't go high. To solve this condition, install a 10K pull-up resistor as shown in both images. On the left it's the one in the lower portion of the image.

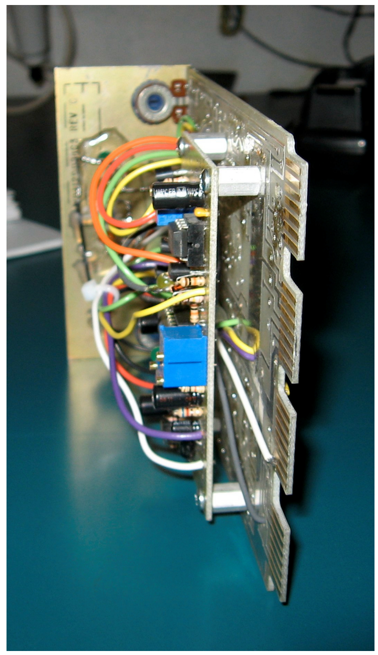
The last item; for tone squelch station used the CG decoder board, PL 19D417261G1, 6 or 3. The combined PTT inputs on this board and goes out on the delayed PTT. If you need to pull this board and run in carrier squelch you need to install CR1010 (between the in and output PTTs. It's shown here just to the right of that yellow wire soldered o the system board.

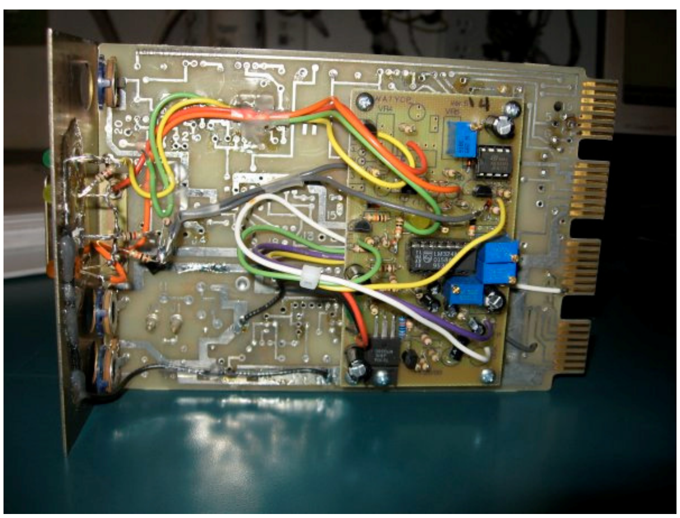
COR/AF Board mount:

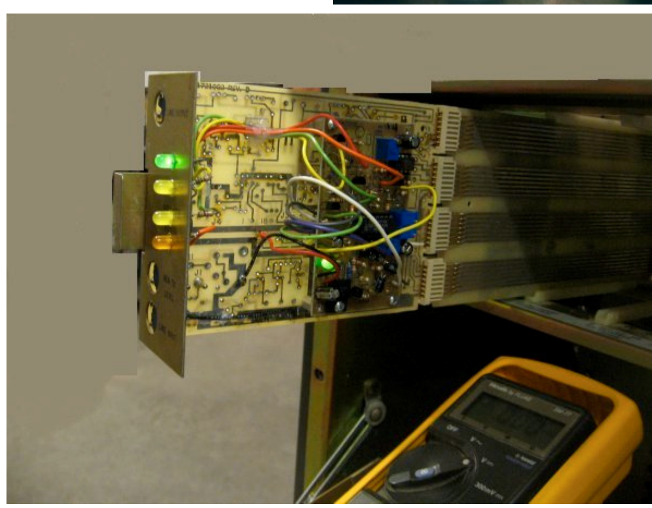
This board is an independent, custom board designed by the Author for many different interface applications for SRG projects. In this case it takes both the RUS and CG decoder lines to make an AND squelch either for the PTT, audio or both. The PTT and audio lines then will drive a downlink transmitter.

This task is to mount the cor board on a station card. The line driver (remote audio) card was selected (19A129924G3) because several were available and the stock card would not be used in any SRG projects. First, remove all the components except for the front pots. There's about 120 components and 5 jumpers typically, so this will be labor intensive. The (daughter board) pins in the center can be removed; however, in most cases this destroys the runs as well. An alternative is to cut them off, flush with the board. The board on the left is the stock, right with the components removed. The pins are yet to be cut or removed. The right pictures show the completed task ready to insert on the shelf.









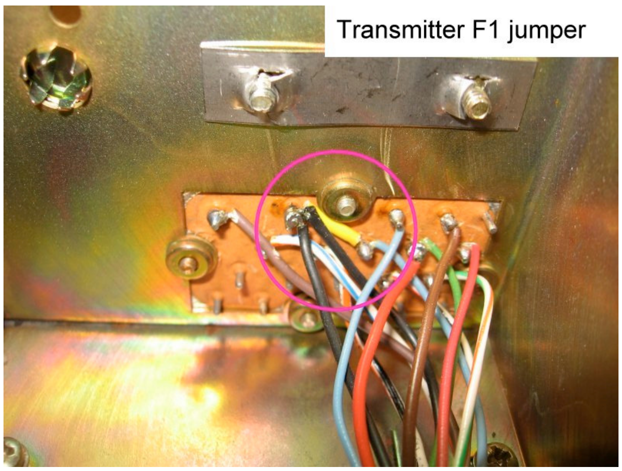
Shown on the left is the completed COR card ready for testing and alignment. The right shows it plugged into an extender card plugged into the station shelf in slot 8. The OEM repeat audio and repeat control cards are not used in this case. Only the regulator/control card is used. Note: the old term "PLI" label has not been updated to say "SDI" in the above image.

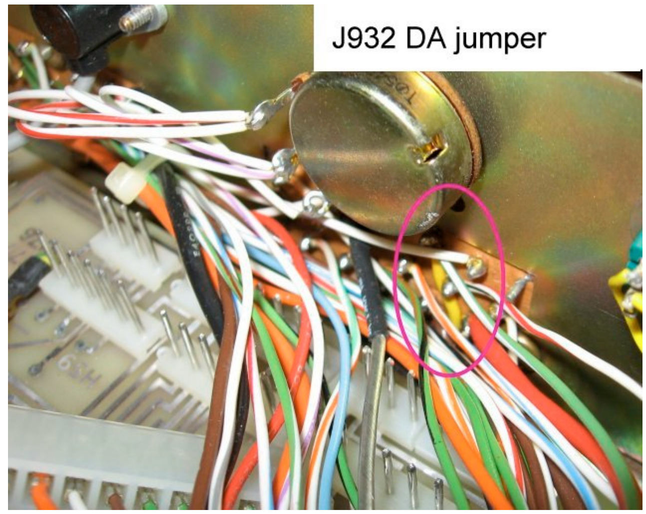
<u>F1 control</u> <u>(single frequency):</u>

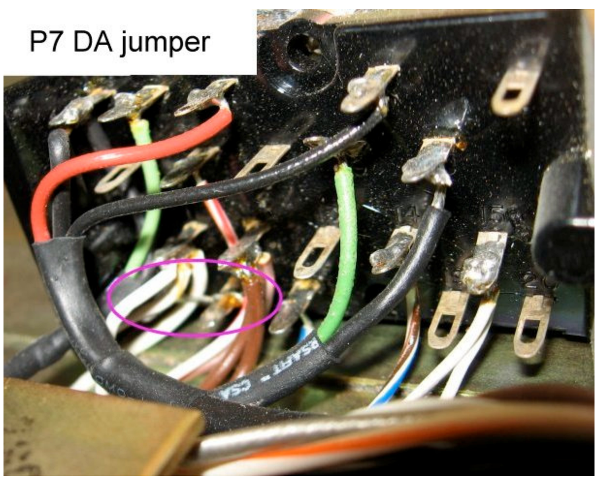
This repeater is set up for single-frequency operation (F1) for both transmit and receive. OEM strapping is done in two separate locations and may be difficult to find without a detailed search of the drawings and their functions. Both are tied "low" via "A -". A- is the same as ground. Each jumper location is:

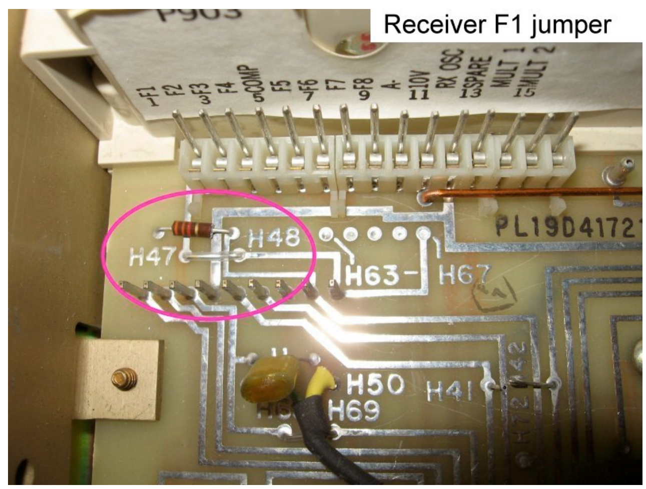
For the transmitter, is located inside Tx-Rx "drawer" unit and inside the exciter section. There's a jumper on the back of J933 pin 8 to pin 4; the latter being ground. It's usually a short, white wire sometimes behind the blue (F1) wire and may be hard to find.

For the receiver, is located inside the Tx-Rx "drawer" unit and on the "system" board, A901. There's a jumper between points H47 and H48; the latter being ground.





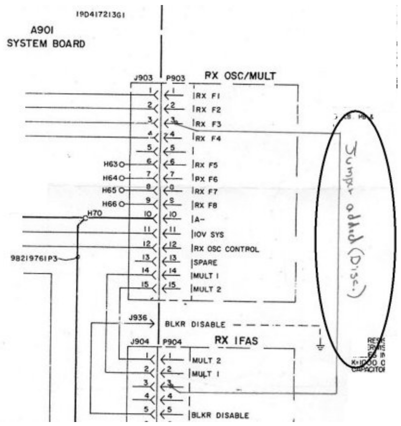




<u>More difficult circuitry:</u>

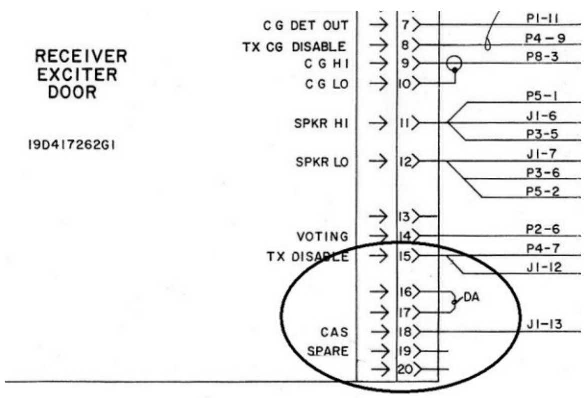
The OEM manual shows most of the connection lines between various components of the station, such as the system board, motherboard, etc. You will need to do a lot of back - and – forth tracing since these lines appear on several pages of the manual. The Author provided a simplified block and level set of diagrams that are supplements to this document. It greatly clarifies the circuits to someone just starting out understanding this radio.

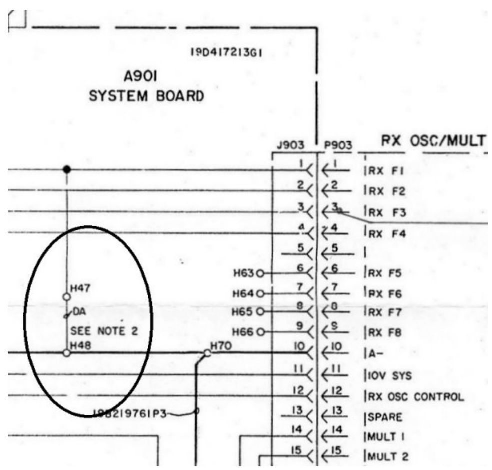
Another circuit that's hard to trace physically (wires) and in the OEM manual, are a couple of jumpers for the "VOL SQ HI" circuit. Inside the drawer unit (Tx-Rx chassis) the receiver outputs this circuit on P904 pin 11 which plugs into J904 pin 11 on the System board. The System board's run takes this over to J951 pin 8. (J951 is the closest jack to the chassis edge). P951 pin 8 plugs into this. Within the short wiring hardness a white wire takes this to J932 pin 16. P7 plugs into J932. P7, pin 16, has a little bare jumper (DA) on the outside going to its pin 17 (left image). This goes back inside to J932 on pin 17, now.



A white wire takes this to the top of the squelch adjustment pot (located in the chassis of the drawer unit). There is also a short (yellow) jumper (called DA) from J932 pin 17 to 3 for other functions (right image). Wow, what a wild circuit !

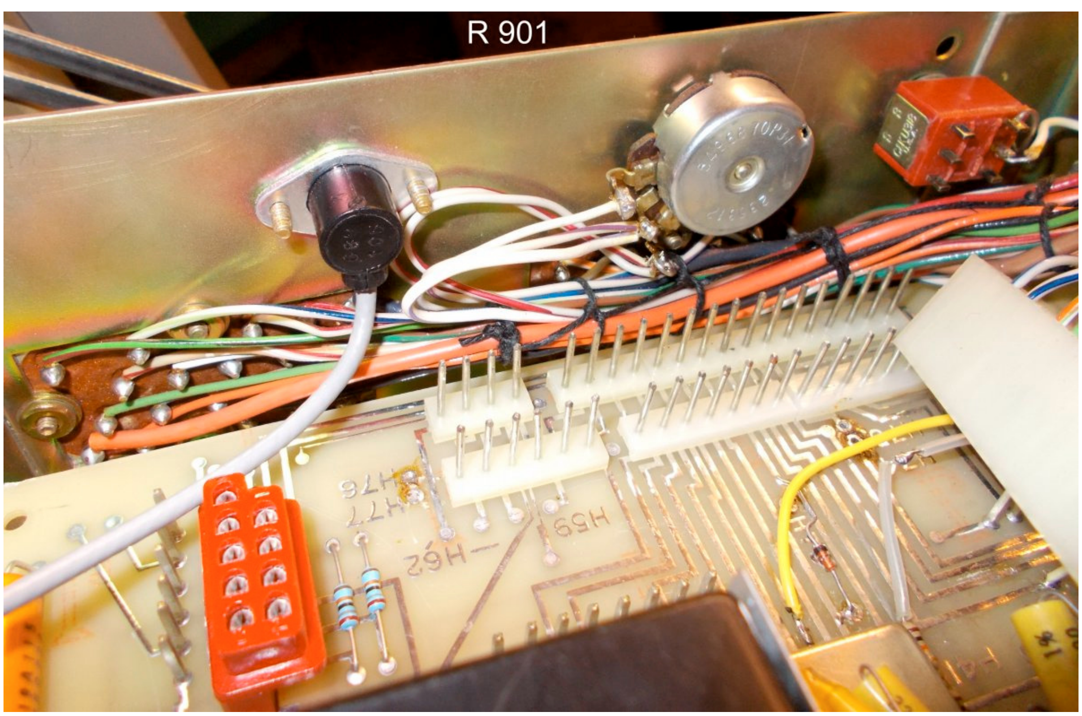
Here's the schematic locations (from the OEM manual) for the Rx F1 jumper, the "VOL SQ HI" jumper DA and the discriminator jumper to be added.





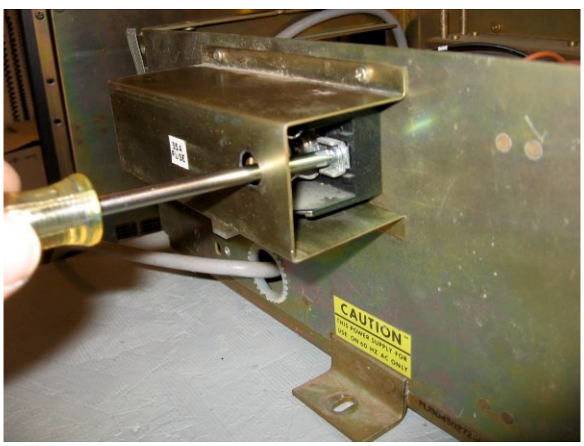
Squelch pot:

Almost all of the world's brands of radio's receiver squelch adjustment to "loosen" the carrier squelch is CCW and tighten is CW. Why the boizs at GE, Lynchburg (making a fine product), did the opposite is beyond the Author. Perhaps something in the water ? To correct this issue the outer wires of the pot are reversed as shown here.



Another modification is the type of screws used on the power supply output for the high current section. This powers the RF-PA and is straight blade which can be annoying while working in tight spaces. To improve handling a phillps screw is used. First you need to tap it out, such as for a 10-32 screw. Note: It was later discovered some versions of the supply already use a 10-32 therefore, you can skip this step.

The next modification is to make an access hole for the screwdriver on the right screw. This way the power cable can be removed or installed without having to take the protective cover off, as shown here.



Here, shows the completed modification and using the screwdriver. When doing this be sure to either leave the power off or insulate the screwdriver, for obvious reasons !

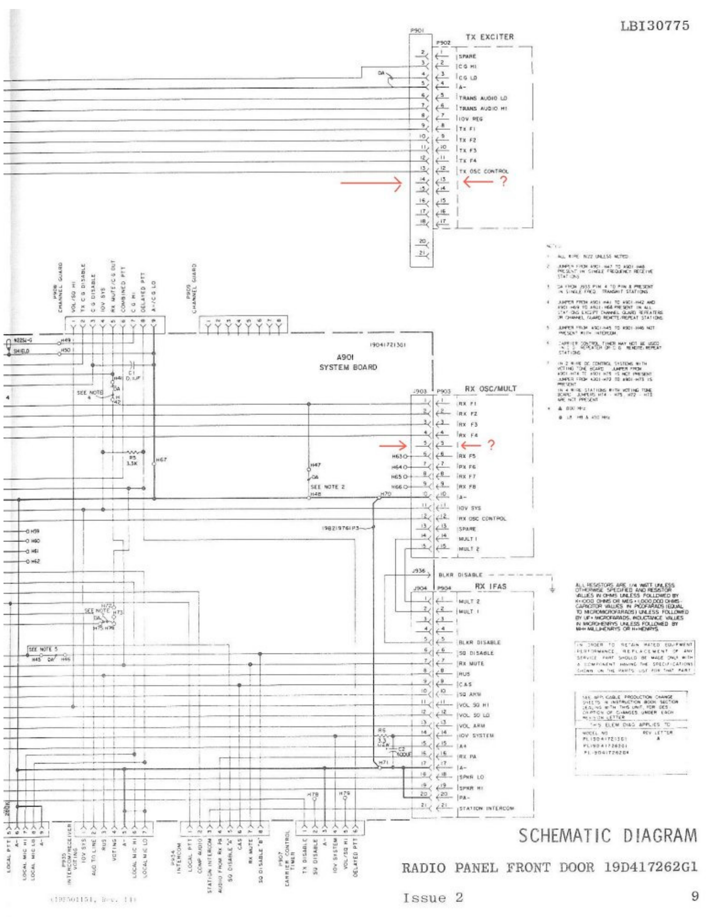
Speaking of the supply, in the front are three additional fuses. These holders have three different type of caps; two are bayonet and one is the screw type.

NOTES:

As earlier mentioned good discipline is needed for a project like this. For example, documentation both in modified circuits and new theory for SRG should be done during the R&D. For this project some of it was skipped (time restraints) causing some possible lost ideas and how it was built. In 2019 a few “pieces” of this was reconstructed as best as possible at the cost of some possible errors. This also was time-intensive. Therefore, it’s best to do it sooner than later. The following changes were made to the best of memory serves, because the station equipment was not available for close lab-shop tracing.

Normally, in a stock station, the repeat audio is controlled with the repeater audio board. For SRG this board (card) is not used. The local mic audio is control with the 10v/control card. When keyed its audio is unmuted via Q9 and permitted to go through out on pin B14. CR3 on the PTT logical controls this.

For SRG the IDer uses one PTT in-output line. It’s connected to the “local” PTT line on TB1201-2. However, the stock station uses separate in and out on the PTT line so some modifications needed to happen for a common PTT line. During the IDer’ active the PTT line is pulled low to keep the station keyed during the ID string. The first modification on the 10v/control card is to jumper CR3 so any PTT activity will enable the local mic audio circuit (which the IDer uses). However, this will also enable the local (physical) mic to be “hot”, thus sending any sounds in the equipment room over the air. Rather than having to unplug the local mic from J1215 each time a site visit is done another modification is needed. This is a simple one to use the mic’s contacts to make and break the mic high line as the physical PTT button is pressed and un-pressed.



The manual text leads one to believe you only need one 5C ICOM to provide compensation voltage to any of the other EC ICOMs either in the receiver, exciter or both.

Note: In this (SRG) configuration, it’s not really “compensation voltage because there’s no temperature control, rather just a “bias” to simulate the former.

The schematic drawings for the transmitter and receiver shows this. For example, the exciter compensation voltage line is on P902-13 on the exciter board and on P903-5 on the receiver’s osc/mult board.

However, the system board shows there is no connection between these two points, as the image shows in red. Pretty lame.

Therefore, the Author runs one 5C in the transmitter’s exciter board and another 5C on the receiver’s osc/mult board. This is for conventional operation (not FM).