

RC-850 Repeater Controller
Hardware Reference Manual

Firmware Version 3

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8/87 Rev 3

This manual provides hardware reference information for the RC-850 Repeater Controller.

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**Chapter 1
Specifications and Features**

This chapter provides specifications and features of the RC-850 Repeater Controller with Version 3 Firmware.

Specifications

Microprocessor: 80C85

Memory: Total expandable beyond 384K bytes

 EPROM - 136K

 E2PROM - 8K bytes

 RAM - 8K bytes, expandable to 16K bytes

Logic Inputs: Low <.8 volts

 High 2.4-15 volts

 Impedance 10K

 Programmable active high/low

Logic Outputs: VMOS power transistors (open drain)

 60V / 100 mA drive capacity

 Programmable active high/low

Audio Inputs: 100K impedance, adjustable levels

Audio Outputs: 5V p-p transmitter and link audio

Power: 11.5 to 15V DC @ 175mA

Operating Temperature: -15 to +55 degrees C (5 to 131 degrees F)

Cabinet size: 17" W x 14.5" D x 2.5" H, 19" rack mountable

Weight: Approximately 4 lbs.

Features

Standard Features (on main controller board)

- Main controller board is a complete standalone repeater controller
- Remotely programmable with Touch-Tone commands:
 - Messages - over 200 (ID's, tails, mailbox, etc.).
 May include CW, paging tones, DTMF tones, external devices, synthesized speech (w/VRT option), and Digital Voice Recorder tracks (w/DVR)
 - Morse code parameters:
 Speed - 5-35 WPM, Pitch - DC-3000 Hz, Level - 4 steps
 - Control Op and user command codes (30 prefix groups, up to 7 digits each)
 - Courtesy tone parameters (13 sets - pitch, durations, spacings fully programmable)
 - Timers - 27 sets, 0-30 minute with 1 second resolution
 - Autodialer numbers (250)
 - Telephone exchange tables
 - Pager memories
 - Remote base frequency memories
 - Non-volatile E2PROM storage (no batteries)
- Autopatch / Autodial (requires Telephone Interface Option for local line)
 - Supports up to two local phone lines, three remote phone lines (3 total)
 - Store/forward, DTMF or rotary (2 speeds each)
 - Optional phone number readback
 - User Loadable Autodial - 240 numbers (50 numbers hold up to 35 digits)
 - Emergency Autodial (10 numbers) with message readback
 - Antidialer - traps 10 numbers, permits wildcards and globals for blocks of numbers
 - Toll restrict - leading 1/0 and digit count; or exchange tables for telephone exchanges in 2 area codes, 3 permitted area codes
 - Full or half duplex patch
 - Cover tone for semi-private patches
 - Activity timer with warning warble
 - Autodial storage of credit card / MCI / Sprint access codes
- Reverse patch - general or directed to 100 stored user call signs
- Paging - two-tone, 5/6 tone, DTMF, CTCSS, HSC display, GSC digital, commandable or may be included in any programmable messages
- Electronic Mailbox
 - User-to-user mail
 - System generated mail; system generated mail - unanswered reverse patch and alarms
 - Addressed by user call sign slot, 100 user call sign storage
 - 10 "canned" messages; digits may be appended to messages, i.e., phone numbers
- Remote bases and links
 - Up to 4 transceivers
 - Commandable frequency and offset of 2 transceivers
 - Remote base frequency memories with names
 - Cross-linking of the transceivers
 - Command entry from the remotes and links

- 11 access and control modes
 - PL for access, user level, or Control Op level command
 - Main and "user level only" PL inputs
 - Touch-Tone access mode with programmable timeout
 - Individual user access codes for 800 users
 - Attributes for further custom tailoring
- 10 "Macro Sets" for easy Control Operator selection of predefined repeater setup parameters
- General purpose remote control
 - Logic outputs - 6 expandable to 64
- Audio delay line (75 ms) to mute squelch tails and fully mute Touch-Tone
- Courtesy tone
 - 13 sets to convey information
 - Selectable by Control Op or logic inputs
 - Programmable pitch, delay, and spacing of 3 segments per tone set
- Low distortion computer synthesized tone generation, single and dual frequency, programmable to 1 Hz resolution, 4 levels
- Noise and kerchunker filtering
- Control receiver provisions
- Fully integrated CMOS 16 digit DTMF decoder
- Intelligent ID algorithm - automatically selects from up to 14 programmable IDs
- Tail messages - 13, selectable occurrence rate
- Command acknowledgement with unique response messages
- Built-in E2PROM programmer/eraser for remotely programmed parameters
- Low power, single supply operation with built-in battery switchover circuitry
- Fully socketed with top quality machine contact IC sockets for reliability and easy service
- Proven reliability designed in, with watchdog timer, voltage monitoring circuitry, transient protection, conservative design
- Compatible with ACC's Digital Voice Recorder
- Manual, free telephone technical support

Voice Response Telemetry Option

- Natural sounding speech synthesizer for effective user/repeater interface
 - Custom ham/repeater oriented vocabulary of over 300 words, expandable to over 600 words
 - Letters, numbers, phonetic alphabet
 - Amateur radio terms - club net, meeting, hamfest, amateur, etc.
 - Male and female voices, sound effects
 - Easy to use interactive message editor
- Clock/calendar
 - Scheduler
 - 10 "Setup States" storing over 200 parameters each
 - 30 Time/day of week changeovers and events
 - Commandable readback of time
 - Time, date, and morning/afternoon/evening available as run time variables in programmable messages

- Analog metering
 - 16 channel analog measurement
 - Readback on command and inclusion in any programmable messages
 - Immediate readings, and ongoing min/max readings for each channel
 - Firmware defined talking meter faces for voltage, current, S-meter, deviation, quieting, power, temperature, weather conditions, etc.
 - Built-in sensors for temperature and voltage
 - Internal telemetry logging
- Alarm inputs with programmable identification messages; leaves mailbox message if alarm is not cleared

Computer Interface Option

- Two hardware RS-232 serial I/O ports
 - Firmware supports packet radio "bulletin board" like user interface
 - Selectable baud rates
- Two auxiliary dedicated Touch-Tone receivers
- Three memory sockets for expansion to 384K bytes and beyond
- Personal computer software for printout of programming information

Vocabulary Expansion Option (requires Computer Interface Option)

- Over 600 synthesized speech words and phrases
- Days of the week, months of the year
- Additional weather, emergency, and public service words

Telephone Interface Option

- FCC registered or non-registered board available
- Electronic hybrid, AGC
- Three-terminal gas discharge tube for effective lightning protection

Front Panel Display Option

- Internal and I/O status
- 55 LED indicators, one digit
- Off, on, blink, wink indicator states
- Display on/off switch to minimize power consumption
- Local microphone jack (for Kenwood MC-48, MC-80 and compatibles)
- Local speaker jack, volume control

Features and specifications subject to change without notice

**Chapter 2
Initial Installation**

The RC-850 Repeater Controller is designed to mount in a standard 19" rack (at least 15" deep) or it may be operated tabletop.

Installation of the controller into the repeater system requires connection of power, COS logic input, PTT logic output, receiver audio input, and transmitter audio output. Optionally, a local telephone line may be connected for phone patch and phone line control. A great deal of flexibility is built in to simplify interfacing, such as virtually universal logic level compatibility with selectable active high or active low (high true or low true) and adjustable input audio levels.

These are the only connections necessary to the rest of the repeater system. Other inputs and outputs from the controller allow you to build a "Super System" with a control receiver, PL operation, remote bases, links, remote phone lines, alarms, metering, Digital Voice Recorder, and remote control outputs. These are described elsewhere in this manual - here we'll just describe the basic interface to the repeater receiver, transmitter, power supply and local telephone line.

Interface Signals Required

- Power - system 12 volt supply (4 pin Jones plug)
- Carrier-Operated Switch (COS) - logic input from receiver (Digital I/O connector pin 17)
- Push-to-Talk (PTT) - logic output to transmitter (Digital I/O Connector pin 7)
- Receiver Audio - audio input from receiver (phono jack RX)
- Transmitter Audio - audio output to transmitter (phono jack TX)
- Telephone line - required for local phone line patch, reverse patch, phone line control (modular connector)

Power

The RC-850 controller operates off a single twelve volt supply. Since the receiver and transmitter in your repeater probably operate off of 12 volts, a suitable supply is either already available or is needed anyway. Good system design suggests avoiding unnecessary duplication of power supplies in the repeater system, so it shouldn't be necessary to dedicate a supply to the controller.

The operating voltage range is 11.5 to 15 volts dc, and the supply should be reasonably well regulated. Since the controller's circuitry is primarily low power, high performance CMOS, its current requirements are modest - typically about 250 mA. At times, current drain can rise to approximately 400 mA for short periods, or to 500 mA with the Front Panel Display on and all the options installed. (Note: To minimize power drain and to minimize heat generation, the Front Panel Display should normally be switched "off" unless you're at the site.)

Power is applied to the four-pin Jones type plug on the rear panel. Primary +12.6 volt power, optional backup battery power, and two separate grounds connect to the repeater power system. The primary supply and battery inputs are diode isolated, so that the battery is normally isolated from the load through a back biased diode until the primary supply goes away, at which time the battery instantly begins supplying the power. The battery is only necessary to continue operation of the controller - remotely programmed information is stored in non-volatile memory and does not require battery backup.

The two grounds should be kept separate back to the supply to prevent digital noise from appearing in the audio signals. Both grounds (AGND and DGND) must be connected to the power supply. Use #18 or larger diameter wire and keep it as short as possible. BOTH GROUNDS MUST BE CONNECTED TO THE SUPPLY GROUND.

Carrier-Operated Switch

The output from the receiver which indicates that a signal is present is called COS, or carrier-operated-switch. It's a logic signal which is at a particular logic state when a signal is at the receiver's input or the squelch is open, and at the opposite state when the squelch is closed. Most receivers designed for repeater service have such a logic output called "COS", "COR", "squelch gate", or something similar. With other receivers, such as transceivers put into repeater service, it's necessary to find a usable logic signal for COS. Look after the FM detector, following the noise amplifier and rectifier in the squelch circuit.

Since signals from different receivers can vary in characteristics, the RC-850 controller is designed to accept a variety of logic levels and to accept "high true" and "low true" signals. The only requirements are that a logic low be less than .8 volts and a logic high be greater than 2.4 volts (up to about 15 volts). The COS input impedance is approximately 10K ohms so that it won't load down the circuitry providing the COS signal (but be sure to measure the receiver's COS high and low voltage with it connected to the controller just in case!). A DIP switch on the controller board allows selection of high or low true based on what your receiver provides. See "Setting DIP Switch Options" later in this chapter.

Push-to-Talk

The PTT signal is just as easy to interface to the transmitter. The controller provides a solid-state switch closure to ground capable of sinking up to about 100 mA from a positive source. Most any transmitter has a keying line (PTT), so if a contact closure to ground normally keys your transmitter, you're in business. If a logic high keys your transmitter, the controller also allows PTT high true operation so that a pullup resistor on the output can define a logic high level to the keying logic. High or low true operation is selected by a DIP switch option.

If your transmitter has a negative voltage on the keying line, it's necessary to buffer PTT with a relay or other transistor circuitry. The PTT output is capable of keying positive voltages only and may be damaged if connected to a negative voltage. If greater than 100 mA is required to key the transmitter, the PTT output can be buffered with a larger transistor or relay.

Receiver Audio

Audio from the repeater receiver needs to be supplied to the controller. The receiver audio is mixed with other audio sources before being sent along to the transmitter and phone line and is supplied on a prioritized basis to the Touch-Tone decoder.

The receiver audio circuitry in the controller allows for a variety of signal levels and impedances. The audio input is capacitively coupled, which means that a DC level may be present on the signal supplied. The level is internally adjustable so that a fairly wide range of input levels is acceptable, but for best results the input audio should be .5 to 2.5 volts peak-to-peak. If the level available is lower than this, the gain of the input stage can be increased by adding a resistor to the controller board at R70 which increases the gain of the non-inverting op amp input buffer to greater than one ($\text{gain} = 1 + (100\text{K}/\text{R70})$). For example, if 300 mV p-p audio is available, installing a 33K resistor at R70 ($\text{gain}=4$) is equivalent to supplying 1.2 volts at the input and is well within the desired range.

The input impedance for receiver audio is 100K ohms so that audio may be picked off from anywhere inside the receiver without loading problems. No impedance matching is necessary either. Find a point past the FM detector where the audio is de-emphasized. It does not need to be squelch gated, since audio gating circuitry is built into the controller. (Note that a COS signal is required from the receiver, however.)

Transmitter Audio

Audio is supplied by the controller to the transmitter. The audio consists of receiver, speech synthesizer, tone, link and phone patch audio, switched and mixed under the control of the computer in the controller.

The audio supplied is high level and low impedance so it's easy to find a good place to inject it into the transmitter. The high level minimizes hum and noise pickup, and it may be knocked down to the level required at the transmitter's audio input stage if necessary.

The microphone input may be OK, but it may be necessary to knock down the level with a resistor voltage divider. If the transmitter audio input is very sensitive, it may be best to reduce the gain of its audio input stage by changing a resistor value. The controller's audio output is DC coupled - it may be necessary to capacitively couple to the transmitter depending on where audio is injected. Remember to use a large enough capacitor to let the lows through - about 10 uF for input impedances as low as 600 ohms, and if it's an electrolytic capacitor, install it so that it's polarized correctly (controller output is at DC ground).

Transmitter audio is available at phono connector "TX" on the rear panel.

Telephone Line

With the FCC Registered Telephone Interface option, the RC-850 Repeater Controller may be directly connected to the national telephone network and comes under the control and regulations of Part 68 of the Federal Communications Commission (FCC).

(1) The RC-850 controller cannot be connected to party lines or to coin operated telephones.

2) In case of any malfunction of the RC-850 Repeater Controller or telephone line, disconnect the unit from the phone line. If the RC-850 Repeater Controller Telephone Interface Board is found to be inoperable, return it Advanced Computer Controls for repair. Do not attempt field repairs or modifications as this violates FCC regulations and will void the warranty. Refer to warranty information supplied with the controller.

3) Before connecting the phone line, call the local telephone company. State the following FCC required information:

FCC Registration Number: AU492x-69442-DP-E
Ringer Equivalence: 0.8B
Novation Phone Line Interface Part Number 490278

Connect one end of the modular cable to the phone line connector box, usually located on the wall.

With the TP-3 Non-Registered Telephone Interface Board, run a wire from the terminal block center terminal directly to your system ground for optimum lightning protection.

Setting DIP Switch Options

Switch settings on the RC-850 controller board select high or low true sense for the COS and PTT signals (see below). It's necessary to set the switches correctly now to properly control the repeater. Switch 1 selects COS sense and switch 2 selects PTT sense. Assuming you don't have a control receiver connected yet, switch 3 must be set ON so that the controller doesn't think that a control receiver is active, therefore grabbing the Touch-Tone decoder. The other switches should be left off for now. Appendix I provides details of switch selections for the various options.

Setting Audio Levels

The audio levels of the various internal audio sources are pre-adjusted at the factory. However, depending on the audio level supplied by the repeater receiver, an adjustment must be made to optimize the signal level through the analog delay line. Not performing this adjustment may result in unacceptable audio quality through the repeater.

With normal audio received by the repeater receiver, pot R113 on the main controller board should be adjusted for approximately 3 volts p-p at test point TP2 as measured with an oscilloscope.

If an oscilloscope is not available, adjust the pot so that receiver audio is about the same level as the speech synthesizer audio, or slightly louder than the Morse code audio. This approach relies on the fact that the levels for the other audio sources are preset at the factory.

This adjustment ensures that, on the one hand, clipping does not occur in the analog delay line, and that on the other hand, you take advantage of the signal-to-noise capability of the delay line. The setting is dependent on the audio signal level supplied from the receiver.

Note: If your controller uses an SAD4096 chip at position U35, then R113 should be adjusted for 1.25 volts p-p at TP2 rather than 3 volts. Controllers supplied after early 1985 use a newer delay line sub-assembly which operates at the higher signal level.

The transmit audio output level is now fixed at approximately 4 volts p-p, and should be knocked down and adjusted at the transmitter if necessary. Do not load the audio output with less than approximately 600 ohms.

If you'd like to change the relative levels of the various audio sources within the controller, refer to Appendix III, Adjustments.

The controller includes audio processing (predictive attack agc) which reduces the transmitted audio level variations for different received levels. Don't try to get a linear "x kHz out for x kHz in" relationship with a deviation meter - the transfer function is shown below.

Interfacing to Specific Repeaters

The RC-850 controller can work directly with any repeater receiver and transmitter. Working with a bare receiver and transmitter simply involves making the four connections described earlier (COS, PTT, transmit and receive audio).

If you're upgrading an existing repeater, chances are that there is already a control system of some sort interconnected between the receiver and the transmitter. When installing the RC-850 controller, it's necessary to disable the existing internal control system so that the RC-850 "calls the shots". This is easily done by

- (1) disconnecting the internal PTT from the repeater's transmitter, and
- (2) disconnecting the internal transmit audio from the repeater's transmitter.

These connections are typically available at feedthrough capacitors on the transmitter's rf tight enclosure. The transmitter's PTT and audio input should be connected to the RC-850 controller. In that way, the internal control system is effectively disabled.

Avoid connecting to the repeater's "accessory" connector, if one is available, unless you're very sure you understand the existing controller's internal operation. Connection in this way may result in dual audio and keying paths - one through the repeater itself and one through the '850 controller. An obvious symptom would be audio "echo" through the repeater.

The receiver COS and audio may be picked off from any convenient point, such as the feedthrough capacitors on the receiver enclosure or from an internal "COR" board, if that's where they are readily available.

The RC-850 controller can interface easily to any repeater. Appendix III shows several examples of hooking up to popular repeaters we've come across.

Chapter 3
Input / Output Characteristics

Basic interfacing of the RC-850 Repeater Controller for initial installation into the repeater was described in Chapter 2 - Initial Installation. This chapter provides a brief general description of the hardware I/O characteristics.

Logic Inputs

The logic inputs to the controller are high impedance with input logic levels compatible with TTL, 5/12 volt CMOS, and logic levels found in many discrete circuits. Logic low is defined as 0-.8 volts and a high may be 2.4-15 volts. Voltages between .8 and 2.4 volts are undefined and must be avoided. Unconnected logic inputs are internally pulled to the logic low state.

The logic driver should be capable of driving a 10K ohm load to a Darlington transistor base. It needs to source at least 100 uA to be recognized as a logic high. If the driver is not capable of sourcing sufficient current, a pullup resistor may be added to a positive supply to source additional current in the high state while the driver sinks the current in the low state.

Logic Outputs

The logic outputs from the controller are open drain, high voltage, high current VMOS transistors. A logic low is equivalent to a contact closure to ground (actually about 5 ohms) and a logic high is an open circuit. The outputs can switch positive DC signals and can sink up to 100 mA when low (on) and can withstand up to 60 volts when high (off).

The logic outputs can be interfaced to TTL and CMOS by adding a pullup resistor to an appropriate supply to define the logic high voltage. For example, interfacing to TTL or 5 volt CMOS can be accomplished by adding a 10K pullup resistor to the 5 volt supply. Interfacing to 12 volt CMOS would require a pullup resistor to 12 volts.

Interfacing to inductive loads, such as relay coils, requires the addition of a protective diode across the coil to prevent damaging the output transistor with an inductive kickback voltage.

Audio Inputs

The audio inputs to the controller are high impedance, capacitively coupled, and level adjustable. They include inputs for the repeater receiver and up to four link / remote base receivers (which may include a control receiver and a spare audio source).

These input levels should be between 1 and 5 volts peak-to-peak (repeater receiver input should be .5-2.5 volts p-p). Input sensitivity may be increased by adding a resistor to increase the gain of the input buffer amp from unity (as supplied) to any desired value. The input sensitivity may be doubled by inserting a 100K resistor, tripled with a 47K resistor, and quadrupled with a 33K resistor.

R70	Repeater Receiver	R80	Link 2 Receiver	R86	Link 4 /
R87	Link 1 Receiver	R81	Link 3 / Spare Audio		Control Receiver

Two unswitched audio inputs to the transmitter audio mixer and telephone audio mixer are available for bringing in additional audio sources, such as the Digital Voice Recorder. These inputs are 10K impedance and are not level adjustable, so they must be adjusted externally. Any audio present at these inputs will always appear at the output of the mixer.

Audio Outputs

In addition to the repeater Transmitter Audio Output, a Processed Receiver Audio output is available for special applications, such as driving links or remote base transmitters. It is an unbuffered, high impedance output with a level of approximately 300 mV p-p. It consists of repeater receiver audio with squelch tails and Touch-Tone stripped.

Analog Measurement Inputs

A sixteen channel analog-to-digital converter allows remote measurement of analog parameters. Two of the channels are internally connected to a temperature sensor and a voltage monitoring circuit. The other fourteen channels are brought to the "Analog Input" connector for connection to external real world sensors.

Measurement range: 0 to 5 volts DC (-9 to +16 volts absolute maximum)
Source impedance: inputs should be driven from source impedance <10K ohms

Serial I/O

The four serial I/O ports provided on the Computer Interface Board present RS-232 compatible electrical characteristics.

Chapter 4 Sub-Audible Tone

The controller may operate in conjunction with a sub-audible tone decoder (PL / private-line) for tone access and control (see Operation Manual - Access and Command Modes).

Two PL logic inputs are available - one which qualifies for all PL activities and another which qualifies only for user level command activities. For example, users may operate PL 100 Hz allowing them access to the repeater and to user level commands. Control operators may operate a different tone frequency, such as 77 Hz, allowing them access to control operator level functions, as well as user level functions.

The external PL decoder may be any device capable of supplying a logic signal to the controller when PL is present on the incoming signal. We'll show two examples - the popular Communications Specialists TS-32 encoder / decoder and the Comm Spec TP-38 shared repeater tone panel. We'll also show how to inexpensively remotely control a PL encode or decode frequency using the TS-32 or SS-32.

Controller PL Logic Inputs

The PL Logic Inputs may be driven by a sub-audible tone decoder which senses the presence of PL tones on received signals.

The PL inputs may be configured to be high true or low true (i.e., high = PL present or low = PL present). The input logic sense is configured by the repeater owner with a programming command.

```
*5104s      User/Control Op (Main) PL Logic Input Logic Connector Pin 15
*5112s      User Only PL Logic Input      Analog Connector Pin 18
```

```
s = 0 => low true / active low
s = 1 => high true / active high
```

Communications Specialists TS-32

The Comm Spec TS-32 Encoder/Decoder unit can supply either a high true or low true output. We'll select OUT-1 which is low true. Jumper JU-1 must be removed and a 10K pullup resistor added to 12 volts or to 7.9 volt point "A".

The figure below shows how the TS-32 can be connected in the repeater system. Audio input to the TS-32 Tone Input should come from a point in the receiver where sub-audible tones have not been filtered out - the proper point is receiver dependent and in some cases must be taken directly from the discriminator. Other receivers have wide frequency response and sub-audible tone is present at later points throughout the receiver.

The TS-32 includes a high pass filter which may be wired in-line with the receiver audio to the controller. The high pass filter removes the sub-audible tone components from the received signal so that they are not retransmitted. Use of the high pass filter in your installation is optional. Some systems are designed to allow user PL to pass unaffected, others filter out PL, and still others regenerate PL on the repeater transmitter.

Note: The CTCSS Tone Decoder - Installed, available as a factory supplied option for the controller, connects to the Receiver Audio supplied to the controller. Therefore, audio should be taken from the receiver at a point where sub-audible tone has not been filtered out. The Audio Filter in the TS-32 is not used.

Comm Spec TP-38 Shared Repeater Tone Panel

The TP-38 tone panel is a cost effective replacement for community repeater tone panels which are used to decode several different tones on a repeater system. Different groups of users sharing the repeater are each assigned their own tone frequency so that they don't need to listen to other users of the repeater who are not part of their group.

In the application shown here, the TP-38 is used as a general purpose sub-audible tone decoder, connecting to the repeater receiver and providing a PL logic signal to the controller.

The TP-38 decodes any or all of the 38 standard sub-audible tone frequencies. With its DTMF option, each tone may be enabled or disabled independently, remotely, using Touch-Tone commands (independent of the RC-850 command set). The unit can also cross code, or generate a different tone output in response to a particular received tone. Use of the TP-38 can provide the system owner the ultimate in flexibility in sub-audible tone operation.

Program the hang time in the TP-38 to zero and connect it to the RC-850 controller as shown below. The TP-38's "PTT" output becomes the PL signal to the RC-850 controller.

Remotely Controlling the TS-32 / SS-32

The Comm Spec sub-audible tone encoder/decoders allow frequency selection by DIP switch settings. The five DIP switches permit selection of one of 32 tones. It's easy to "remote" the DIP switches by connecting them to remote control logic outputs of the controller.

The expanded general purpose remote control outputs from the controller allow group control of two eight-bit groups (see Operation Manual - General Purpose Remote Control). A single user Touch-Tone command can control all eight bits simultaneously. We can use five bits of one of the groups to control the TS/SS-32 frequency and a sixth if we want to turn it on or off.

Another method of controlling the encoder/decoder uses the PL frequency bits included in the remote base frequency data stream supplied by the controller. This approach is best used for PL encoding on the remote bases since the information is stored in remote base memories along with the transceiver frequency.

The TS/SS-32 internal circuitry may operate at its internally regulated 8V supply or at a lower voltage if VR1 is jumpered. With the circuitry shown below, it's important that the TS/SS-32 internal circuitry operate at the same voltage level as the shift registers. Otherwise, the logic signals supplied by the shift registers may not drive IC-107 in the encoder/decoder properly.

**Chapter 5
Control Receiver and
Other Audio Sources**

Control Receiver

A control receiver may optionally drive Spare 2 Audio Input jack and the Control Receiver COS logic input. When a control receiver is used, Link / Remote Base channel 4 should be mapped appropriately (programming command *576443).

Audio input level should be in the range of 1-5 volts peak-to-peak. The control receiver COS may be high true or low true - DIP switch 3 should be set based on its logic sense - ON for high true, OFF for low true. If a control receiver is not connected, DIP switch 3 must be on.

Except for the local mic, the control receiver has the highest priority for access to the Touch-Tone decoder. The Control Receiver COS input to the controller may be driven either by the receiver's COS logic output or by a PL decoder signal in the control receiver for greater security. If a PL decoder is used on the control receiver, PL would need to be transmitted on the control channel to activate the control receiver function. Use PL if there is spurious "grunge" on the control channel.

The control receiver may be optionally retransmitted out the repeater transmitter by Control Op selection. It may also serve as the uplink for remote telephone lines.

Spare Audio 1 Input

The Spare Audio 1 input may be activated by user commands. When the Spare Audio Input command is entered, the repeater transmitter is held on and the audio supplied to this input is retransmitted by the repeater. The function may be turned off by entering the user level Hangup command. A programmable timer may limit the duration that the Spare Audio 1 function is kept on in case the user forgets to turn it off.

The input may be used for a monitor receiver, site monitor microphone, or other audio source.

When the Spare Audio 1 input is used, Link / Remote Base channel 3 should be mapped appropriately (programming command *576330).

Part 97 rules prohibit the retransmission in the amateur service of signals originating from other services. The Spare Audio 1 input should not be used in the amateur service; for example, for monitoring a NOAA weather radio or local police radio.

Digital Voice Recorder

ACC's Digital Voice Recorder may interface to the RC-850 controller so that any of the remotely recordable "tracks" may be addressed through the Message Editor. Any programmable messages may include DVR tracks, as well as synthesized speech, Morse code, etc.

Control signals are passed to the DVR through the Remote Base Data logic output as part of the serial data stream supplied at that output. Information from the DVR is supplied to the RC-850 controller at its External Device Busy logic input.

Audio from the DVR drives the Transmitter Mixer Input and may be level adjusted at the DVR. Audio should be supplied to the DVR from the repeater receiver.

Additional operational instructions for use of the Digital Voice Recorder with the RC-850 controller are supplied with the DVR.

Chapter 6
Courtesy Tone Selection

User Tone Select Inputs (UTI-3) allow external hardware to have a say in the selection of eight Courtesy Tone sets (see Operation Manual - Courtesy Tones). Remember that the hardware inputs do not, by themselves, select the Courtesy Tone. Rather, their choice is considered along with the Control Operator's choice. The highest numbered courtesy tone requested is the one which will be generated at the end of a user's transmission.

The UT logic inputs may be connected to circuitry which monitors received signal characteristics, or site status, to help convey information automatically to users.

Information which might be of value to feed to the UT inputs may go away when the user's signal goes away. For example, S-meter information or voter selection information would be gone when the controller started to generate the Courtesy Tone, about a half second after the user's transmission. For this reason, the controller latches the UT information about 100 ms prior to the end of the user's transmission. No external latches are required to hold the information at the UT logic inputs.

We'll look at two simple examples of interfacing the UT logic inputs to equipment at the site to convey information on the Courtesy Tone.

Example #1. We would like to use the Courtesy Tone to tell us if the repeater is operating on ac power or battery backup. A signal indicating that the battery is powering the repeater, or that ac power is absent, may drive a UT logic input. The other two UT inputs may be left unconnected - like all unconnected logic inputs, they're internally pulled low. The figure below shows how the Courtesy Tone sets are selected. Two are selected by UT3 and the other six are available for Control Operator selection for use as alert status, net in progress, etc.

Example #2. Our system uses two receivers with a voter to select the signal with the highest signal-to-noise ratio. We can take the voter's "receiver selected" signals to the UT inputs to indicate which receiver was active during the user's transmission. Additionally, we can supply an indication of ac or battery power as before. In this example, Courtesy Tone #1 would never be selected, because the hardware UT selection would always request tone 2 or higher.

Chapter 7
Telephone Interface

The RC-850 controller has extensive phone patch and phone line control capabilities which are described in detail in the Operation Manual - Telephone Interconnect. This chapter describes hardware considerations for use of local and remote telephone lines.

Telephone Interface Board

An internal telephone interface board is available as an option for the controller. It interfaces the logic and op amp type electrical signals from the main controller board to tip and ring of the telephone system. It's available as an FCC registered or as a non-registered interface. Both boards serve identical electrical functions, but the FCC registered board is legally required for direct connect to the public switched telephone network.

FCC Registered Interface - Installation information and FCC data for this interface is provided in Chapter 2 - Initial Installation - Telephone Line.

Non-Registered Telephone Interface - This interface is similar electrically to the registered interface. It may be used in applications where the controller is connected to a PBX or other private system.

Second Local Phone Line

The controller supports three telephone lines for outgoing calls. One or two of these may be local lines while up to three may be remote phone lines linked by radio to the repeater. Autopatch calls may be directed to one of the three lines based on the Autopatch command used while autodial numbers are automatically directed to the proper line based on a prefix stored with the telephone number in memory.

Two local lines are distinguished by a logic output at Digital I/O connector pin 23. This signal may be used to switch a DPDT relay to select one of the two lines into the controller's Telephone Interface Board. The relay used should be appropriate for telephone switching applications, such as an Aromat DS series relay.

Remote Phone Lines

The controller can access up to three different remotely located telephone lines for outgoing calls. From the user's standpoint, the patch directed to remote phone lines operates exactly the same as when directed to a local phone line. All the Autopatch and Autodial features are available. The controller handles the signalling and control of the remote site.

The "downlink" from the repeater to the remote phone line site may be via the repeater transmitter or one of the auxiliary link / remote base transmitters. The "uplink" from the remote line site to the repeater may be through one of the auxiliary link / remote base receivers or the control receiver. The uplink and downlink are specified using Programming commands (see Programming Reference Manual - Patch Restrictions and Mapping).

Equipment required at each remote phone line site includes

- a transmitter on the "uplink" frequency
- a receiver on the "downlink" frequency
- a signalling decoder to control the phone line on/off hook, such as ACC's HSC tone decoding board
- a simple phone patch, such as the Heathkit HD-1515
- a sub-audible tone decoder, if the downlink is the repeater transmitter

If the repeater transmitter is chosen to be the downlink, the sub-audible tone decoder is required at the remote phone line sites. The potential exists for a feedback loop consisting of telephone audio transmitted up to and out the repeater transmitter, back down to the remote receiver, injected back into the phone line. In order to break this feedback loop, audio into the remote phone line may be gated by the controller. This is done with a PL encoder at the repeater, activated by the controller when audio should be injected into the phone line, such as during DTMF dialing, and when the mobile station is transmitting. The signal for controlling the PL encoder at the repeater is available at the Digital I/O connector pin 23. It may connect directly to a Comm Spec TS-32 encoder/decoder or a SS-32 encoder. To control the TS-32, connect the signal to the junction of CSR202 and C18. With the SS-32, connect it to the junction of C7 and R6.

Sharing the Phone Line

Several controllers at a common repeater site can share one phone line with handshaking among controllers to indicate when the phone line is currently in use. When the "Phone Line Shared" mode is selected by the repeater owner with a programming command, Digital I/O Connector pin 23 becomes a low true Phone Line Busy output which may be or-tied with other controllers' busy outputs. The signals are also connected to all the controllers' Phone Line Busy inputs.

When a user attempts to bring up the patch and the phone line is in use by another controller, the RC-850 controller responds by saying, "Busy". If the phone line is not in use, the patch proceeds and the RC-850 controller pulls the busy output low to indicate to the other controllers that the phone line is now in use.

Each controller may be set for identical phone answer delays so that all controllers answer an incoming call. Commands addressed to a particular controller will keep it on the line while the other controllers will drop off within 15 seconds.

Using An Existing Coupler

An existing telephone coupler or autpatch may be used in place of the Telephone Interface Board option. If you choose to use such an existing coupler or patch, the design of the proper interface to the main controller board is entirely your responsibility. This section provides the specification for the telephone interface connector at the main controller board.

Four basic signals must be interfaced to the existing coupler - telephone receive audio, transmit audio, offhook logic control, and ring detect signal.

Telephone Receive Audio - This signal must be supplied from the coupler to the main controller board and should be at least 1 volt p-p.

Telephone Transmit Audio - This audio signal is supplied from the controller to the coupler and is approximately 1 volt p-p.

Offhook Logic Output - This 0 to 5 volt CMOS logic signal is supplied from the main controller board to the coupler and signals phone on/off hook. Use programming command *51050 for low true or *51051 for high true.

Ring Detect Logic Input - This low true zero to five volt logic signal should be supplied from the coupler to the main controller board. In its low state it indicates ring voltage present on the phone line.

The signals are available on the main controller board at connector J7. Note that the connector pin numbering is "1" upper left, then pin 2 is directly across from it, i.e., the numbering zig-zags left/right left/right down the connector. This is standard pin numbering for this type of connector. The connections required at connector J7 are:

PIN	SIGNAL
1,2,3	no connect
4	this line must be grounded
5	audio to phone line
6	audio from phone line
7	ring logic signal (5V logic input, low true)
8	offhook logic signal (5V CMOS output, programmable low/high true)
9	analog ground
10	digital ground (may tie to pin 9 and go to patch ground)

Dial Tone Detector

When originating a phone call, the controller delays a minimum two second period before dialing in order to wait for dial tone. It dials "blind", however, assuming that dial tone is present after the delay.

In the extremely rare installation where dial tone is consistently unreliable, a logic input to the controller is available for connection to a dial tone detector. The Dial Tone Detect logic input causes the controller to wait until it indicates dial tone is present before dialing. The Dial Tone Detect logic input should be held high until dial tone is present. In general, the dial tone detector is not necessary, and if none is connected, the controller operates normally.

Chapter 8 Remote Bases and Links

Four remote base or link transceivers are supported by the RC-850 repeater controller. The transceivers may be controlled by user commands to be off, on in receive-only mode, or on in receive-transmit mode. Two of the transceivers may be frequency controlled. In addition to direct frequency selection, frequency memories with "names" simplifies operation. The operation of the transceivers may be scheduled as well as controlled manually. See the Operation Manual - Remote Base and Links for a discussion of commands available for control of the transceivers.

Receive Audio

Remote base or link receiver audio signals connect to the controller's link audio input jacks. Each input is independently level adjustable with the pot shown in the table below. Input level should be in the range of 1-5 volts peak-to-peak. If the level available is lower than this, the controller's input sensitivity may be increased by inserting a 47K resistor on the main controller board as indicated below.

Remote Base / Link	Audio Jack	Level Adjust	Sensitivity Increase
1	L1	R111	R87
2	L2	R110	R80
3	SP1	R109	R81
4	SP2	R108	R86

Link Transmit Audio

Audio for the remote base or link transmitters is available at two locations. The processed main repeater receiver audio is simply receiver audio with squelch tails and Touch-Tone removed by the audio processing circuitry. This audio allows the link to sound identical to a simplex signal. The disadvantage of using this audio source is that only repeater receiver audio is present. Cross-linking (linking one remote transceiver to another) is not possible using this audio nor is command response from the controller.

The other signal available to drive the remote base or link transmitters is the repeater transmitter audio output. It may drive the remote base or link transmitters as well as the repeater transmitter. Simply add a phono "Y" adapter to drive more than one transmitter. This audio is supplied from the transmitter audio mixer and includes speech synthesizer, tone, and other link channel audio signals as switched by the microcomputer. The advantages of using this output is that cross-linking is feasible, and commands entered from the links may be acknowledged to the links.

Audio Source	Jack	Level	Impedance
Processed Receiver Audio	PRX	.5V p-p	10K
Transmitter Audio	TX	4V p-p	< 200 ohms

COS and PTT

Remote base or link COS and PTT signals are available at the the Digital I/O connector and the Analog Input Connector. Link 1 and 2 signals may be configured to be active high or active low (high true or low true) using Programming Commands (see Programming Reference Manual - Logic I/O Senses). Link 3 and 4 provide low true PTT. When interfacing Link 3 or Link 4, be sure to assign these channels as remote bases or links (see Programming Reference Manual - Remote Bases / Links).

Remote Base or Link	COS	PTT
1	Digital I/O Pin 4	Digital I/O Pin 19
2	Digital I/O Pin 16	Digital I/O Pin 6
3	Analog Input Pin 22	Digital I/O Pin 22
4	Analog Input Pin 23	Digital I/O Pin 10

Frequency Control

The frequency of the remote base 1 and 2 transceivers may be controlled. Frequency information, as well as PL, antenna direction, and band select information is available at RB DATA output, clocked serially by the RB CLK signal. The information is recovered by shift register IC's, typically mounted inside the transceivers. The serial scheme minimizes the number of interconnect wires to the radio and the number of discrete output pins required of the controller.

The frequency information is provided for two transceivers as 3 1/2 digits of BCD data compatible with common "thumbwheel" BCD type synthesizers, plus offset information. An on/off bit is also available for controlling power to the transceiver.

Five PL frequency select bits plus an on/off bit is available for controlling a PL encoder (or decoder) for the remote base transceivers.

Three band select bits respond to user commands. These bits allow convenient design of multiple transceivers (such as IC2/3/4A) or a multiband transceiver (such as Drake UV-3) on one remote base port.

Finally, seven bits of antenna direction select information are available for external servo-like control of an antenna rotor.

The serial data stream is defined below. The data burst is sent by the controller on reset, scheduler changeovers, and in response to user remote base or link commands, and is approximately 1 ms in duration.

The serial-to-parallel conversion is performed by one or more 8-bit shift registers, such as 74C164 or 4094B, external to the controller. Only those shift registers required to capture the desired information are required. The first shift register in the chain recovers bits 40-47 (the last bits shifted out). For example, two shift registers capture link / remote base 1 frequency information. A chain of five are required to capture the PL information.

Interface to ICOM IC-22U Synthesizer

As an example of an actual interface to a particular radio, the figure below illustrates an ICOM IC-22U transceiver as a synthesized two meter remote base.

Driving Two Shift Register Chains at Different Logic Levels

The logic signals applied to the transceiver's frequency synthesizer, PL encoder, etc., must be at voltage levels compatible with its circuitry. In the case of the IC-22U above, the circuitry operates at 9V. The ICOM IC2/3/4A synthesizers operate at 5V. Independent shift register chains may operate at different voltages, as shown below, when it's necessary to drive circuitry operating at different logic levels.

Controlling an HF Remote Base

An HF transceiver may be controlled through the repeater system using ACC's ShackMaster SM-100. ShackMaster may connect to one of the controller's four link ports and may support an ICOM IC-751, Yaesu FT-757, Kenwood TS-440S or TS-940S, and certain other HF transceivers. The system permits repeater users to "operate" the HF station with similar benefits offered by VHF/UHF remotes.

ShackMaster normally operates half-duplex, that is, it listens or transmits, but not both at the same time, on the control channel. It does this through its "control window" which forces it to listen periodically for your control transmissions on the control channel. In this repeater application, since the control transceiver is actually a full-duplex link port on the RC-850 controller, the control window isn't needed. Set ShackMaster's control window delay to zero and no control window will be generated. When the link is on, ShackMaster is always listening to the user, capable of decoding commands to control the HF transceiver.

The figure below shows how the RC-850 controller may connect to ShackMaster for control of the HF transceiver through the repeater. For more information on ShackMaster, contact ACC.

Chapter 9
Alarms

The alarm logic inputs to the controller provide over-the-air alarm announcements when the alarm logic inputs are activated. The alarm messages may be programmed by the repeater owner to indicate the nature of each alarm. The alarms may be used as an indication of intrusion, over-temperature, or water on the floor, or as a weather radio storm alert or aviation ELT warning.

An alarm is activated by applying a logic high signal (2.4 - 15 volts) to the alarm input at the Analog Input connector. The signals can be derived from other circuitry, such as a temperature sensor switch or a limit switch which applies a voltage to the alarm inputs when closed. Alternatively, for more security in intrusion detection applications, a pull-up resistor can be grounded by a normally closed switch, and if the switch is opened or if the wires are cut, the alarm will be activated.

The alarm is rising edge triggered and is latching - meaning that once the logic input is taken high, the alarm condition remains even if the logic input is returned low. This insures that detectors such as limit switches for intrusion detect cause a continuing alarm that does not cancel once the switch is closed. The input must be taken low, then high again after being cleared to re-activate the alarm.

Activation of the site alarm causes the appropriate preprogrammed alarm message to be announced over the repeater transmitter at 10 second intervals, until cleared by a Control Op. If not cleared by a Control Op, the announcement will continue for a period determined by the Alarm Timer. If the Alarm Timer is allowed to expire, the alarm message is left in the mailbox for the Control Op (it's left for callsign slot 78, from slot 79).

Chapter 10
General Purpose Remote Control

The controller provides logic outputs available for general purpose, scheduled, remote control of equipment at the repeater site.

Remote Control Logic Outputs

The Remote Control Logic Outputs allow remote control of equipment at the repeater site with user level commands. Each logic output may be controlled independently. The current state of each output may be interrogated and states may be commanded high or low remotely. Programmable response messages return information indicating the meaning of the high and low states of each output in your system. For example, one output may control an antenna relay which selects between an omnidirectional antenna and a beam. The response messages could be configured by the repeater owner to be "OMNI" and "BEAM". The response to interrogation or change state commands would be "OMNI" or "BEAM", based on the current or newly commanded state.

Other equipment at the repeater site controllable by the remote control outputs could include a voter, remote base transmitter high/low power, an ATV camera and transmitter to provide a view from the repeater site on command, etc.

Six open collector outputs are available directly at the DIGITAL I/O connector for remote control.

An expanded mode offers up to 64 remotely controllable outputs, available from a serial data stream shifted out by the controller. The expanded mode is selected with programming command *51061 (see Programming Reference Manual - Logic I/O Senses). The outputs can be recovered by a series of shift registers, or by using one or two FC-1 Frequency Control Boards. Thirty-two of these outputs may be scheduled while the other 32 power up in the low state and are affected only by user commands.

The expanded mode redefines the UF1, UF2, and UF3 output pins to provide a serial data, clock, and transfer signal at those pins for the 64 UF outputs. In the expanded mode, all "User Function" (UF) outputs appear at the shift register outputs, while UF4, 5, and 6 remain available at the connector pins directly, as well.

When any of the outputs UF1-6 are interrogated, a short (~1ms) pulse is generated on that output - that is, the output toggles to the opposite state and back. The pulse is too short to disturb equipment being controlled, but long enough to trigger a one-shot or 555 timer to stretch to any duration required.

With Version 3.4 firmware, several of the output pins may be redefined to serve specific functions based on other controller selections. These are described in Appendix I - Controls, Indicators, Connectors, and DIP Switches.

Chapter 11
Remote Metering

Operation of the metering capabilities is described in the Operation Manual - Voice Response Telemetry. This chapter describes hardware design and interfacing techniques for custom metering systems.

S-Meter

The controller allows users to read back their S-meter reading in synthe-sized speech. An S-meter signal voltage from the repeater and remote base receivers can be applied to the controller's analog inputs.

Two S-meter meter faces are available. One is appropriate for reading the repeater receiver (02) and the other for remote base receivers (30).

Meter face 02 measures the S-meter signal approximately one second into each repeater user transmission. The measured value is stored in memory, and if the user requests an S-meter reading, the stored value is read back in S-units. The user should remember to key down for a minimum of one or two seconds to ensure that the controller has had a chance to check the meter.

Meter face 30, like most other meter faces, makes its measurement when the user's command is evaluated, at the end of his transmission (or after a "D" key which forces command evaluation). This meter face is useful for checking the signal strength of remote base or link signals.

Many receivers, such as the Spectrum SCR-200, have internal signal strength circuits which may be tapped to provide a signal voltage to drive the controller. Other receivers may not have such a circuit - circuitry to obtain an S-meter voltage appropriate for the Motorola Micor is shown below. It can be easily adapted to other receivers with relatively low frequency i.f.'s.

The meter voltage would ideally range from zero to five volts. However, if the voltage range is too high, it can easily be knocked down with a resistor voltage divider. If it does not range all the way to five volts, the reading will simply "top out" at less than S9+60.

As an interface example, the Spectrum Communications SCR-200 receiver S-meter output can drive the RC-850 controller as shown below. The meter itself should be disconnected from the circuit, since it would load down the signal voltage to be measured.

The Motorola Micor may be metered with the circuit shown below. Connect the circuit to Point H (UHF receiver) which is after the output capacitor (junction C165, L127, R131) at the first i.f. amplifier. The rectified signal is amplified with an op amp and adjusted to match the RC-850 controller's S-meter "meter face".

Quieting

A measurement which can be as useful as S-meter readback is percentage quieting. A signal voltage proportional to the noise level can be applied to the controller's analog inputs and permit a percent quieting readback to users.

When no signal is present, the FM receiver discriminator contains broad band audio noise. As a carrier increases in strength, the level of the noise decreases until the receiver is fully "quieted". Measuring the level of noise present on a signal gives the degree of quieting.

Since the discriminator contains the intended baseband audio signal as well as some level of broadband noise when a signal is present, a quieting measurement circuit should examine only relatively high frequency noise so it isn't fooled by voice. The filtered noise can then be rectified to form a DC voltage which may be measured by the controller to read back quieting. Since a noise filter/rectifier is a fundamental part of all noise operated squelch circuits, most of the circuitry may already be present in your receiver. It may only be necessary to boost the DC voltage to match the controller's zero to five volt input range. Otherwise, the discriminator may directly drive a circuit which provides band pass noise filtering, an "ideal" rectifier, and scaling circuit.

The controller's meter faces read in inverse percent from 100 to 0. Two quieting meter faces are available. One is appropriate for reading the repeater receiver (04) and the other for remote base receivers (32). Meter face 04 makes its actual measurement at one second into each repeater user transmission so it is necessary to key down at least one second when requesting a quieting measurement readback. The measurement of meter face 32 is made when the user command is evaluated, at the end of his transmission.

Temperature

The controller allows placing temperature sensors at various places at the site to allow remote synthesized speech readback of temperature as well as inclusion of the readings in any programmable messages. A running record of the lowest and highest temperature are also stored in memory, tagged with the time and date of the low/high reading.

The temperature measurement capability is valuable for monitoring outside temperature, temperature inside the building, in the cabinet, temperature of the power amp heat sink, etc. Knowing how high and low the temperature reaches, and when, is also of value.

Temperature measurement is based on the National Semiconductor LM335 Precision Temperature Sensor. The LM335 is electrically like a zener diode with a precision temperature/voltage characteristic. It's available in a plastic (LM335Z) and metal (LM335H) transistor package. If sensing the temperature of a heat sink, the metal package is preferred because it's easier to thermally couple. Remember that the metal package is tied to the negative pin which is ground in our application. Portions of the LM335 data sheet are shown below.

Two meter faces are available for measuring temperature. Meter face 05 - "Temperature - LM335 Sensor" operates with an extremely simple circuit - the LM335 temperature sensor IC and resistor as shown below. The resolution of the meter face is 0.2 degrees which is adequate for many applications. The internal temperature sensor on Analog Channel 15 uses this circuit. This meter face is calibrated using a programming command (see the Programming Reference Manual - Telemetry Meter Faces - Temperature Calibrate for the calibration procedure). The procedure is performed on one channel and applies to all channels with this meter face assigned. The sensors normally have an untrimmed accuracy of approximately one degree, so that calibrating one channel calibrates them all.

Meter face 06 - "High Accuracy Temperature" provides the option of a one degree resolution measurement but requires an external op amp circuit to amplify the voltage vs. temperature change of the sensor. The circuitry is shown below.

Voltage

Several voltage meter faces are available for measuring voltage with full scale values of 16, 32, and 256 volts.

Scaling of voltage levels to match the zero to five volt measurement range is easy - just a voltage divider composed of two resistors. The 16 and 32 volt scales are useful for monitoring DC power supplies and batteries and internal test points of equipment.

The 256 volt scale can be used to monitor ac line voltage with a simple transformer, rectifier, and filter. This can be particularly valuable if power at the repeater site is unreliable, and with the automatic high/low storage tagged with time and date, the controller can provide information on brownouts and overvoltage conditions.

Current

Meter faces are available for measuring current with full scale values of 4, 8, 16, and 32 amps, and 64 microamps.

Measuring current requires a circuit which develops a voltage proportional to current. This can be easily accomplished with a small value current sensing resistor, and a differential, or instrumentation type amplifier, constructed with an op amp and four resistors. The output of the op amp is equal to the current times the sensing resistor times the voltage gain of the amplifier. The value of the sense resistor that should be used depends on the maximum load current since the voltage drop across the resistor reduces the voltage to the load. Be sure to calculate the worst case power dissipation of the resistor (I^2R) and use an appropriately rated resistor.

Ideally, a power supply with remote sensing capability would be used with the sense return after the sensing resistor. That way, the voltage to the load would be independent of current.

The four resistors around the op amp should be 1 or 2 percent metal film types (available from RCA in "bubble pack"). Be sure that the common mode input voltage range of the op amp will accommodate the operating voltages that result from resistor/gain selection. For example, an LM324 or LM358 op amp operating at +12 volts and ground will operate properly with input voltages between zero and ten volts (input common-mode voltage range from data sheet).

An example is shown below for measuring current drain from a repeater power supply.

Power

Nine meter faces are available for measuring power, with full scale values ranging from 2 to 256 watts. Resolution of the lower range meter faces is .1 watt while the higher range meter faces have a resolution of one watt.

Remote readback of rf power from the repeater site helps diagnose system problems, such as transmitter, power amp, feedline, or antenna difficulties before going to the site so that you can go prepared. It also permits you to evaluate SWR during different weather conditions, and so on. You can monitor the repeater's transmitter, link transmitters, and other rf equipment at the site.

Power is different than other types of measurements in that meter deflection is not linearly proportional to power level. The scale is expanded out at the low end and crowded in at the high end. This is largely due to the fact that power is proportional to voltage or current squared. There are other non-linearities in the meter's sensing circuits which contribute additional non-linearities in the scale. The power meter faces in the RC-850 controller are based on a power proportional to voltage squared relationship, which provides readings accurate to a few percent. Remember that a 25% error is only 1 dB.

As an actual interface example, we'll show how to interface the Daiwa CN-550 140-250 MHz dual needle meter to the controller. The CN-550 has its sensors mounted in a shielded enclosure with rectified DC output for forward and reflected power available at two feedthrough capacitors which drive the meter movements through adjustable resistors. The DC voltages at the feedthroughs can be tapped to drive op amp circuits to increase the levels to match one or more of the power meter faces.

Resistors are selected based on the power level of your system to provide zero to five volt DC levels to the controller's analog inputs and should be adjusted for accurate reading at the normal power level.

For reflected power, you might want to drive two different meter inputs to allow accurate readback of both normal (small) reflected power and a higher full scale face in case of antenna problem, to avoid "pinning" the talking meter.

Everything You Need to Know About Op Amps (at least to get started)

Designing custom circuits for creative interfacing of sensors to the RC-850 controller is easy, but it does require a basic understanding of op amp circuits. Although op amps are the most common analog function block, they may seem like black magic until you understand a few simple principles. We'll try to summarize the basics of op amps here, and you should be an expert when you leave the page!

The important characteristics of op amps are:

- Op amps have (almost) infinite gain
- Op amps have infinite input impedance and draw no input current
- Op amps have two inputs: inverting and non-inverting
- In linear applications, the op amp likes to stay out of saturation
- To stay out of saturation, the op amp would like the voltages at its inputs to be equal, and as circuit designers, we're willing to help, through feedback

The basic op amp symbol is a triangle with the inverting (-) and non-inverting (+) inputs on the left and the output on the right. The op amp's basic goal in linear applications is to stay out of saturation. If the op amp saturates, or bangs its head against the supply rails, it becomes useless in linear applications. Since it has (almost) infinite gain, the only way the output voltage won't be infinite is if the two inputs are at exactly the same voltage. Almost infinity times zero is zero!

An op amp with feedback (a portion of the output signal routed back around to the inverting input) keeps out of saturation through a concept called the "virtual ground". This simply means that negative feedback from the output to the inverting input forces the inverting input voltage to equal the non-inverting input voltage. Since in many applications the non-inverting input is taken to ground, the inverting input is dubbed "virtual ground".

If the inverting input voltage happens to be higher than ground, the output voltage drops, pulling the inverting input voltage back down towards ground. If it happened to be below ground, the output would rise, pulling the input up to ground. The point to remember is that if the op amp is not saturated, both inputs are held at exactly the same voltage by the negative feedback.

Now if we remember that no current flows into the op amp inputs, it's easy to understand how to calculate the gain of simple inverting and non-inverting amplifier circuits. The current flowing through the input resistor, which we can calculate, determines the current which will flow through the feedback resistor. Since we know the currents and resistor values, we can determine the voltage drops, and therefore, the gain.

If one volt is applied to R1 of the inverting amplifier, we know the current flowing through R1 since the other side of the resistor is at "virtual ground". $I = (1V/R1)$. Since no current flows into the op amp, it all must flow through R2, creating a voltage across R2 of $V = (R2 \times 1V/R1)$. The gain, or V_{out}/V_{in} is then $-(R2/R1)$. See why it's negative, or "inverting"?

In the case of the non-inverting amplifier circuit, we apply the input signal directly to the non-inverting input of the op amp. Again, negative feedback forces the inverting input to be at the same voltage (although in this case it's not ground), so we know the current through R1. $I = 1V/R1$. Since no current flows into the op amp input, it all flows through R2, creating a voltage of $(1V/R1 \times R2)$. The output voltage is the voltage across R1 plus the voltage across R2. The gain, or V_{out}/V_{in} , is therefore $(R1/R1 + R2/R1)$, or $(1 + R2/R1)$. See why?

All analysis of linear op amp circuits is based on these principles. Feedback keeps the input voltages equal because of the op amp's infinite gain, and because no current flows into the op amp inputs.

As one more example, we'll analyze the High Accuracy Temperature Sensor circuit. The LM335 temperature sensor and its 10K pullup resistor form a low impedance voltage source. The voltage at the junction is (relatively) independent of the load current drawn from the node. We know easily that the gain of the circuit is -5 ($-100K/20K$). The op amp inverting input (-) is not at ground, however. It's kept at the same voltage as the non-inverting (+) input by feedback. The effect is to offset the signal voltage from the LM335 as well as to invert and amplify it - in this application to match the High Accuracy Temperature Meter Face.

Stable metal film, 1% resistors are recommended (except the 10K pullup) to keep the circuit stable over temperature since small offset or gain changes result in significant temperature reading errors.

Of course, in the real world, nothing is perfect. The op amp's gain isn't really infinite but is very high - typically about a hundred thousand. And its inputs don't try to be exactly the same, but may be offset by a few millivolts. The input current isn't really zero either, but may be a few microamps or so. And inputs to the op amp must be within a certain voltage range. If a voltage at either input is outside the op amp's common mode input range, in other words, too close to the supply rails, the op amp won't function properly.

For signal conditioning applications, we recommend LM324 quad or LM358 dual op amps. These op amps can be operated with a single twelve volt supply ($V+ = 12$ volts, $V- =$ ground). Unlike 741 type op amps, these allow input signals to extend down to their $V-$, which in our application is ground. That is, their common mode input range extends to $V-$. Excerpts from their data sheets are shown below.

Chapter 12
Principles of Operation

This chapter provides an overview of the principles of operation of the RC-850 Repeater Controller.

The controller consists of several boards interconnected with simple cabling. The Main Controller Board contains the microcomputer with its CPU, ROM, RAM, E2PROM, I/O, and fail-safe circuitry, E2PROM programmer, audio processing circuitry, audio switching and mixing circuitry, tone generator, the Touch-Tone decoder, and various I/O and control circuitry.

The Telephone Interface Board provides the interconnect to the phone line, providing isolation, protection, impedance matching, ring detection, and on-hook/off-hook control. It also provides an electronic hybrid which permits duplex patches and a received audio agc circuit. The FCC registered board complies with FCC Part 68 regulations regarding telephone inter- connect to the public switched telephone network.

The Front Panel Display Board provides visual display indicators for internal and I/O status and amplifiers for a local microphone and speaker.

The Voice Response Telemetry Board includes a speech synthesizer, time of day clock, and analog measurement circuitry, plus additional microcomputer logic inputs.

The Computer Interface Board provides four serial I/O ports along with a socket for additional firmware memory and two Touch-Tone decoders.

Main Controller Board

The Main Controller Board provides a complete, stand alone repeater controller with all the features of the RC-850 controller except Telephone Interface, Front Panel Display, Voice Response Telemetry, and Computer Interface (see Chapter 1 - Specifications and Features).

The board is powered by a single external +12 volt supply, and the necessary +5, +21, and -9 volts for the various circuitry are derived on- board (U1, U24, U25).

The crystal controlled clock for the microcomputer and various other circuits on the board is derived from the 3.58 MHz oscillator on the Touch-Tone decoder chip (U40).

The CPU is a CMOS, low power, 80C85 (U4). The CPU provides the microcomputer's registers (including the accumulator), arithmetic logic unit (ALU), instruction decode, interrupt control, and timing and control circuitry.

The CPU uses a multiplexed data bus. The address is split between the 8 bit address bus and the 8 bit multiplexed data bus. The 8 bit 74HC373 latch (U5) de-multiplexes the low order address information from the multiplexed data bus.

The address decoding circuitry (U14, U33) generates chip select signals for the various memory and I/O devices in the microcomputer.

Several fail-safe protective circuits help prevent CPU lockup in case of soft error. A watch-dog timer (U11, U34) is strobed every five seconds by the microcomputer software. If the watch-dog timer is allowed to time out, as if the CPU were to hang up, the CPU is reset, initializing program execution.

Circuitry monitors the +12 volt and +5 volt supplies (Q1, Q2, Q4) and if either drops below the level required for proper operation, the CPU is clamped reset so that it initializes properly when the supply voltages are restored to their proper levels.

The CPU is capable of addressing up to 64K bytes of memory. Five memory sockets are provided on the Main Controller Board. Each socket is decoded as an 8K byte site and is compatible with 2K, 4K, and 8K devices, allowing easy memory upgrade on-board. Three sockets are intended for EPROMs (U6, U7, U8 - 2764), one for RAM (U9 - 6116 or 6264), and one for an E2PROM (U10 - 2815, 2816, 2816A, 9864). The controller is supplied with the 6264 8K RAM device.

A memory expansion board, the MX-1, may plug into the U10 E2PROM socket to provide sockets for two 2K byte E2PROMs. The MX-1 allowed use of 4K of non-volatile memory before the larger devices, such as the 9864, became available. An 8K byte E2PROM, the 9864, may plug into U10, providing 8K of non-volatile memory for use with Version 3 firmware. The controller is supplied with the 9864 8K E2PROM device.

An on-board 21 volt supply (U24) provides the programming voltage required for the older 2815 or 2816 E2PROMs. The 21 volt supply is controlled by the microcomputer software and is kept off unless new data is being programmed into the E2PROM. The 21 volt supply is not needed with the 8K byte 9864 E2PROM. When the 9864 is installed instead of the MX-1/2815's, U24 should be removed to avoid the possibility of damage due to turn-on of the 21 volt supply.

Another memory expansion board, the MX-2, may plug into the BUS connector of the Main Controller Board to provide an additional 32K bytes of program memory using a 27256 EPROM.

The repeater receiver audio is processed by the controller to remove squelch tail and Touch-Tone and to provide a degree of automatic gain control to reduce level variations through the repeater. The receiver audio is pre-filtered (low pass, U43) to limit its bandwidth before being applied to the audio delay line. The audio passes through a gate (U45), then is delayed 75 ms in the delay line (U35). Post filtering (U43) removes high frequency clock components generated in the delay line. The delayed audio passes through an agc circuit (U36) whose control voltage is derived from the undelayed receiver audio, providing a "predictive attack" agc characteristic. The processed receiver audio is then available with the controller's other audio inputs to be switched and mixed.

Two audio mixers (U17) combine audio signals under computer control to drive the repeater's transmitter and the phone line. Each input to the mixers has its own level adjust and is switched independently into the mixers. In addition, an unswitched input is available to each mixer for expansion. The mixer outputs drive the repeater's transmitter and the Telephone Interface Board.

One of several audio sources is selected under computer control (U31) to drive the Touch-Tone receiver. A bandsplit filter (U40) separates the high and low tone components of the Touch-Tone signal, squares them up, and applies them to the decoder inputs (U41). The logic outputs of the decoder can be read by the microcomputer to determine what Touch-Tone keys have been sent to the controller (U42).

Buffered logic I/O interfaces the microcomputer to the other equipment in the repeater system including the receiver and transmitter, link equipment, courtesy tone select circuits, and various other equipment to be controlled at the site (U29, U30, U19, U20, Q9-21). Inputs are TTL and CMOS compatible Darlington transistor arrays while outputs are high voltage, high current power FET transistors capable of sinking current to ground ("open collector").

Telephone Interface Board

The Telephone Interface Board interfaces to the Main Controller Board and to the telephone line.

FCC Registered Interface - The heart of the board is an industrial grade, FCC registered Phone Line Interface Module from Novation. The module connects to the phone line and provides DC isolation and protection to telephone company equipment. It also provides impedance matching and audio coupling, ring detection, and switchhook control.

Non-Registered Interface (TP-2) - This board replaces the Novation PLI module with a high quality telephone coupling transformer (T1), relay (K1), and optocoupler ring detector (U1).

Non-Registered Interface (TP-3) - This board is a redesign of the TP-2 interface and includes a built-in three-terminal gas discharge tube for extremely effective lightning protection. A three position terminal block provides screw terminals for tip and ring (interchangable) and a third (center) terminal for the gas discharge tube common pin. This terminal should be taken directly to the system ground through its own separate wire for maximum lightning protection effectiveness.

Each board also includes logic level shifting circuitry, an electronic hybrid for duplex patches (U3), and agc circuitry (U5).

Front Panel Display Board

The Front Panel Display Board consists of LED indicators with their drivers and a local mic amplifier and local speaker amplifier.

The LED displays consist of several bar graphs, each containing 12 LED indicators, plus a single 7 segment LED digit. They are driven by CMOS shift registers (U3-10), loaded serially by the Main Controller Board every 30 ms.

For units with serial numbers less than 686, the local mic amplifier (U2) interfaces to an ICOM HM-8 preamplified microphone. Regulated 9 volts is provided to the microphone and approximately 1 to 2 volts peak-to-peak audio is expected from the mic. For units with serial numbers 686 and above, the local mic amplifier (U2) interfaces to a Kenwood MC-48, MC-48B, or equivalent microphone.

The local speaker amplifier (U1) drives an 8 ohm speaker with several hundred milliwatts of audio from the transmitter or phone mixer.

Voice Response Telemetry Board

The Voice Response Telemetry Board provides an electronic speech synthesizer and hardware time of day clock, an eight bit, sixteen channel A/D converter, and additional microcomputer input ports.

The speech synthesizer (U12) is controlled by the microcomputer and provides audio back to the Main Controller Board, applied to the transmitter and phone audio mixer inputs. The synthesizer includes some speech vocabulary information on the board (U6-8) and additional vocabulary in the microcomputer firmware on the Main Controller Board, loaded into the synthesizer through the microcomputer bus. The pitch of the synthesizer speech is adjustable by pot R9 on the board.

The time of day clock (U13) is based on a 32.768 kHz quartz crystal. It is a 12/24 hour clock with built-in calendar. It can be set and read by the microcomputer through I/O ports.

The A/D converter includes a sixteen channel analog multiplexer (U9, U10), a DAC (U14), and a comparator (U11). A successive approximation conversion routine is performed in software to read the voltage present at any of the multiplexer inputs.

An additional eight bit input port (U1, U2) interfaces to the microcomputer bus for additional system logic inputs.

Computer Interface Board

This board supplies additional resources for the controller including serial I/O to allow remote control and programming of the controller from an ASCII terminal. Two serial ports are made available by the CMOS 8251A UARTs (U7, U8). These ports are buffered by CMOS RS-232 compatible drivers (U2, U3, U4, U5). The baud rate of one of the ports is DIP switch selectable from 300 to 9600 baud. The other port is either 300 or 1200 baud, depending on the RS-232 signal level on pin 12 of the DB-25 connector. It is intended to be compatible with the Hayes 1200 baud SmartModem.

Sockets for three jumper selectable 27256 or 27128/513/011... EPROMs (U15, U16, U17) provide unlimited memory expansion - to 384K bytes with currently available memories, further with future memory devices.

Two uncommitted Touch-Tone decoders (U19, U20) provide the controller with two additional full-time decoders. These may be hardwired by the user to any desired signal sources, such as links and the phone line.

Chapter 13
Troubleshooting

Maintenance

The RC-850 controller is designed conservatively with high quality, reliable components, and it is very unlikely that a component failure will take the controller out of service. No periodic maintenance is necessary to ensure long life. Simply follow common sense in installing the controller, such as avoiding locating it in extremely hot or dirty areas. You should expect your RC-850 controller to run virtually forever.

Servicing

However, since Zap, the Lightning God, has been known to visit repeater sites, it's possible that it may become necessary to repair the controller at some time in its service life. The RC-850 controller includes transient protection to minimize the possibility of damage and this protection should be supplemented with sound site engineering to minimize impact of lightning on all equipment in the system. See Appendix IV, "Lightning Protection for Your Repeater System", for system design considerations.

Since all ICs are socketed (in extremely reliable sockets), troubleshooting and repair should be relatively simple.

Of course, the controller may be returned to the factory for repair, but it would be desirable to attempt to diagnose and repair failures at the site when possible to minimize repeater down time. While all potential failure modes can't be anticipated, the guidelines will help isolate the problem to a particular component or area.

In general, hardware failures can be classified into two broad categories - those where the computer executes its program correctly and those where it executes garbage or nothing at all. If the computer is executing its program correctly, as evidenced by partial operation of the controller, the failure is probably a peripheral or interface circuit. Otherwise, the problem is probably the CPU, memory, or decoding circuitry.

General Checklist

- ICs firmly seated in sockets?
- Cable connectors properly inserted?
- +12 volt and 2 grounds connected properly?
- DIP switches set correctly and firmly?
- Any components hot? (careful!)
- Both grounds connected?

TROUBLE	PROBABLE CAUSE	REMEDY
Computer Dead	+12 volt supply not present Defective supply Defective power wiring	Repair supply Repair wiring
	+5 volt supply not present Defective 7805 regulator Defective IC overloading Oscillator not running Grounds not connected	Replace regulator Locate and replace defective IC Replace xtal Y1 Connect both grounds
No audio	-9 volt supply not present	Trace "V-"
Distorted Audio	Excessive input level Excessive deviation	Reduce input level Reduce deviation control in transmitter
Audio "echo"	Internal audio path in repeater Poorly regulated supply Turn off local speaker RF feedback from transmitter	Disable internal path Improve power supply Improve rf isolation to receiver
Audio noise, Touch-Tone feedthrough	Overdriving transmitter into soft clipping limiter (not deviation)	Reduce transmitter audio level before the
Logic Inputs Not Sensed	Defective input buffer	Replace U14
Logic Outputs Not Operating	Need pullup resistor to define high level Defective output port Defective output buffer	Add pullup resistor Replace 4724B Replace VN10KM
Touch-Tone Decode Unreliable	Audio clipping throughout system Excessive twist frequency response Interdigit or sequence-to-end-of-transmission timer too short	Reduce level Flatten system Lengthen timers

RF Interference

The controller uses relatively high speed digital logic which results in signals with fast edges. The logic signals contain harmonic energy throughout the HF and VHF frequency ranges. Because the controller uses CMOS with somewhat slower edges than TTL or low power Schottky logic, the harmonic energy is lower than it would be in TTL based systems. Since a repeater system contains receivers sensitive to signals as low as tenths of a microvolt, it's possible for rf from the controller to interfere with the repeater or remote base receiver. It's even possible for rf energy to enter the transmitter and modulate the transmitted signal on unexpected frequencies.

In most installations, there is no difficulty because the receiver equipment is typically well shielded (to prevent transmitter energy from affecting it), and the antennas are some distance from the controller. If rf interference is a problem, several simple steps should eliminate or reduce the effects.

If the receiver equipment is not well shielded, it should be. Signals entering and leaving the receiver should go through feedthru capacitors. It may be desirable to add small chokes (about 10 uH), ferrite beads, or torroids in series with the signals where they reach the feedthru to improve the effectiveness of the filtering.

RF energy entering the transmitter can be another source of RFI through intermodulation effects. Small chokes or beads on power and control lines entering the transmitter may be helpful as well.

Signals from the controller to external equipment may be filtered with small chokes or ferrite beads at its connectors, and cables may be shielded to eliminate radiation of rf energy.

Try to determine if the rf enters the receiver through the antenna or through some other path - put the receiver on a dummy load to see. If it's entering from the antenna, see if it's possible to increase the separation. The antenna pattern is such that equipment located directly under the antenna is generally in a null which reduces rf coupling. Shielding of wiring and cabling may be helpful when rf enters at the antenna.

If the rf path is other than through the antenna, shielding and filtering of the interface cables should be improved.

RF energy from the controller varies with the computer's bus activity or program execution. A continuous component is present at 146.76 MHz, which is the 41st harmonic of the controller's 3.579545 MHz crystal clock oscillator.

In general, the controller is not susceptible to rf from repeater equipment unless it is exposed to very strong local fields.

**Appendix I
Controls, Indicators, Connectors, and Switches**

The RC-850 Repeater Controller is available with a full complement of controls and indicators. Various connectors allow interfacing to other elements in the repeater system.

Controls

POWER

Enables power from the main input and backup battery input to the controller.

RESET

Manually resets the controller's microcomputer.

DISPLAY*

Enables power to the Front Panel Display and enables the local microphone and speaker amplifier. The display should normally be kept off unless observing the operation of the repeater, or operating it locally, to conserve power.

VOLUME*

Controls the audio level to the local speaker when the DISPLAY switch is ON.

XMTR/PHONE*

Selects the audio routed to the transmitter or to the phone line to drive the local speaker when the DISPLAY switch is ON.

* Supplied with Front Panel Display option only.

Indicators

POWER

Indicates power applied to the controller. This indicator is independent of the DISPLAY switch.

NOTE: The following indicators are available with the Front Panel Display only. They are enabled with the DISPLAY switch "ON".

BLINK refers to 50% duty cycle, 1 Hz display (slow flash).

WINK refers to 20% duty cycle, 2 Hz display (fast flash).

STATUS

ENABLED

OFF Repeater system disabled
ON Repeater system enabled
BLINK Repeater timeout timer "timed out"

PL ACCESS

OFF PL not required for access or command
ON PL required for access and command

Controls, Indicators, Connectors & Switches - Appendix I

BLINK PL required for Control Op level command only
WINK PL required for Control Op and User level command

TT ACCESS

OFF Touch-Tone Access Mode disabled
ON Touch-Tone Access Mode enabled, down
WINK Touch-Tone Access Mode enabled, up

IDENT

OFF ID not required
ON ID required, not waiting
BLINK ID required, Pending ID waiting
WINK ID required, Anxious / Initial ID waiting

KERCHUNK

OFF No recent Kerchunks
WINK Recent Kerchunk

AUTOPATCH

OFF Primary Autopatch disabled
ON Primary Autopatch enabled, long distance enabled
BLINK Primary Autopatch enabled, long distance disabled
WINK Primary, Secondary, or Tertiary Autopatch in use

AUTODIAL1

OFF User Loadable Autodial Bank 0 disabled
ON User Loadable Autodial Bank 0 enabled and unlocked
BLINK User Loadable Autodial Bank 0 enabled and locked
WINK User Loadable Autodial Bank 0, 1, or 2 in use

AUTODIAL2

OFF Primary Emergency Autodial disabled
ON Primary Emergency Autodial enabled
WINK Primary or Secondary Emergency Autodial in use

LINK1/2

OFF Link / Remote Base disabled
ON Link / Remote Base enabled, off
BLINK Link / Remote Base enabled, receive only
WINK Link / Remote Base enabled, receive / transmit

UNLOCKED

OFF Normal locked mode
ON Unlocked programming mode

PROGRAM

OFF Normal
ON Non-volatile memory being programmed

CONTROL

INPUTS

COS Indicates repeater receiver COS active
COS/LINK1 Indicates Link / Remote Base 1 receiver COS active
COS/LINK2 Indicates Link / Remote Base 2 receiver COS active
PL Indicates main PL input or User Only PL input active
PHONE RING Indicates phone is ringing
TAPE SENSE Indicates control receiver COS active

OUTPUTS

PTT Indicates repeater transmitter PTT active
PTT/LINK1 Indicates Link / Remote Base 1 transmitter active
PTT/LINK2 Indicates Link / Remote Base 2 transmitter active
POWER AMP Indicates Power Amp output active

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PHONE OFFHK Indicates phone line offhook

AUDIO

XMTR Indicates active inputs to transmitter audio mixer
RCVR Repeater receiver audio input
LINK1 Link / Remote Base 1 receiver audio input
LINK2 Link / Remote Base 2 receiver audio input
SPARE1 Spare Audio 1 or Link/Remote Base 3 receiver audio input
SPARE2 Control receiver or Link/Remote Base 4 receiver audio
input
SPEECH/LM Speech synthesizer / local mic audio
PHONE Telephone audio
TONE Tone generator audio

TOUCH-TONE

DIGIT Indicates DTMF digits decoded by Touch-Tone decoder,
or digits outpulsed when originating a telephone call
CHANNEL Indicates audio selected for input to Touch-Tone decoder
RCVR Repeater receiver audio input
LINK1 Link / Remote Base 1 receiver audio input
LINK2 Link / Remote Base 2 receiver audio input
SPARE1 Spare Audio 1 or Link/Remote Base 3 receiver audio input
SPARE2 Control receiver or Link/Remote Base 4 receiver audio
input
PHONE Telephone audio
LOCAL MIC Local microphone
SENDING Indicates outpulsing DTMF or dial pulse into phone
SEQ IN PROGRESS
OFF No command sequence in progress
ON Command sequence in progress
WINK Sequence interdigit timer timed out

USER I/O

OUTPUT Indicates user function output high
INPUT Indicates user tone select input active (high)

Connectors

LOCAL MICROPHONE (with Front Panel Display option only)
Compatible with ICOM HM-7, HM-8 or equivalent microphone if S/N < 685,
or compatible with Kenwood MC-48, MC-48B or equivalent microphone if S/N
> 686.

PIN	ICOM Microphone Kenwood Microphone	
	FUNCTION	FUNCTION
1	Audio out (1-2 volts p-p)	Mic
2	+9 volts regulated	PTT
3	-	-
4	-	-
5	PTT	B+

Controls, Indicators, Connectors & Switches - Appendix I

6	PTT ground -		
7	Audio ground	GND	J2-1
8	-	GND	J2-2

AUDIO I/O

RCA phono jacks

RX	Repeater receiver audio input
L1	Link/RB 1 receiver audio input
L2	Link/RB 2 receiver audio input
SP1	Spare audio 1 or Link/Remote Base 3 receiver audio input
SP2	Control Receiver or Link/Remote Base 4 receiver audio input
TX	Transmitter audio output
RXOUT	Processed receiver audio output (squelch tails and Touch-Tone stripped)
TMIN	Transmitter mixer input (unswitched, for expansion of audio mixer)
PMIN	Phone mixer input (unswitched, for expansion of audio mixer)
1-9	Unconnected spares (for user's application)

LOCAL SPEAKER (with Front Panel Display option only)
4-16 ohm speaker, miniature phone jack

DIGITAL I/O (see "Inputs" and "Outputs" for pinout)
Mates with DB-25P (supplied)

ANALOG INPUTS (see "Logic Inputs" and "Analog Inputs" for pinout)
Mates with DB-25S (supplied)

TELEPHONE

Modular telephone cord and plug

POWER

4 pin "Jones" plug

Pin	Function
1	Analog ground
2	+12.6 volts
3	Digital ground
4	Battery

Outputs

Connector	Pin #	Function
Digital I/O	5	power amplifier (control op selectable)
Digital I/O	20	UF1 or UF DATA†
Digital I/O	8	UF2 or UF CLK†
Digital I/O	21	UF3 or UF XFER†
Digital I/O	9	UF4 or External Device Strobe††
Digital I/O	22	UF5 or Link 3 Transmitter PTT†††

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Digital I/O	10	UF6 or Link 4 Transmitter PTT†††
Digital I/O	11	RB DATA
Digital I/O	23	††††
Digital I/O	7	Repeater Transmitter PTT
Digital I/O	19	Link 1 Transmitter PTT
Digital I/O	6	Link 2 Transmitter PTT
Digital I/O	18	RB STROBE

† Determined by UF latched/expanded mode, Prog. Ref. Manual p.10-1

†† If any messages are programmed including External Device 1 (Prog. Ref. p. 4-7), then this output provides a 1 second low true pulse to strobe the external device. If used for this purpose, UF4 should be programmed high in all Macro Sets, and should not be manually commanded.

††† Determined by Remote Base / Link Channel Assignment, Prog. Ref. p.15-2

†††† This output serves one of several functions:

If Phone Line Shared mode is selected (Prog. Ref. p.14-3), this output becomes the "Phone Line Busy" output which may be "or-tied" with other controllers' Phone Line Busy outputs and to all Phone Line Busy inputs, pulled high with a 1K resistor.

If the Repeater Transmitter is selected for the remote phone line down channel (Prog. Ref. p.14-4), this output becomes a PL encode control output for encoding PL on the repeater transmitter. Decoding the PL at the remote phone line site may control audio gating of repeater audio into the phone. The output is normally low (ground) except when signalling DTMF down to the remote phone and when the mobile is talking during a remote phone line patch. The output is high true and may be connected directly to a PL encoder at a point which will bias it off when grounded.

If a "Local Phone Line #2" is selected (Prog. Ref p.14-3), this output becomes a phone line select. It is low (ground) during an outgoing call directed to local phone line 2 and may drive a DPDT relay for phone line selection into the Telephone Interface Board.

Otherwise, this is a patch tape logging output which goes low during a patch and remains low for 15 seconds following hangup.

Inputs

Connector	Pin #	Function
Digital I/O	3	Control Receiver COS
Digital I/O	2	UT1
Digital I/O	1	UT2
Digital I/O	14	UT3
Digital I/O	17	Repeater Receiver COS
Digital I/O	4	Link 1 Receiver COS
Digital I/O	16	Link 2 Receiver COS
Digital I/O	15	Main PL logic input
Analog	17	Dial tone detect
Analog	18	User-Only PL logic input
Analog	19	VOX logic input or External Device Busy
Analog	20	Alarm 1
Analog	21	Alarm 2
Analog	22	Link 3 Receiver COS
Analog	23	Link 4 Receiver COS
Analog	24	Phone Line Busy logic input
Analog	7	Analog Measurement Input Channel 1
Analog	9	Analog Measurement Input Channel 2
Analog	11	Analog Measurement Input Channel 3
Analog	13	Analog Measurement Input Channel 4
Analog	8	Analog Measurement Input Channel 5
Analog	10	Analog Measurement Input Channel 6
Analog	12	Analog Measurement Input Channel 7
Analog	25	Analog Measurement Input Channel 8
Analog	1	Analog Measurement Input Channel 9
Analog	2	Analog Measurement Input Channel 10
Analog	4	Analog Measurement Input Channel 11
Analog	6	Analog Measurement Input Channel 12
Analog	3	Analog Measurement Input Channel 13
Analog	5	Analog Measurement Input Channel 14
Analog	14	Analog Ground

**Appendix II
Interface to Specific Repeaters**

ICOM IC-RP3010 Repeater

The ICOM 440 MHz repeater includes a simple controller board which may be replaced by the RC-850 controller. Simply unplug the existing controller board and connect the appropriate connector points to the RC-850 controller. Disconnect power from the 3010's control board by removing its J4.

Signal	3010 Connector	RC-850 Connector/Pin
Receiver audio	P2-4	RX phono jack
Transmitter audio	P10-8	TX phono jack
Receiver COS	P2-8	Digital I/O connector, pin 17
Transmitter PTT	P10-1	Digital I/O connector, pin 7
+12.6 volts	P2-5	Power connector, pin 2
Grounds	P10-5	Power connector, pins 1, 3 Digital I/O connector, pin 13 and phono jack shields

Transmitter Audio

A 10K resistor may be added across R139 in the TX unit audio preamp to reduce the audio input sensitivity. With the RC-850 controller levels properly adjusted, adjust pot R134 so that audio out of the second stage of IC2 just enters clipping.

Local Speaker

Audio to the local speaker may be changed from receiver audio, as supplied, to the controller audio to the transmitter instead, which may be more useful to monitor. Disconnect the wire going to the high side of the volume control pot, and connect instead transmitter audio supplied by the controller.

Schematic

See the schematic on the next page for further information.

ICOM IC-RP1210 Repeater

The ICOM 1200 MHz repeater includes a simple controller board which may be replaced by the RC-850 controller. Simply unplug the existing controller board and connect the appropriate connector points to the RC-850 controller.

Signal	1210 Connector	RC-850 Connector/Pin
Receiver audio	P6-3	RX phono jack
Transmitter audio	P5-4	TX phono jack
Receiver COS	P6-4	Digital I/O connector, pin 17
Transmitter PTT	P5-5	Digital I/O connector, pin 7
+12.6 volts	P4-1	Power connector, pin 2
Grounds	P5-1	Power connector, pins 1, 3 Digital I/O connector, pin 13 and phono jack shields

Transmitter Audio

A transmitter level adjustment may be added which may simultaneously reduce the transmitter audio input sensitivity and provide a level adjustment. A 100K pot may be placed across R22. With the RC-850 controller levels properly adjusted, adjust the pot so that audio out of the second stage of IC2 just enters clipping.

Local Speaker

Audio to the local speaker may be changed from receiver audio, as supplied, to the controller audio to the transmitter instead, which may be more useful to monitor. Disconnect the wire going to the high side of the volume control pot, and connect instead transmitter audio supplied by the controller.

Motorola Micor Repeater

The Motorola Micor series repeaters interface easily to the RC-850 controller. For these instructions, we'll assume that the Micor repeater is equipped with the Station Control Card and the Squelch Gate Card. The Station Control Card provides the several keying voltages necessary to activate the transmitter. Circuitry may be substituted to provide the keying signals if the card is not available. The Squelch Gate Card provides a COS logic signal, but is not essential for the interface since an alternate COS signal is available directly from the receiver.

Receiver COS

The COS signal is available at two points in the repeater. The T-O-T RESET output from the Squelch Gate Card (pin 22 on the backplane) provides a suitable low true COS signal. A pullup resistor, approximately 10K, must be added from that point to 12 volts since the output is a transistor open collector.

Alternately, a COS signal may be obtained from the Receiver Audio & Squelch Board pin 8 (Receiver Unsquelled Indicator).

Transmitter PTT

The controller PTT output may connect to the backplane at the Squelch Gate Card pin 18 (REPEATER PTT). JU12 on the Squelch Gate Card should be removed to open up the repeater's internal keying path.

Receiver Audio

Receiver audio may be obtained from the Receiver Audio & Squelch Board pin 7 (Pre-amp Output). If the audio level at this point is below .5 volts p-p, then install a resistor on the controller's main board at location R70 to increase its input sensitivity. This will avoid marginal Touch-Tone decoding problems.

Transmitter Audio

Transmitter audio from the controller may be applied to the backplane pin 11 (at the Squelch Gate Card) through a potentiometer or attenuator. Cut the trace on the Squelch Gate Card between C17 and pin 11 of the backplane to open the repeater's internal audio path.

Motorola MSR-2000 Repeater

The MSR-2000 Repeater is supplied with the following cards: Station Control, Squelch Gate, and Time Out (if not deleted on order).

Following these instructions, the repeater will operate with the RC-850 controller, or by the flip of a switch, with the Motorola "cards". This capability allows you to remove the RC-850 for maintenance without taking the repeater off the air.

Squelch Gate Card Modification

Remove the Squelch Gate Card from the cage. Install a DPDT switch (Radio Shack #275-1546) just above the "Rept Level" control. Then remove JU-12 and run a wire from both jumper holes to the switch. This is to allow the jumper to be opened when in the RC-850 controller position. Also remove JU-10 and attach wires from the jumper holes to the DPDT switch. Attach the wires so that this connection is also open in the RC-850 position. As well, the JU-10 hole not connected to Q-18 must go to the center contact of the switch. Attach another wire from the RC-850 side of the switch to a ground foil (this applies only to the JU-10 connections).

Back Panel Board Wiring

Using shielded wire, connect the center conductor to pin 17 of the Audio- Squelch strip (Position 13) and the shield to pin 14. This wire will be run to a second switch (Radio Shack #275-324) that can be mounted in a convenient place. This switch breaks the audio.

Connect another shielded wire from pin 17 on the Squelch Gate strip (Position 7) shield to pin 23. Run this wire to the switch. Wire the switch so that this circuit is open in RC-850 position.

Also at pin 17 of the Squelch Gate strip there is a printed circuit that goes off at an angle - this circuit needs to be cut between the pin and solder spot on board.

Cabling to Controller

Prepare two shielded cables with phono plugs on one end for connection to the controller (cables can be acquired from Radio Shack). Connect as follows:

- Center conductor to Position 13 strip pin 17, and shield to pin 14. This cable goes to "RX" phono plug on back of the controller.
- Center conductor to Position 7 strip pin 17 (you can cut off the shield from this cable). This cable goes to the "TX" phono jack on the controller.

Using a three wire cable we can now connect the COS and PTT lines and ground:

- E8 (ground) on the backplane to controller Digital I/O connector pin 25.
- E5 (Rpt PTT) on backplane to Digital I/O connector pin 7.

Interface to Specific Repeaters - Appendix II

- Position 13 strip pin 20 (SQ indicate) to Digital I/O connector pin 17.

If you have the TIME OUT card, set the jumper to disable timeout. The REPT LEVEL control on the Squelch Gate card will be used for the exciter level adjust and should be set to the value on the sticker from the factory.

RepcO Dimension Series Repeater

The following describes how and what to connect for carrier access operation.

References

DIMENSION Series Repeater (VHF/UHF) Instruction Manual, Repco, Inc. Orlando, FL.

Connections Required

Only 4 connections are required. Refer to equipment manuals and the following chart:

RC-850 Connector	REPCO Connector	Cable Type	Function
'RX' phono jack†	J4-3 term. screw	audio coax	Receiver audio to controller
'TX' phono jack†	J5-4 term. screw	audio coax	Transmit audio to repeater
Digital I/O pin 17	J5-6 term. screw	single wire	Squelch signal to controller
Digital I/O pin 7	J5-7 term. screw	single wire	Transmit keying to repeater

† Ground at RC-850 end only.

Setup Adjustments

Adjust the REPCO according to the following table:

Control	Location	Adjustment
R7 - repeat level	control board	to minimum level (off)
R8 - telephone level	control board	1/2 position
R28 - audio in level	control board	1/2 position
S4 - repeat mode	front panel	"local" position
S1 - XMIT control	control board	"normal" position
S3 - tone switch	front panel	off (no PL)
S1-1 - COS logic sense	RC-850	COS active low
S1-2 - PTT logic sense	RC-850	PTT active low

The following audio level adjustments should be made with a calibrated deviation monitor and signal generator before the system is put into service.

- 1) Connect transmitter to dummy load and deviation monitor.
- 2) Inject 30 dB or better S/N signal, 1 kHz tone at 2.5 kHz deviation into receiver.

RC-850 Adjustments (in order listed)

Control	Location	Adjustment
R113 - audio delay level	RC-850	TP-2 - 3-4Vp-p
R112 - rcvr into xmtr	RC-850	2.5 kHz deviation
R106 - speech synth.	RC-850	desired peak deviation
R105 - tone generator	RC-850	1.5 to 2.0 kHz deviation

Interface to Specific Repeaters - Appendix II

Since the RC-850 provides agc, dynamic receive to transmit levels will not match. Verify maximum voice deviation by injecting a voice signal into repeater varying between 2.0 kHz and 5.0 kHz deviation. Output typically will average between 2.5 - 3.0 kHz and peak at about 3.5. R112 can be adjusted if slightly higher average is desired.

Spectrum Communications SCR1000/4000, SCR77, etc.

The Spectrum series of repeaters and transmitter / receiver subassemblies may be easily interfaced to the RC-850 controller. This information is for SCT110 transmitter / SCR200 receiver based equipment.

The subassemblies may be interfaced directly as shown below. The repeaters should have their internal control system disabled by disconnecting transmitter audio and PTT between the internal control system and the transmitter. This is most easily done by removing the wires at the feedthrough capacitors at the transmitter enclosure. Bring out four wires for the interface - transmitter audio and PTT from the transmitter enclosure and COS and receive audio from the receiver.

Receiver COS

The COS signal, called COR by Spec Comm and appearing at receiver terminal E107, is described as LOW when squelch is OPEN (low true). From the SCR-200 manual, we see that it is capable of sourcing 10 mA and sinking 1 mA. The logic high output is 7 volts and low is .1 volt. These levels and drive capabilities are well within the requirement of the controller's COS input so the COS signal is directly compatible. Since it's low true, we set DIP switch 1 "OFF" and connect the signal from the receiver E107 directly to Digital I/O connector pin 17.

Transmitter PTT

The Spec Comm manual says that the PTT terminal "keys" the transmitter by connecting it to ground. The driver should be capable of sinking up to 25 mA, and the terminal voltage must be allowed to rise to the full supply voltage to turn the transmitter off. Since our PTT output can sink up to 100 mA when on and can withstand up to 60 volts when off, again we are directly compatible with the requirements of the Spec Comm transmitter. Wire the transmitter PTT terminal E203 to the RC-850 controller Digital I/O connector pin 7. Since the transmitter is keyed with the logic low level, or is low true, we set DIP switch 2 "ON".

Receiver Audio

The most convenient point to pick off the audio appears to be at the high side of the AF pot. At this point, we have several volts of low impedance, de-emphasized, squelch gated audio. We can connect the audio from the Spec Comm receiver AF Pot (high side) directly to the RC850 controller Receiver Audio Input phono jack through shielded cable.

Transmitter Audio

Note that the audio into the SCT-110 transmitter is divided down by a potentiometer before driving the AF PREAMP. The gain of the pre-amp is approximately 50 with the output clipped to about 1.2 volts p-p audio. Rather than knock down the high level supplied by the controller to the tens of millivolts wanted by the transmitter, we can reduce the gain of the preamp by changing R202 from 470K to about 22K, or by paralleling a 27K resistor across R202. Now we can connect our audio directly to the transmitter AF input and have reasonable level adjust range, with better signal-to-noise ratio, than we would have obtained without the modification.

Appendix III Adjustments

The RC-850 Repeater Controller may require several adjustments to be made upon initial installation (Chapter 2) or when adding links or additional audio sources. This chapter describes these normal user adjustments, plus factory adjustments which should not be changed unless it becomes necessary due to replacement of components or accidental misadjustment.

User Adjustments

Adjustment of the audio level into the audio delay line on the main controller board (R113) is described in Chapter 2 - Initial Installation - Setting Audio Levels. Proper adjustment of this pot is important for best audio signal- to- noise ratio through the controller.

Additional audio level adjustments are available for Spare Audio and Link Receiver audio inputs. The relative levels of the other internal audio sources (tone, speech, etc.) may also be adjusted with level control pots.

Assuming that R113 has been adjusted as described in Chapter 2, pots R105 through R112 should be adjusted for consistent levels, approximately four volts peak-to-peak, at the transmitter audio mixer output (TX). If your repeater transmitter requires low level audio input, do not use these pots as a transmitter audio level adjustment - you will degrade the audio signal-to-noise performance. Knock down the audio level at the transmitter or reduce the transmitter's input sensitivity. Pots R102 through R104 should be adjusted for consistent levels into the phone line.

The levels for the internal audio sources are preset at the factory and may require only slight readjustment. The proper spare and link audio level settings are dependent on the input levels provided to the controller, so these will most likely need adjustment when audio sources are installed.

The table below lists the functions of the user adjustable audio level pots. The multi-turn audio level pots may be accessed by removing the four front panel screws and pulling out (gently) the front panel. The pots are then accessible from the front of the unit. Be careful not to pinch front panel wires when remounting the front panel on the unit.

Audio Level Adjustment Pots - Main Controller Board

Pot	Description	Pot	Description
R105	Tone generator level to tx	R102	Tone generator level to phone
R106	Speech synth./local mic level to tx	R103	Speech synthesizer level to phone
R107	Phone level to tx	R104	Repeater receiver level to phone
R108	Control receiver / Link 4 level to tx		
R109	Spare Audio 1 / Link 3 level to tx		
R110	Link 2 level to tx		

R111 Link 1 level to tx
R112 Repeater receiver level to tx
R113 Repeater receiver level to audio delay line (see Chapter 2)
Telephone Interface Board Hybrid Balance

Pot Description

R100 Telephone hybrid balance
This pot balances the electronic hybrid circuit for duplex patches. It should be adjusted during a full-duplex patch for optimum null.

Factory Adjustments

Several pots are adjusted at the factory and should not normally be readjusted. They are on the Main Controller Board unless noted.

Pot Description

R117 Audio delay line DC bias
This pot adjusts the DC bias level at the SAD4096 audio delay line input. Misadjustment results in clipping of the positive or negative peaks of the audio through the delay line.
This pot has no effect if the audio delay subassembly is used in place of the SAD4096 at U35. Instead, R1 and R2 on the sub-assembly board perform this function.

R116 Audio delay line balance
This pot balances the differential outputs of the SAD4096 audio delay line, to minimize the 15 kHz clock frequency component in the audio output.
This pot has no effect if the audio delay subassembly is used in place of the SAD4096 at U35.

R115 21 volt adjust
This pot adjusts the Vpp programming pulses to the E2PROM to be 21 volts.
This pot has no effect if the 9864 8K byte E2PROM is used at U10.

R9 Speech synthesizer pitch adjust (VRT Board)
This pot adjusts the clock frequency of the speech synthesizer, affecting the pitch of the speech generated. It should be adjusted for natural sounding male and female speech.

C4 Time of day clock frequency adjust (VRT Board)
This capacitor adjusts the clock oscillator to 32.768 kHz.

**Appendix IV
Lightning Protection For Your Repeater System**

You've invested considerable time and money in your repeater system, and we all want it to continue working forever. It probably will, if you keep "Old Man Lightning" away.

We'll look at what lightning is, how it can enter a repeater system and how to keep it out, some approaches to minimizing damage, and insurance policies which can cover the cost of damage that can't be avoided.

The extent of protection you provide should be based on the amount of investment in your equipment, the frequency of thunderstorm activity in your area, and the level of reliability you want to achieve from your system. But in any case, protection for your equipment will pay in the long run!

Lightning - Free Electricity

Lightning is a cloud-to-cloud, cloud-to-ground, or even ground-to-cloud electrical discharge. Frontal type thunderstorms result in larger strokes, and more strokes to ground, than convection thunderstorms. The southeastern U.S. and portions of the midwest have the greatest incidence of destructive storms. But virtually every area of the country is susceptible to thunderstorms, and being at a high elevation (i.e., at a repeater site) obviously increases the odds of damage.

The actual stroke, or discharge to ground, is equivalent to a current source of magnitude up to a hundred thousand amperes. The current pulse has a typical rise time of 2 microseconds and a decay time of around 40 us. The fast rate of rise of the pulse contributes to its destructive power, since even just a small portion of the stroke traveling through a small inductance can generate large voltage potentials. But its speed also helps make it easier to tame.

Direct hits are rare - the greatest likelihood for damage are near misses and surges induced in power and telephone lines.

Keep Out

The first goal is to keep destructive lightning current out of your equipment. The second goal is to make it easy to exit if it does enter.

The likely entry points into your system include (most obviously) the antenna, the phone line, and the ac power line. Attention should be paid to each of these potential entry points, but the key to any form of protection is grounding.

Ground It Out

A good ground must be low resistance, and because of the lightning stroke's fast rise time, must be low inductance. The good ground is the essential first step, since it provides a non-destructive discharge path for lightning currents that we intend to keep out of our equipment.

The extent of the grounding system needed depends on the resistivity of the soil, and generally more than one ground rod is required to achieve a "good" ground. Several shorter rods, interconnected with bare buried wire, will have a lower impedance than one longer rod. Radials can reduce the impedance further in rocky or sandy earth.

Your earth ground, equipment ground, telephone company, and power company grounds must be interconnected properly to prevent large differential voltages from appearing between them due to ground surge currents. Each ground may be connected by a separate line to every other ground, or a "ring" closed loop may surround the installation. The interconnections should be large (#8) solid wire - not braid or stranded wire. The strands eventually oxidize and corrode, and with their many twists become highly inductive. Metals should be similar - copper should never touch steel.

With a good ground system, we can proceed to keeping the lightning current out of the equipment.

The Antenna - The Unwanted Lightning Rod

Since the antenna is the highest point at the installation, it's the most likely entry path. Grounded towers, DC grounded antennas bonded to the tower, and lightning rods are important. The transmission line should run along the tower to the base, then loop before entering the building.

A coaxial impulse suppressor should be mounted at the grounded tower leg or grounded bulkhead panel - not at the equipment. The feedline should wind its way with as many bends as possible to the transmitter.

The Phone Line

The telephone lines are subject to direct hits, as well as induced transients from nearby lightning activity. Although the telephone company usually installs some form of lightning protection, it should not be relied upon.

The best form of protection is a three terminal gas tube which limits differential voltages (between the two conductors) as well as voltage to ground. When the gas ionizes, it provides a simultaneous path to ground for both conductors. Other types of protectors, such as a pair of MOVs to ground, aren't as effective. Since each MOV has a slightly different turnon time, a common mode transient will appear as a full differential signal for a period of time, which can cause more damage than if no MOVs were installed.

The telephone cord from the protector to the equipment can be coiled or tied in knots to increase its inductance and help impede the transient.

Power Supply

Another entry point for damaging transients is through the power line. ACC's controllers operate from an external twelve volt supply. Because the available supply is regulated, you may feel that it's regulated from transients on the ac line. It is not! A typical supply will pass high frequency components of an impulse from the ac line.

A site may be otherwise well engineered, but if your site neighbors protect their equipment from line surges and you don't, you may be the only one to suffer damage.

The MOS large scale integrated circuits used in modern computer based equipment, such as our controllers, are more susceptible to damage from transients than rugged rf transistors in your transmitter and receiver. The best protection is a transient protector which mounts at the fuse box. A variety of surge protectors which plug into the wall are available which are intended for use with small computers and will provide some level of protection. A transient suppressor may be added at the DC output of the power supply to help limit relatively low energy pulses.

Protection Devices

A variety of technologies are available, ranging from semiconductors, to gas discharge tubes, to simple inductance. Zener diodes can offer a low level of protection, limited by their turnon speed and energy absorbing capability. A better device is the TransZorb (General Semiconductor) which is similar to a Zener but optimized for surge protection.

MOVs (metal oxide varistors) are effective for higher voltages, but are slower and allow a high peak voltage to result, relative to their rated clamp voltage. Gas discharge devices are also effective for high voltage applications (such as telephone line protection), and can handle very high transient currents. They're particularly effective for phone line use since they provide both excellent common mode and differential mode protection.

None of these devices by themselves offer complete protection for sensitive components at a typical repeater site. A well-engineered protector combines several technologies and must be applied properly in the system.

Important Guidelines

The protector should be separated from the protected. Keep the transient energy away from the sensitive circuits. Provide the protection well away from the equipment being protected - not inside it.

Separate the exposed wires from the protected wires. Run the input and output lines from the protector with as much separation as possible, and preferably at right angles.

A "series" protector will provide considerably greater protection than a "parallel" protector. A protection device installed across the equipment (like a TransZorb) will obviously only share the transient with the equipment. A series protector will prevent the transient from reaching the equipment.

Protection Inside ACC Controllers

ACC's RC-850 and RC-85 Repeater Controllers include built-in protection from transients due to lightning. As we've seen, this built-in protection should be considered as a last resort safeguard only and should not be viewed as a substitute for following the principles discussed above.

Each controller has at least one TransZorb protector across the twelve volt power supply input. This device protects against relatively low energy surges reaching the controller from the power supply.

The RC-85 controller and the RC-850 controller with the TP-3 Telephone Interface Board include a three terminal gas-discharge tube installed across the phone line. The RC-85 controller returns the tube's third terminal to the power connector ground. The RC-850 controller TP-3 board takes the third terminal to a separate terminal block connector - it should be wired directly to the main ground system.

Insurance

Assuming reasonable precautions are taken to prevent damage, insurance is a viable option to protect against unavoidable damage. Some homeowner's policies cover the cost of repair or replacement of equipment damaged by lightning - check your policy.

The best value appears to be available to ARRL Members, with the "All-Risk" Ham Radio Equipment Insurance Program. At a cost of only 1% of the equipment value per year (plus a \$5 administrative fee), the insurance covers virtually all forms of loss, including lightning damage. For \$5000 worth of repeater equipment, that's just \$55 per year. If you're not an ARRL member, their insurance program is a good reason to join.

Bottom Line

For a high level of protection we'd suggest the LEA TET-200-100 device on the phone line, the LEA SE-115-10-BF on the ac power line, and a PolyPhaser coaxial impulse suppressor appropriate to your frequency and power level. Devices from the manufacturers listed below, and others, may also provide effective levels of protection.

Sources for Protection Equipment

Lightning Elimination Associates
12516 Lakeland Road
Sante Fe Springs, CA 90670
(213) 944-0916
(power line and phone line protectors)

Decibel Products, Inc.
3184 Quebec
Dallas, TX 75247
(214) 631-0310
(coaxial impulse suppressors)

Joslyn Electric Systems
P.O. Box 817
Goleta, CA 93116
(3 terminal gas tube phone line protectors)

PolyPhaser Corporation
1420 Industrial Way \ P.O. Box 1237
Gardnerville, NV 89410
(coaxial impulse suppressors)

References

This writeup is based on information condensed from the publications listed below. It is intended as an introduction to the subject. We encourage you to write the companies for the literature mentioned below. We also thank Doug Zastrow, WBIUPJ and John Williams, K8JW for their ideas and suggestions.

"About Lightning", Decibel Products, Inc.

"Impulse Protection", PolyPhaser Corporation

"Protection Requirements and Concepts for Data and Control Lines",
Lightning Elimination Associates

"Lightning" Newsletter, Quintron Corp., 13 B Commercial Dr., Quincy, IL
62301