Interfacing a CAT-200 repeater controller to an MSF5000 station

WA1MIK - 22-Jun-03, 24-Jul-03, 30-Jul-03

Someone on the CAT user forum posted the above question. Not wanting to re-invent the wheel, he was wondering if the work had already been done by another user. I replied that I was about to attempt exactly that task. Here's what I've done so far.

Located on the main secure-capable station control board (SSCB) is the MRTI connector J802, shown on one page of the service manual as a two-row 20-pin connector, but on my board (TLN3189A05) and in the schematic, it is a one-row 14-pin connector, with square pins on 0.100 inch centers. I was able to find a mating connector, albeit with 36 positions (easily cut down to 14), plus female contacts, at Jameco, part numbers 103157 and 100765 (.100" Non-Polarized Connector Housings and Crimp Pins). The pin-out for J802 is shown below. Pin 1 is closest to the front panel.

MRTI Connector J802 on SSCB

Pin	Signal Name	Direction	Notes
1	Logic Ground		
2	PL Strip *	IN, low active	Ground to disable PL encode
3	Logic Ground		
4	Monitor *	IN, low active	Ground to disable PL decode
5	PTT *	IN, low active	Ground to activate transmitter
6	Logic Ground		
7	Audio Ground		
8	Audio In	IN, AC-coupled	Terminated with 560 ohms
9	Logic Ground		
10	Audio Out	OUT, DC-coupled	May need external coupling capacitor
11	Rx Carrier	OUT, high active	High with received signal
12	Inhibit	OUT, high active	Unknown function or what sets it
13	Audio Ground		
14	Aux Indicator	OUT, high active	Unknown function or what sets it

NOTES: The "high active" signals are open-collector transistors and will require external pull-up resistors. The circuit seems to be able to provide up to 30 mA of current.

Currently my MSF5000 is set up as a base station with tone remote control. I enabled the MRTI interface via RSS and made sure that MRTI was in the PTT priority list for the receiver and transmitter (mine is set to DWRLM which makes the MRTI the lowest priority right now). I connected my RF signal generator to the RF input, set the ACC DIS switch on the base station, selected a non-PL channel (446.000 MHz), and gave it a healthy -60 dBm signal.

I played with the audio deviation level and frequency. I was able to recover receiver audio on pin 10 (Audio Out) and measured it with a digital AC voltmeter. The level varied from 2.212 VAC at 300 Hz, to 0.093 VAC at 4000 Hz, all using a 5 kHz deviation from my signal generator. The audio level rolls off at the higher frequencies due to the

receiver's de-emphasis circuit. There was a very sharp peak at 300 Hz, and very little signal below that (the sub-audible PL frequencies are highly attenuated). Note that pin 10 is DC coupled and will have about 4.8 VDC on it. The CAT-200 controller already has a coupling capacitor in it's receive audio path so another one is not needed. A plot of dBm vs. frequency on a logarithmic scale shows almost a 6 dB per octave slope. See the table below.

Recovered audio level - MSF5000 MRTI Connector Pin 10

Hz	mV	dBm	Hz	mV	dBm
100	27		2500	204	
200	58		2600	192	
300	2212	9.11	2700	182	
400	1414	5.22	2800	172	-13.05
500	1227	3.99	2900	163	
600	1051	2.65	3000	155	
700	903	1.32	3100	146	
800	786	0.12	3200	139	-14.93
900	693	-0.96	3300	132	
1000	618	-1.96	3400	125	
1100	557	-2.84	3500	119	
1200	506	-3.68	3600	113	-16.72
1300	460		3700	107	
1400	423	-5.26	3800	102	
1500	390		3900	98	
1600	362	-6.11	4000	93	-18.39
1700	336		4100		
1800	314	-7.85	4200		
1900	293		4300		
2000	275	-9.00	4400		-19.98
2100	258		4500		
2200	242	-10.09	4600		
2300	229		4700		
2400	216	-11.11	4800	65	-21.58

Similarly, using a 1 kHz sine wave audio signal, I varied the deviation level and obtained the following output voltages:

Receive audio sensitivity - MSF5000 MRTI Connector Pin 10

Dev: kHz	1	2	3	4	5
Audio: mV	126	251	376	500	620

Luckily it does seem to be very linear.

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I attached a 10k ohm pull-up resistor from pin 11 to a nearby source of +5 volts. When there was a carrier present (with PL on channels that required it), the signal on pin 11 (Rx Carrier) went to +5 volts; with no carrier (or carrier without PL on channels that required it), pin 11 was pulled to ground. This signal is high when active and is pulled low by an open-collector transistor which requires an external pull-up resistor to function. The circuit components would seem to be able to provide enough current to light an LED through a 150 ohm resistor (about 30 mA) so it should have no problem connecting to the CAT-200B's COR input with an adequate pull-up resistor. I intend to put LEDs on all of the signals (one thing the engineers at Motorola didn't do was put any indicators on the receiver signals).

I was able to make the station transmit by grounding pin 5 (PTT*).

While transmitting on a channel with PL encode, grounding pin 2 (PL Strip*) disabled the transmit PL tone. Releasing pin 2 allowed the PL tone to be transmitted again.

I did NOT test the Monitor function by grounding pin 4, but I feel reasonably sure that it will put the receiver into carrier squelch mode on a channel where PL decode is required and enable PL decode when released.

On my existing repeater (using MaxTrac radios and a CAT-200B controller) I use one of the switched output pins to enable/disable the monitor function of the receiver. When the monitor input pin on the mike jack is grounded, the radio requires PL to open the squelch. The MSF5000 logic seems to be the opposite in that grounding the Monitor signal (pin 4) would put the station into carrier squelch mode, thus not requiring PL to open the squelch. As I have never opened the squelch on my current repeater, I may just forego this functionality on the MSF5000 setup.

I connected a sine wave audio source (the LF OUT from my RF signal generator) to pin 8 (Audio In) and pin 7 (Audio Ground). I connected a dummy load and deviation meter (via a sampling tap) to the station's antenna jack. My AC voltmeter was across the audio input signal. I manually grounded pin 5 (PTT*) and measured the deviation on a PL encode channel. With a 1 kHz sine wave, I measured the following signal sensitivity:

Transmit audio sensitivity - MSF5000 MRTI Connector Pin 8

Peak mV	Deviation kHz	RMS mV	dBm
0	1.0	0	Just PL
100	1.7	70	-20.9
200	2.4	140	-14.8
300	3.2	211	-11.3
400	3.8	281	-8.8
500	4.0	351	-6.9
600	4.3	422	-5.3
700	4.5	492	-3.9

I then set the audio oscillator for a 100 mV peak signal (-20.9 dBm or 70 mV RMS) and adjusted the audio frequency while recording the deviation indication. The following table shows the results.

Transmit audio level - MSF5000 MRTI Connector Pin 8

Frequency Hz	Deviation kHz
300	1.4
400	1.5
500	1.6
600	1.6
700	1.8
800	1.8
900	1.9
1000	2.0
1100	2.1
1200	2.2
1300	2.2
1400	2.3
1500	2.3
1600	2.4

Frequency Hz	Deviation kHz
1700	2.4
1800	2.5
1900	2.4
2000	2.4
2100	2.4
2200	2.4
2300	2.5
2400	2.5
2500	2.6
2600	2.6
2700	2.7
2800	2.7
2900	2.8
3000	2.8

For some reason, I did not get the same deviation indication at 1000 Hz as I did in the previous test. As far as I can tell, the transmitter audio input gets limited at a signal level exceeding 0.500 VAC.

The CAT-200B controller manual documents the following interface. I propose to wire it to the MRTI connector pins as shown below.

CAT Pin	CAT Signal	MRTI Pin
1	Logic In 1	
2	Logic In 2	
3	CTCSS In 2	
4	CTCSS In 1	11
5	COR In 2	
6	COR In 1	11
7	CTCSS Encode	
8	Fan Control	
9	PTT Out 2	
10	PTT Out 1	5
11	Tx Audio Out 1	8
12	Rx Audio In 2	
13	Rx Audio In 1	10

CAT Pin	CAT Signal	MRTI Pin
14	Switch Out 1	4
15	Switch Out 2	
16	+12VDC Out	
17	Ground	1,3,6,9
18	Ground	7,13
19	Switch Out 3	
20	Switch Out 4	
21	Logic In 3	
22	Logic In 4	
23	Tx Audio Out 2	
24	Reserved	
25	Ground	

The station model number is C64RLB7106B. It is equipped with a trunked tone wire line remote control interface (TTRC) and secure-capable station control board (SCCB).

I used the following equipment to test the MSF5000 station:

- Hewlett Packard E4430B digital RF signal generator. Internal sine-wave oscillator used for transmitter modulation. Calibrated against an HP 8591E spectrum analyzer using Bessel functions (signal nulls at specific modulation rates and frequencies).
- Heathkit IM-4180 deviation meter, calibrated against the RF signal generator.
- Bird 150w dummy load with appropriate adapters and coaxial cables.
- CDI 7992 adjustable RF tap-off, set for 30 dB of attenuation. Used to provide an attenuated signal to the deviation meter.
- Fluke 189 True RMS digital multi meter, used for all AC and DC voltage readings.

The CAT controller is made by Computer Automation Technology of Florida. The components I bought and integrated consist of the following:

- CAT-200B repeater controller.
- DL-1000C audio delay line.
- MAX-232 circuit and DB-9M connector were wire-wrapped using the schematic and parts list from the CI-200 serial interface.
- LM-7812 regulator with two 0.33 uF bypass capacitors.

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Update - 24-Jul-03

I ran a separate coax from the output of the transmitter's low pass filter out of the cabinet where it will eventually connect to the duplexer. The receiver still gets its signal through the original base station antenna connector, but I have pulled the plug on the T/R relay so it stays in the receive position all the time.

I used the +15v power supply for the power amplifier to operate the CAT controller, which has a separate 12v regulator in the enclosure. This seems to provide a very nice, clean supply of power to the controller.

As originally configured, I had made two wiring errors in the cable from the CAT-200B controller to the MRTI connector: I had reversed the Tx and Rx audio lines. These were easily corrected at the MRTI connector (pins 8 and 10). This at least gave me audio out of the controller to the station and audio from the receiver into the touch-tone decoder on the controller. I was unable to get the incoming audio to repeat through the controller, however.

The bigger problem was that the Receive Carrier line, pin 11, which was a high-active signal in my earlier tests, now reversed itself and remained high with no incoming carrier. Fortunately the CAT-200B controller has DIP switches to select the COR polarity, so I was able to reverse the COR sense, and after similarly setting a jumper on the DL-1000C delay board, I got audio to actually come through the repeater. I adjusted the various level pots on the CAT-200B controller and it sounds quite nice right now, with the exception of the problem noted below.

I also had to make some changes to the MSF5000's programming to enable repeater operation but I arranged the PTT priority so MRTI has highest priority, followed by repeater, local, and finally line. If I unplug the CAT-200B controller, the Motorola MSF5000 controller takes over and provides repeater hang time as well as a CW ID. With the CAT-200B controller enabled, it does the voice and CW ID and all the timings.

As the repeater stands now, there is one glitch that prevents it being put into operation. When the CAT-200B controller releases the PTT line, the Receive Carrier line momentarily pulses low. The controller sees this as a quick key-up, so it keys the repeater by applying ground to the PTT line. Since the Receive Carrier line has gone back high, the controller waits for the hang time to expire, then releases the PTT line. The cycle then repeats forever. In essence, the transmitter stays on the air all the time.

I was playing around with the Multiplexer Bits display and decided to disable Tx PL and see what happens. Well, when the controller drops the PTT line, the momentary glitch on the Receive Carrier line does NOT occur. The transmitter shuts all the way off and works exactly like it should. It seems like the receiver is sensing the transmitter's PL somehow. I will repeat this experiment using different receive and transmit PL tones to find out the exact circumstance and see if there is something I can do to fix it.

An alternative solution I need to investigate is to pull a Receiver Active signal from the TTRC board instead of the MRTI connector. I shall record the various signal levels in the idle, receiver active, and transmit states, to see how they react, and to see if one of them does not exhibit the glitch I'm seeing now when the transmitter is un-keyed.

In the tables below, I only looked at the RSTAT and RdSTAT signals, as most of the others were either 0v, 2.6v, or 4.9v and didn't change with any input or output signal.

J2900 on TTRC Logic Board

Pin #	Signal Name	Idle	PL Rx	Car. Rx	Notes
8	RdSTAT	4.6	0.0	4.6	Active low with PL decoded, goes low only with PL, long squelch tail

J2901 on TTRC Logic Board

Pin #	Signal Name	Idle	PL Rx	Car. Rx	Notes
11	RSTAT	0.0	5.1	5.1	Active high with any carrier, goes high with or without PL, short squelch tail

The CAT-200B controller has separate inputs for COR and PL DECODE. They are currently tied together but it seems I should connect the RdSTAT signal to the PL DECODE line using active low, and connect the RSTAT signal to the COR line using active high. The controller would then be set to recognize an input signal when both of these control lines are active.

I tested the controller by using the RSTAT signal first and configuring the controller for active high signals. Everything operated perfectly. When the controller unkeyed the transmitter, everything went quiet. I did note that a PL tone was NOT required on the repeater's input signal.

I then tested the controller by using the RdSTAT signal and configured the controller for active low signals. Again, everything operated perfectly and the transmitter shut off when the controller released the PTT line. This line would only go active if the input signal to the repeater had the proper PL tone.

I did not experiment with the MONITOR input during these tests. If I rewire the cable to utilize both of these signals, I will not need to bother with the MONITOR line, as the controller can manage the logic to respond to carrier with or without a PL tone.

Other than the inconvenience of needing to connect to three connectors within the MSF5000 control unit, the interfacing job would appear to be complete once I rewire the cable from the CAT-200B controller.

The new cable will be wired as follows:

CAT Pin	CAT Signal Name	Connector and Pin Number	Wire Color
1	Logic In 1		
2	Logic In 2		
3	CTCSS In 2		
4	CTCSS In 1	TTRC J2900, Pin 8, Active LOW	YELLOW
5	COR In 2		
6	COR In 1	TTRC J2901, Pin 11, Active HIGH	BROWN
7	CTCSS Encode		
8	Fan Control		
9	PTT Out 2		
10	PTT Out 1	MRTI J802, Pin 5, Active LOW	GREEN
11	Transmit Audio Out 1	MRTI J802, Pin 8	WHITE
12	Receive Audio In 2		
13	Receive Audio In 1	MRTI J802, Pin 10	BLACK
14	Switch Out 1	MRTI J802, Pin 4	RED
15	Switch Out 2		
16	+12VDC Out		
17	Ground	MRTI J802, Pins 1,3,6,9	BLUE
18	Ground	MRTI J802, Pins 7,13	ORANGE
19	Switch Out 3		
20	Switch Out 4		
21	Logic In 3		
22	Logic In 4		
23	Transmit Audio Out 2		
24	Reserved		
25	Ground		

CAT-200B DIP switches will be configured as follows:

Switch #	Description	Setting
1	COR #1 logic: on = active low, off = active high	OFF
2	CTCSS #1 logic: on = active low, off = active high	ON
3	COR #2 logic: on = active low, off = active high	ON
4	CTCSS #2 logic: on = active low, off = active high	ON
5	Mode: off = Repeater, on = remote weather station	OFF
6	CI-200 interface module attached: on = yes, off = no	ON
7	Initialize controller	OFF
8	Enter new un-lock number	OFF

DL-1000C J2 2-3 = active low, 1-2 = active high 1-2

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Update 30-Jul-03

Well, not everything worked out as planned. The signals on the TTRC connectors certainly did what I measured them to be. I then found out that with no PL on the input signal, the MSF5000's receiver would not output any audio on the MRTI connector. The various control lines still operated as expected. Unfortunately this meant that I could not disable the PL decode function from within the CAT-200B controller. I had to connect the MRTI MONITOR* signal back to the controller so I could use the switch #1 output to disable the PL decoder in the receiver. I also set the CAT-200B's COR/CTCSS logic to the AND function, so both of the TTRC signals must be present for the repeater to be keyed up. Hopefully the MONITOR* line will still allow both of these signals to function just like they do when PL decode is enabled. The final cable is wired as follows:

CAT Pin	CAT Signal Name	Connector and Pin Number	Wire Color
1	Logic In 1		
2	Logic In 2		
3	CTCSS In 2		
4	CTCSS In 1	TTRC J2900, Pin 8, Active LOW	RED
5	COR In 2		
6	COR In 1	TTRC J2901, Pin 11, Active HIGH	BROWN
7	CTCSS Encode		
8	Fan Control		
9	PTT Out 2		
10	PTT Out 1	MRTI J802, Pin 5, Active LOW	GREEN
11	Transmit Audio Out 1	MRTI J802, Pin 8	WHITE
12	Receive Audio In 2		
13	Receive Audio In 1	MRTI J802, Pin 10	BLACK
14	Switch Out 1	MRTI J802, Pin 4, Active LOW	YELLOW
15	Switch Out 2		
16	+12VDC Out		
17	Ground	MRTI J802, Pins 1,3,6,9	BLUE
18	Ground	MRTI J802, Pins 7,13	ORANGE
19	Switch Out 3		
20	Switch Out 4		
21	Logic In 3		
22	Logic In 4		
23	Transmit Audio Out 2		
24	Reserved		
25	Ground		

The various internal settings in the CAT-200B are shown in the tables below. The initial setup was done using the CI-200 Windows configuration editor. Note that the Switch Outputs in Zone 3 supply a LOW signal when ON, and a HIGH signal when OFF.

Zone 1:

Bit	Function / Description	Default	For MSF5000
1	Repeater Transmit enable	ON	ON
2	Repeater CTCSS required	OFF	ON
3	COR AND (off) OR (on) CTCSS logic	OFF	OFF
4	Identification enable	ON	ON
5	Courtesy Tone enable	ON	ON
6	Hang Time enable	ON	ON
7	DTMF Muting enable	OFF	ON
8	Repeater Time-Out enable	ON	ON

Zone 2:

Bit	Function / Description	Default	For MSF5000
1	Link Transmit enable	ON	OFF
2	Link CTCSS enable	OFF	OFF
3	Link Receive Only enable	OFF	OFF
4	Link Control enable	ON	OFF
5	Link Voice enable	OFF	OFF
6	Link Auto Disconnect enable	OFF	OFF
7	Link To Repeater Output enable	OFF	OFF
8	Link Time-Out enable	ON	OFF

Zone 3:

Bit	Function / Description	Default	For MSF5000
1	Logic Input #1	ON	OFF
2	Logic Input #2	ON	OFF
3	Logic Input #3	ON	OFF
4	Logic Input #4	ON	OFF
5	Switch Output #1 - OFF = PL, ON = CARRIER	OFF	OFF
6	Switch Output #2	OFF	OFF
7	Switch Output #3	OFF	OFF
8	Switch Output #4	OFF	OFF

Zone 4:

Bit	Function / Description	Default	For MSF5000
1	DTMF Pad Test enable	ON	ON
2	Beacon enable	OFF	ON
3	Weather Report Mode enable	ON	OFF
4	Fan Control enable	OFF	OFF
5	Voice ID enable	ON	ON
6	Voice ID Link Inhibit	OFF	OFF
7	Reserved	OFF	OFF
8	Reserved	OFF	OFF

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The MSF5000 was programmed using the RVN-4077 Field Programming Software (RSS) with an after-market RIB and a home-made 6-pin cable that plugged into the Control/Mic jack on the front of the MSF5000 control box. The software was loaded onto the hard drive of a Dell Inspiron 8000 850 MHz laptop computer, but the computer was booted with a Windows 98 DOS floppy disk and ran in DOS mode.

Initially the radio was programmed with three frequencies and two modes (besides the tuning channel/mode). It was controlled via a two-wire desktop tone remote control unit. All the parameters were set to the RSS default values. I then modified the information for one channel, one mode. The code plug data was printed out from RSS. Deviations from the defaults are noted below.

Repeater Operation: ENABLED
Trunking Operation: DISABLED
Spectra-TAC Operation: DISABLED
SECURE Operation: ENC/DEC
Duplex Operation: HALF
XL Decryption Operation: ENABLED
TTRC Equipped: ENABLED
SECURE Equipped: DISABLED
SAM Equipped: DISABLED
MCS Equipped: DISABLED
PASSWORD Equipped: DISABLED
SmartZone Operation: DISABLED

Number Of Channels: 01
Auto ID Tone Frequency: 0880
Auto ID Delay: 000
Auto ID Interval: 008
Auto ID Rate: 20
Local Channel Control: STATION
Local Mode Control: STATION
Local Key Control: STATION
Memory Station: DIABLED
MRTI Enable/Disable: ENABLED
RSTAT Mode: NORMAL

Mode Slaving: ENABLED
Mode Locked: DISABLED
ID over the Wire-line: ENABLED
Default Mode Number: 01
Call Sign: <EMPTY TO DISABLE ID>
Channel Scan: DISABLED
Tx Slave: DISABLED

Mode 01:
RX PL/DPL Code: 100.0 Hz
TX PL/DPL Code: 100.0 Hz
PTT Priority: LWM (add R to activate internal controller)
Line TOT: 180
Local TOT: 180
Repeater TOT: 180
Data TOT: 000
MRTI TOT: 000
Rx Audio Control: C
Repeat Audio Activation: C
Repeat Audio Hold-in: SC
Rptr Dropout Delay: 010
Over-The-Air Alarms: ENABLED
Over-The-Wire-line Alarms: ENABLED
Rpt TOT DOD Reset: ENABLED
MRTI PP Mode: CLEAR

To enable the internal (MSF5000) controller, reprogram the unit so the 'R' qualifier is in the PTT Priority list instead of, or after, the 'M' qualifier, and add a call sign to the appropriate channel data.