

GB3LD - Repeater Keeper's Notes

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Introduction

This version of GB3LD is based upon two Philips MX294 synthesised FM radios. One unit functions as the repeaters' transmitter, the other as the receiver.

The control system for this repeater is entirely original and developed specifically for the Lake District Repeater Group. The heart of the system is the microcontroller, a PIC 16C74A which offers sufficient input/output capacity to meet all of the needs of this project with pins to spare. The PIC runs at 4MHz.

Almost all of the audio handling is performed by a CML FX828. This device performs amplification and bandpass filtering (300Hz to 3300Hz), audio tone detection (1750Hz), audio gating and CW tone generation. In addition the FX828 also generates the transmit CTCSS tone. The microcontroller communicates with the FX828 via a serial interface which CML call the "C-Bus", a 4-wire system comprising chip select, command data, reply data and serial clock. Further details are contained in the data sheets.

The repeater has a range of DTMF remote control facilities, most of which will probably never be used, the most noteworthy of these are Remote "Pause" and Raynet Mode. Other DTMF commands are available for diagnostic use when on-site.

Remote Pause puts the repeater into a standby state and it behaves, for all practical purposes, as though it had been switched off. Pause mode can be cancelled remotely, obviating the need for a site visit to restart the machine.

Raynet mode makes the repeater behave as a carrier operated system. All access requirements are ignored and any carrier will get talkthrough. Whilst in Raynet mode the repeater will not send any CW idents or Pips. Talkthrough hangtime is the same as the access carrier validation time of 1.6 seconds.

The software functionality is based upon that in use at GB3GD and GB3AS. Both of these systems were developed using a 6502 microprocessor by G4TUZ. Although the functions have been cloned, the code has been written entirely from scratch for the PIC microcontroller by GD4HOZ.

Technical notes

With a supply of 13.8 volts, the MX294 transmitter is capable of producing more than 40W. The heatsinking arrangements have been tested at this power level over a four-hour period of continuous transmission and were adequate for the purpose even without the two CPU cooler fans which were fitted as a "belt and braces" measure.

The microcontroller is likely to be the most sensitive component to mains fluctuations, however it is well protected by an effective "triple regulation" system. The power supply provides the first line of regulation. The second stage of regulation is provided by the receiver's own 10 volt regulator from which the controller board is fed. Finally, a 7805 regulator on the controller board itself provides the third level of regulation.

During development it was noticed that the VCO's in the two radios were beating together and superimposing a heterodyne on incoming signals whilst the transmitter was off. When the transmitter is keyed the transmit VCO jumps to another frequency, removing the problem. However the heterodyne on receive could affect the detection of access tones and is therefore undesirable. The cure is simple: Since it is not needed anyway, the receiver VCO in the transmitter block has been deliberately unlocked by off-tuning it. For this reason, the VCO lock light in the transmitter block should never be lit whilst the repeater is in standby.

The few component changes and wiring modifications which were carried out on the radios are noted on the circuit diagrams. Tests showed that the discriminator did not have sufficient swing to cover the full audio level range required for a 12.5KHz channel, which was surprising as the radio is specified for that bandwidth. In order to get sufficient peak audio without limiting effects R37 was reduced from 2K2 to 820R.

It will be noticed from examination of the unit that there are precious few "tweakables". They aren't necessary. The relative levels of cue tones ("pip" and CW) and talkthrough audio are pre-set. The tone levels chosen set the higher deviation tones at just over half system peak deviation. The only other adjustments, which should never need touching, are peak deviation and modulator balance, the latter requiring an oscilloscope for correct adjustment. These are both located in the transmitter.

Receiver squelch is set to open at -118dBm (0.28uV PD).

No De-Sensitisation was noted between the transmitter and the receiver, with the transmitter developing full power into a dummy load and the receiver fed with a signal barely sufficient to open the squelch.

Technical Description

The very low component count makes a separate circuit diagram almost unnecessary, since the FX828 block diagram is, almost, the entire circuit! The description which follows uses component references from the CML block diagram. A modified diagram is on the following page.

Squelched and de-emphasised receive audio is derived from terminal F of the facilities connector. This is, in effect, the top of the volume control.

This audio is routed to the FX828 RX Amp input on pin 14 via C7 and R4. The components around the RX amp, contrary to the data sheet, are not used to provide de-emphasis, hence C5 is not fitted.

From the RX Amp, the audio is split into two. One path feeds the CTCSS/Selcall tone decoder. This is where in-band tones (i.e. 1750Hz) are detected. The CTCSS decoder is not used. The second audio path routes via the bandpass filter, removing received CTCSS tones, to pin 16 which is linked to MOD1 input on pin 20.

MOD1 is used to control talkthrough. When MOD1 is disabled, received audio cannot reach the transmit path. When MOD1 is enabled it exhibits a gain of 0dB, allowing RX audio to be relayed by the transmitter.

The output of MOD1 is routed to the SUM IN terminal on pin 18 via a gain setting resistor.

The Selcall TX Tone generator is used to generate in-band tones (i.e. CW signalling). The tone generator output is presented on pin 17 and is summed with talkthrough audio at the SUM IN terminal, pin 18, via gain setting resistor R7.

The total summed audio (Talkthrough audio and CW tones) is fed to MOD2 which normally runs at a gain of -6dB (for reasons to be described in a moment). From there, the output at pin 23 is routed to the transmitter facilities connector, terminal C (In-Band TX Encode). Within the transmitter, the TX audio is routed to the microphone input terminal V via a wire link. This ensures that the audio is correctly pre-processed, prior to transmission, by the pre-emphasis and peak limiter circuits.

The repeater is capable of producing CW tones at two different amplitudes. In order to achieve this MOD2 is used, in effect, as an amplifier. During talkthrough and also when low-level tones are required (e.g. in-use CW idents), MOD2 is run at a gain of -6dB. When high-level tones are needed, MOD 2 is set to a gain of 0dB. This gives an effective lift of 6dB over normal talkthrough levels. Since high-level tones are *never* sent during talkthrough, this 6dB lift has no effect on talkthrough audio.

The Transmit CTCSS signal, when required, is presented on pin 21 (TX Sub-Audio Out) and is routed directly to the transmitter facilities connector. Resistors on the facilities board itself are used to reduce the level of the CTCSS to one suitable for transmission, giving 300Hz deviation. Due to the abrupt nature of the switch-off of the CTCSS tone when it is no longer needed, a small click will be heard on transmitted audio. The problems that this causes (none at all!) do not warrant investigation into methods of eliminating it.

Test Facilities

CW Test Transmission

To facilitate on-site testing, the repeater is capable of generating a test sequence. This comprises the following:

5 seconds tone, 1200Hz at 1.75KHz deviation
5 seconds tone, 1200Hz at 850Hz deviation
3 seconds silence
CW message "TEST QRL DE GB3LD H", 1200Hz at 1.75KHz deviation
1 second pause

CTCSS is not generated by the test sequence.

If this mode is initiated by a DTMF command (details later) it will be a one-off, after which the repeater will revert to standby.

If a continuous repeat is desired, the link adjacent to pin 21 of the microcontroller should be placed across both pins provided. When the link is removed the sequence will complete its cycle before closing down.

Audio Sweep

A frequency response test is also available. This mode is initiated by a DTMF command (see later). When activated, the software commands the FX828 to generate a tone sweep which ranges from 250Hz to 4000Hz in 25Hz steps. The tone amplitude produced by the FX828 is nominally flat across the range of the sweep. The sweep repeats until it is turned off again by a further DTMF command.

Fixed Tests

There are six fixed test modes as follows:

1. TX on
2. TX on + CTCSS
3. TX on + 1KHz tone at 1.5KHz deviation
4. TX on + 1KHz tone at 1.5KHz deviation + CTCSS
5. TX on + Talkthrough
6. TX on + Talkthrough + CTCSS

Repeater Operation

Mode 1 - Standby

The transmitter is turned off and the receiver squelch is closed.

Beacons are transmitted at 5 minute intervals at the medium tone frequency of 1200Hz and at high deviation. CTCSS is not sent with mode 1 beacons.

N.B. Non-CTCSS transmissions cannot access the repeater during standby mode beacons. Any attempts to use 1750Hz to access during this time are ignored.

Mode 2 - Talkthrough

Access to mode 2 is gained by the user transmitting a carrier plus a toneburst of not less than 200mS. After the toneburst has ended the carrier must remain for a further 100mS. Alternatively CTCSS at 110.9Hz will gain immediate talkthrough. If these criteria are met, the transmitter is turned on and talkthrough is enabled. The ensuing transmission must last for at least a total of 1.6 seconds in the following three seconds. If the carrier has not been present for this length of time, the repeater will close down without sending any signalling tones ("Pip" etc.)

There are no facilities for the detection of audio. Therefore audio access control is not available,

If the access criteria are satisfied and mode 2 is entered, timing of the over length begins. The timer counts down in 1 second increments towards zero. If the over ends more than 20 seconds from timeout, the pre-set End-Of-Over (EOO) signal is sent at the medium tone frequency (1200Hz), followed by a "pip" 3 seconds later. Shortly after this second pip the transmitter is turned off.

If a user is employing CTCSS, the first EOO will normally be a "T". The second EOO is always a pip.

Once in mode 2, CTCSS operates as follows:

CTCSS is switched on as soon as access is validated and remains on until just after the first EOO is sent. After being switched off, CTCSS is re-enabled as soon as the receiver squelch is opened by another signal.

Beacon callsigns sent during talkthrough are sent at low deviation and at medium frequency (1200Hz)

If the user ends his transmission within 20 seconds of timeout, he is "chastised" by the logic by it's changing the first EOO to a "5", the EOO then reverts to normal.

N.B. Regardless of the actual character sent, the first EOO indicates that the talkthrough timer has been reset, so there is no need to wait for a "pip" afterwards.

Mode 3 - Timeout

If a non-CTCSS user, or a jamming signal, exceeds the talkthrough time limit, the repeater mutes talkthrough, sends the end-of-work signal at low frequency (800Hz) and closes down. If a CTCSS user reaches timeout the repeater will continue in talkthrough but the talkthrough timer will be held at 5 seconds. This ensures that any noise or jamming signal will be effectively locked out within 5 seconds of CTCSS being removed from the input.

Other operators can "re-access" the repeater after timeout by transmitting over the top of the offending signal. Either a toneburst or CTCSS will re-open talkthrough. The offender will again be chastised by the repeater sending a "0" as the first EOO after the re-accessed signal clears the input. After re-access, the timing period starts afresh.

If the offending user is not re-accessed, others are informed that he has finally dropped carrier by the repeater keying-up, sending a "C", to indicate that the input is clear, and closing down again. The code then reverts to mode 1 (standby).

During mode 3 shutdown, beacons are sent at low frequency (800Hz) without CTCSS.

Mode 4 - Standby, input jammed

In this mode the input will have become occupied after normal closedown (i.e. the squelch is open). In this case beacons are sent at high frequency (2100Hz) without CTCSS.

Remote Control Functions

GB3LD is equipped with a range of keeper-accessible commands. Some are intended for remote control purposes whilst others are mainly intended to be used by personnel on-site requiring various test modes.

All functions are accessed by transmitting DTMF on the input frequency. Each function must be preceded by a four digit password. The inter-digit gap must be no more than three seconds. Any longer than this and the code sequence will be ignored. If an incorrect digit is entered as part of the password or if the inter-digit gap is exceeded, all characters received are discarded and the sequence must be entered afresh.

It should be remembered that if the repeater is in talkthrough, any digits entered will be relayed and could be overheard. It is recommended that remote control commands are only sent when the repeater is in standby and that CTCSS should not be used (for obvious reasons). The exception to this is when the repeater is in Raynet mode.

The command structure is made up of three digits which follow the four-digit password. The third digit identifies the command function required (Raynet mode, Change Timeout etc.), whilst the first two digits identify the parameters of the command, i.e. the actual values to be set.

Example: Set timeout to 180 seconds, key 6543 *44
 6543 is the example password, *4 is the timeout value and the
 final 4 is the command to set timeout.

The DTMF character set resembles normal numerics but there are several discrepancies which can be a little confusing when using DTMF to represent numbers. The following table lists the DTMF digits and their decimal and hexadecimal equivalents.

DTMF:	D	1	2	3	4	5	6	7	8	9	0	*	#	A	B	C
BCD:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HEX:	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

So, to send a hex value of 3C, you would use 3# in DTMF

Default password *****

Function Codes

Where a default value is given, this is the value which the system assumes after a power-on reset.

Change End-Of Over Signal (Command 1) [DELETED IN V1.2]

This command only affects non-CTCSS users and then it only affects the first EOO.

Any character from the CW data table may be used but the first 26 characters are in alphabetical order and can be accessed by entering the hexadecimal number corresponding to the desired letter. For example the letter N , numbering from zero, is the thirteenth letter of the alphabet. In hexadecimal, this is 0D. Translating to DTMF, 0 becomes D and D becomes A (see above table). This is then sent with the command code (1) as the third digit.

The default EOO is an "E".

DD 1	-	A	D 9 1	-	J	1 2 1	-	S
D 1 1	-	B	D 0 1	-	K	1 3 1	-	T
D 2 1	-	C	D * 1	-	L	1 4 1	-	U
D 3 1	-	D	D # 1	-	M	1 5 1	-	V
D 4 1	-	E	D A 1	-	N	1 6 1	-	W
D 5 1	-	F	D B 1	-	O	1 7 1	-	X
D 6 1	-	G	D C 1	-	P	1 8 1	-	Y
D 7 1	-	H	1 D 1	-	Q	1 9 1	-	Z
D 8 1	-	I	1 1 1	-	R			

Squelch close to End-Of Over delay (Command 2)

This command sets the time that the software waits after carrier drop before it sends the EOO signal.

The parameter for this command is a multiple of 20mS time periods expressed in hexadecimal and converted to DTMF. The maximum value is 255 periods which equates to 5.1 seconds. The minimum value is 1 second. Sample values are given below

The default value is 1 second.

1.0 secs	-	3 2 2	(i.e. 32h x 20mS)
1.5 secs	-	4 * 2	(i.e. 4Bh x 20mS)
3.0 secs	-	9 6 2	(i.e. 96h x 20mS)

Set Timeout (Command 4)

The parameters for this command are the number of seconds required for talkthrough. Maximum value is 255 seconds, minimum is 30 seconds.

As previously, the required value is expressed in Hexadecimal and converted to DTMF form. Examples follow:

60 Secs	-	3 # 4
120 Secs	-	7 8 4
180 Secs	-	* 4 4
240 Secs	-	C D 4

Default is 255 seconds in V1.3

Callsign on closedown (command 7)

Sets whether the software should send the callsign prior to closedown after being in use. There are certain issues regarding access during the transmission of the callsign which need to be considered. Also, since the software sends a callsign every 5 minutes anyway, the need for this function is perhaps questionable. For my part I **strongly** advise against its use, but it is left at the repeater keeper's discretion.

Send callsign before closedown	-	5 5 7
Don't send callsign before closedown	-	0 0 7 (Default)

Send QRA in beacon mode (Command 8)

If this function is enabled the repeater will send a longer than normal ident every 25 minutes following closedown. The first of these is always the fifth beacon after the repeater was last used, i.e. the repeater must be idle for at least 25 minutes.

Send long ID every 5th beacon	-	5 5 8	(Default)
Don't send long ID	-	0 0 8	

Carrier Access or Raynet Mode (Command 9)

This mode causes the repeater to act as a Carrier-Operated Repeater (COR). When a carrier appears on the input, the transmitter is keyed on immediately and CTCSS is enabled. When the input signal drops there is a short hangtime after which CTCSS is turned off. After a further short delay the transmitter is turned off. The dropping of CTCSS before carrier drop allows CTCSS equipped radios time to mute before the carrier is lost, thus eliminating the squelch "crunch".

With carrier access enabled, the software mutes talkthrough audio whenever a DTMF digit is received. This is in order to prevent the control codes being re-transmitted on the output frequency, where they may be overheard. Through audio is only muted for the duration of the digit.

Note that a small amount of DTMF leaking through is inevitable. This is because the through audio is only muted when the DTMF receiver indicates that it has received a valid tone pair. This detection takes around twenty milliseconds. Consequently a short burst of each tone is passed through but it will be insufficient for any other decoder to detect.

Carrier access mode disables all normal repeater "personality" features - i.e. callsign beacons, end-of-over signal and timeout.

Carrier access on - 5 5 9
Carrier access off - 0 0 9

CW Test Transmission (Command 0)

To initiate a one-off test transmission as described earlier - 0 0 0

Audio Response Sweep (Command #)

Activates a continuous audio sweep ranging from 250Hz to 4000Hz.

Start test sweep - 5 5 #
Stop test sweep - 0 0 #

Test Modes (Command A)

Once one of these modes is entered, the code remains in a loop waiting for either a different test command or the exit command. All other repeater functions cease to operate whilst in test mode. If the repeater is paused whilst in one of these modes (I can't think why you would do that, but...) the test modes are cancelled and the software returns the main program loop, where it waits to be "un-paused".

D D A - Exit test mode
D 1 A - TX on
D 2 A - TX on + CTCSS
D 3 A -. TX on + 1KHz tone at 1.5KHz deviation
D 4 A - TX on + 1KHz tone at 1.5KHz deviation + CTCSS
D 5 A - TX on + Talkthrough
D 6 A - TX on + Talkthrough + CTCSS

Repeater Pause (Command C)

This command renders the repeater effectively inoperative. It remains able to receive DTMF commands and can, therefore, be "un-paused". When the Pause command is issued the repeater will shut down immediately. Any test functions in progress are cancelled. If the repeater was paused whilst in Raynet mode, this is also cancelled. This means that, regardless of what the repeater was doing when it was paused, it will resume normal repeater operations when it is later un-paused.

Pause repeater - 5 5 C
Un-Pause repeater - 0 0 C

GB3LD Liquid Crystal Display

As an economical and flexible alternative to using LED's to indicate repeater status, this design uses an intelligent LCD module which is driven directly by the microcontroller.

Depending upon the current status of the repeater the display will indicate the condition of incoming squelch and CTCSS signals as well as tone detection and other indications.

When the repeater is idle, and in normal operation, the LCD shows a "brag screen" - well even my modest personality demands *some* outlet for my ego!!

When a beacon is being sent the display, quite reasonably, displays the message "Sending Beacon". After the beacon, the display reverts to the brag screen.

If the repeater has been "paused" by remote control, the top line of the display shows the text "GB3LD is Paused". The lower line continues to display received state changes as described later.

In normal operation the display is divided equally between incoming and outgoing indications. In this context, incoming refers to received stimuli such as Squelch opening and CTCSS tone detection. Outgoing refers to TX keying, CTCSS transmission and Talkthrough. Outgoing (i.e. Transmit-related) indications are shown on the top line of the display, whilst Incoming (i.e. Receive-related) indications occupy the bottom line.

Each indication occupies a specific area of the display. If all indications were active at once, the following display would result:

```
TX SUB TT    *180
TB SUB Sq    MF:0
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Looking at the top line first, and from left to right:

- TX = Transmitter is keyed.
- SUB = Sub-Audible Tone (CTCSS) is being transmitted.
- TT = Talkthrough is enabled.
- * = Displayed every even second (i.e. 18, 16, 14 etc.) during the last 20 seconds prior to timeout indicating that the user is in the "Danger Zone".
- 180 = The talkthrough countdown. Decrements from the timeout specified by the Keeper, or the default 255 seconds, to zero.

On the lower line:

TB = A tone within the range of the **ToneBurst** detector is present (1750Hz)
SUB = Sub-Audible Tone (CTCSS) at 110.9Hz has been detected
Sq = The squelch is open
MF: = Incoming DTMF digit display. This is blanked when no DTMF is present.

When the repeater is in Raynet mode, the talkthrough time display is irrelevant (since there is no timeout) and is replaced with the word "Raynet".

The software updates the display 4 times per second. In order to reduce software overheads the display is cleared before the updated data is written. Although the display is blanked for only a matter of milliseconds this approach results in a small amount of flicker which, although visible, does not make the display any the less readable.

PIC 16C74 Input / Output assignments

<u>Pin</u>	<u>Name</u>	<u>Signal</u>
2	RA0	DTMF Bit 3
3	RA1	DTMF Bit 2
4	RA2	DTMF Bit 1
5	RA3	DTMF Bit 0
6	RA4	DTMF Output enable
7	RA5	DTMF Data Valid
8	RE0	Spare
9	RE1	Spare
10	RE2	Spare
15	RC0	Spare
16	RC1	Spare
17	RC2	Spare
18	RC3	Spare
19	RD0	Squelch input
20	RD1	CTCSS Detect In
21	RD2	Test Input
22	RD3	FX828 Comparator out
23	RC4	Spare
24	RC5	PTT out
25	RC6	Spare
26	RC7	Spare
27	RD4	FX828 Chip Select
28	RD5	FX828 RData
29	RD6	FX828 CData
30	RD7	FX828 Serial Clock
33	RB0	INT (From FX828)
34	RB1	LCD RS
35	RB2	LCD R/W
36	RB3	LCD E
37	RB4	LCD D4
38	RB5	LCD D5
39	RB6	LCD D6
40	RB7	LCD D7

Measured Parameters

RX sensitivity: -119dBm (0.25uV) gives 10dB SINAD

Adjacent channel rejection
(145.0875MHz): Better than 114dB

Image response: Unmeasurable

1750Hz detector sensitivity: 300Hz deviation minimum

1750Hz detector bandwidth: +/- 15Hz

CTCSS detector sensitivity: 100Hz deviation minimum

TX Power: Maximum 42 Watts at 13.8V

All parameters were measured using a Marconi Instruments 2955A radiocommunications test set and a Hewlett Packard 8590 spectrum analyser.

Warranty (a.k.a. the self defence page)

Ah, so you have a sense of humour, then!

Basically, you don't get one (a warranty, that is).

During development I have done everything I can think of to bring this machine crashing to a halt. On a couple of occasions I actually succeeded, and in good style too. Each of the problems I encountered occurred under quite unusual operating conditions - for example, commanding the repeater into pause mode while it is sending a CW test transmission - which will simply never happen under normal circumstances. Each problem found was duly fixed but I make no claims to have zapped all potential "bugs". Although I have done my best to catch and kill them, some may remain but I am not aware of them.

Therefore.....

If this beastie should start playing the Welsh national anthem, speaking Chinese or attempt to call "CQ Contest", don't come after me with a blunt instrument. Just tell me, if possible, the circumstances of any problem and the symptoms produced by it.

I have done my best to produce a system which I believe will work well in its' intended role, **BUT** I will not accept any responsibility of any kind for any inability to use this equipment for whatever reason. The sole remedy of the SLRG will be software changes as may be necessary to correct any faults found. The cost of replacement OTP microcontrollers to be borne by the SLRG.

If this machine is put on-air and used then the foregoing will be deemed to have been agreed by the SLRG and it's members.

Having said all that, I really don't foresee any problems and I think that this repeater will serve it's purpose well for many years to come.

Software Change Requests

If it should become apparent that some new software feature would be desirable, or if some existing feature should be removed or modified, I will endeavour to accommodate any reasonable request. The actual software changes will, most likely, be done gratis in the spirit of the hobby but I expect to remain in-pocket. Therefore I would ask that the group either supply replacement OTP IC's as necessary or refund the cost of their purchase on the group's behalf.

(OTP = One-Time-Programmable. i.e. a non-erasable device)