G0BSX 2400 baud Modem

Introduction:

The G0BSX 2400 baud modem was created to fulfil the need for faster packet radio data communications on user access and inter node dedicated links. While 2400 baud does not seem much of an improvement over the standard 1200 baud in common use, this data rate allows the use of unmodified radios and will, in most cases, require minimal modification to existing 1200 baud packet stations apart from installing the modem board. Unlike higher speed modems such as the G3RUH and K9NG 9600 baud modems, it is not necessary to modify radios for direct FM and discriminator audio output. The circuit was designed to be as simple as possible with a minimum component count and size. While originally designed for the BSX2 TNC, the modem plugs into the standard TAPR modem disconnect header and can therefore be used with most TNCs on the market today. TNCs not equipped with the header have, for the most part, a similar modem design interface and it may still be possible to use this modem.

Circuit Description:

The circuit is designed around a high quality 2400 baud full duplex Fast Frequency Shift Keying (FFSK) modem chip. This is presented in a ceramic 22 pin DIL package. The eleven external components have been kept to a minimum and consist of timing and bypass capacitors, a clock crystal, optional jumpers for selecting various options and a transistor invertor to provide an open collector DCD output as per TAPR standard. The modem chip contains built in analogue and digital filters, DCD detection circuitry and both receive and transmit data clock generation. On transmit, synchronous FFSK audio output is generated digitally. On receive, incoming audio is sampled digitally with data extraction using a digital phase lock loop. The transmit data clock is at the transmit data rate and not at 16 times the transmit data rate as specified by the TAPR standard. This problem is not insurmountable on most TNC2 type TNCs because this clock signal is usually fed to a divide by 16 chip on board which can easily be bypassed. Some TNCs, such as the Tiny 2, use a data rate clock rather than a 16x clock and therefor require NO modification. The circuit has been designed to consume minimal power, typically using between 3.6 to 4.5 mA depending on whether it is used in half or full duplex modes.
The complete circuit diagram is shown in Appendix 2. In more detail....

Clock Circuit:
A 4.032 MHz crystal controls the modem chip clock generator. C1 and C2 ensure a clean clock signal without significant voltage overshoot. The value and quality of crystal is critical and controls the transmit and receive baud rates as well as the audio transmit tones.

Transmit circuitry:
The modem chip produces a 2400 Hz transmit clock which is passed to the TNC to clock the TNC SIO for the generation of synchronous transmit data. This data is converted to 1200/2400 Hz phase continuous audio for transmission. Note that the transmit clock is at the same speed as the data and not at 16x data rate as per TAPR specification. Therefore, it is necessary to ensure that this clock is fed directly to the TNC SIO and not via a ÷16 circuit. Some TNCs this will require some minor modifications which are described later.

Receive circuitry:
Audio into the modem should be taken from the TNC board after a de-coupling capacitor on the TNC input. This is fed directly into the modem on pin 15. C5 determines the carrier detect time constant. A long time constant results in better noise immunity but with an increased response time. The value used is an adequate compromise. The modem uses the input audio signal to produce a receive data clock and synchronous data. The data is passed to the TNC. The RX sync is passed to J2 which can be used to select either the modem generated clock or the TNC derived receive clock to pass on to the TNC SIO. In most cases, it is best to use the TNC generated clock since the TNC clock extraction and NRZI to NRZ conversion circuitry may induce some delays and level inversions. Note that the quality of the received audio signal is the main factor in successful signal decoding. The high and low modem tones must be of comparable amplitude. The audio from most rigs is heavily de-emphasised and therefore high tones are badly attenuated. However, in almost all cases this can be easily corrected with a simple RC input combination. In the case of the BSX TNC, the existing on board components can be replaced without any detriment to the TNC on reversion to 1200 baud since the 1200 baud modem will also work better with equalised tones! See the interfacing section for component values and circuit details.

Control circuitry:
J5 allows the selection of full or half duplex power saving modem operation. Full duplex exacts a small current penalty (about 1 mA extra) This jumper has no other function and can safely be left on the full duplex setting if desired.
J2 selects the source of receive data sync to be passed to the TNC. If, as in most cases, the TNC has on board receive clock recovery, this should be used. The internal sync setting was included for experimentatl purposes.
J3 selects whether the modem DCD is passed to the TNC. If the internal setting is selected (default), the modem DCD is ORed with the TNC DCD input into pin 1 of the modem disconnect. If the external setting is used, the modem DCD is ignored completely.

Construction:

Construction is straightforward on a double sided through hole plated printed circuit board measuring 45 by 45 mm. Component layout is printed on the component side of the PCB. Start with the smallest and flat components and finish with the larger ones. Be sure to use a temperature controlled or SMALL soldering iron. Be sure to insert the tantalum capacitor the correct way round. Header pins and links can be used for J2, J3 & J5. If desired, these headers can be omitted completely and simple wire links soldered in their place. Default settings are: J2 - external sync, J3 - internal DCD and J5 - full duplex. J1 is a female 20 pin DIL socket on the underside of the PCB soldered from the component side. A socket is reecommended for the modem IC but is not necessary. Because the PCB is through hole plated, it is not necessary to solder both sides of the PCB or empty holes.

Interfacing and Connections:

Installation for the BSX2 TNC or TNCs with a 16x TX clock

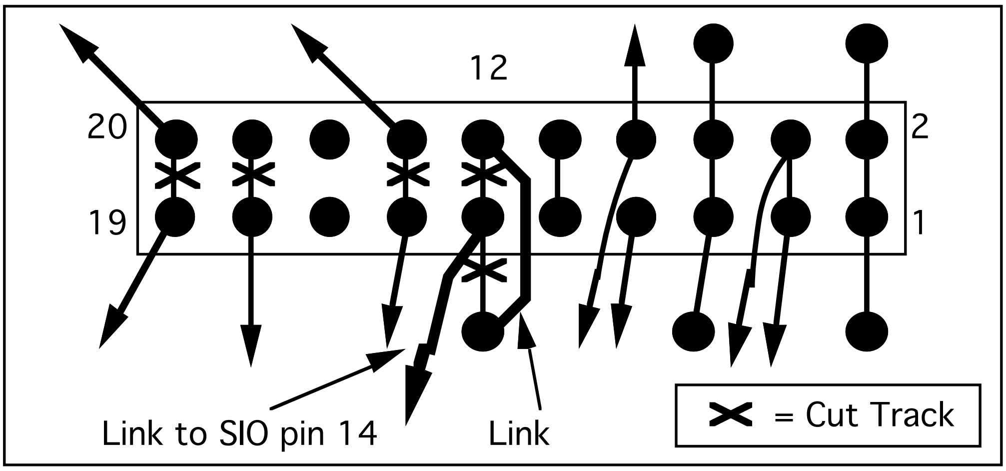
1. TAPR modem disconnect header modification:
On the underside of the TNC PCB modem disconnect header (SK4), cut the links between pins 11&12, 13&14, 17&18 and 19&20. Next solder a 20 pin DIL header strip into the TNC modem disconnect location. Refer to **Figure 1**, a diagram of the solder side of the BSX2 modem disconnect header showing all cut tracks. NOTE: a few older version 5a boards (about 200 in total) have an incorrect modem disconnect header attachment. Refer to Figure 1. If your modem disconnect header has a track on the solder side of the board passing from pin 18 of the header between pins 17 and 19, then this is wrong. This track should be CUT and connected to pin 17 instead.
2. TNC Modification:
The ÷16 circuit must now be bypassed. Cut the track on the underside of the TNC PCB originating at pin 11 of the modem disconnect header so as to isolate the State Machine clock input. Install a jumper wire from pin 11 of the modem disconnect header to pin 14 of the SIO to connect the modem transmit clock directly to the SIO clock input. Next, remove IC7 from its socket and bend out pin 8 before re-inserting it. This is the 74HC393 chip. Other TNCs may use the other half of the chip for this ÷16 function - refer to the circuit diagram. Install a connection between the 16x clock and the state machine clock input (pin 4 of IC6 to pin 11 of IC13). This is most simply done on the BSX2 by connecting Pin 12 of the modem disconnect header to the pad at the end of the track (which was cut previously) emanating from pin 11. Refer to Figure 1, a diagram of the solder side of the BSX2 modem disconnect header showing all the cut tracks and the extra link. On other TNCs it may be necessary to do things slightly differently... If there is no state machine, a clock input is unnecessary! Finally, set the HDLC baud rate select (S2) to the 2400 setting.
3. BSX2 Audio and power connections:
Remove IC15 from its socket. Install a 24 pin header into IC15 socket. Connect the output pins of J4 on the modem board as follows:

tx audio ->	IC15 pin 8	0V	->	IC15 pin 9
rx audio ->	IC15 pin 5	5V	->	IC15 pin 1

Next, it is necessary to alter the input equalisation circuit. Replace R26 (10k) with a 4n7 capacitor and add a 10k resistor in parallel with the protection diodes, D7 and D8. C13 (1n0) can be removed or left as preference dictates. Idealy, R25 (100k) should also be removed but this is not essential, especially if you wish to revert to 1200 baud operation when it is required by the 7910 modem chip. The audio input level to the TNC should be chosen so that the DCD lights reliably on signal

reception but must not be too high to force protection diode clipping. 400-500mV is usually adequate to produce the required 100-200mV on the Modem chip audio input pin. See also *More on audio interfacing* below.
Should you wish to revert to the on board modem at 1200 baud, install jumpers on the male header in the modem disconnect header where the links have been cut , return IC7 and IC15 to their sockets without pins bent out, remove the link to pin 14 of the SIO and reset the HDLC data rate to 1200 baud. It is not necessary to change the audio conditioning circuitry back since it should now produce equal tone levels on 1200/2200 input signals as well! If R25 has been removed, replace it to protect the AM7910 modem input.

Figure 1: Solder side, BSX2 Modem Disconnect header.



Installation for the TINY 2 or TNCs with a 1x TX clock.

1. TNC and TAPR modem disconnect header:
On the underside of the TNC PCB modem disconnect header, cut the links between pins 11&12, 13&14, 17&18 and 19&20. Next solder a 20 pin DIL header strip into the TNC modem disconnect location. Alter the radio baud rate selector to 2400 baud. No other TNC modification should be necessary.
2. Audio and power connections:
Remove the modem IC (TM3105) from its socket. Install a header into the vacated socket. Connect the output pins of J4 on the modem board to this socket as follows:

tx audio	->	pin 11	0V	->	pin 9
rx audio	->	pin 4	5V	->	pin 1

Next, you need to make sure that the input circuitry gives adequate equalisation. This can be done outside the TNC or, the internal audio circuitry can be bypassed completely. As a ballpark configuration, look at Figure 2 in the *More on audio interfacing* section. Use a 4n7 capacitor from the radio audio with a 10k resistor in parallel. I.e. connect the 4n7 capacitor from pin 4 of the Audio socket (J2) to the modem rx audio lead with a 10k resistor to earth from the modem rx audio lead. Be sure to decouple the modem audio input with a 0µ1 capacitor. Audio input level to the TNC should be chosen so that the DCD lights reliably on signal reception but must not be too high to force protection diode (if present) clipping. 500-600mV is usually adequate to produce the required 100-200mV on the Modem chip audio input pin. See the section entitled *More on audio interfacing* if you have problems with reception.
Should you ever wish to revert to the on board modem, remove the BSX modem, install jumpers on the male header in the modem disconnect header where the links have been cut , return the TM301 IC to its socket and reset the radio data rate to 1200 baud. It is not usually necessary to change the audio conditioning circuitry back since it should now produce equal tone levels on 1200/2200 signals as well!!

Jumper settings:

Set J2, J3 and J5 as necessary - refer to the circuit description section for details. Installation is now complete and the TNC can be switched on and connected to the radio as before. I usually do not bother with jumpers and simply solder links into place.

Testing:

Well, I don't really know what to say here! There is not a lot that can go wrong with soldering 12 components into a good quality PCB! Make sure all the corrections are ABSOLUTELY correct. Connect it all up and switch it on! Next install an audio loop-back jumper, set full duplex on and send some packets. These should echo to the screen if all is well. Remove the jumper, connect your rig and use the TNC.

More on Audio Interfacing...

As mentioned previously, the quality of audio signal is the main factor in the successful use of this modem. The comments in this section can also usefully be applied to 1200 baud modems since the same principles apply and, if these criteria are followed, improved reception will result whatever FSK modem is used. The configuration (see figure 2) and values described in the sections on interfacing above are approximate and are good compromises of values used in prototype installations. If you wish to be a bit more scientific about getting things absolutely right, the following method can be used....

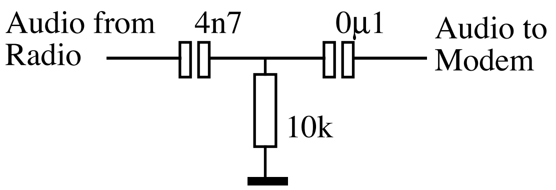


Fig. 2. Modem Audio input.

Attach an oscilloscope to the audio input on the modem board and observe the received wave forms. It is useful but not essential if the transmitting station sends high and low tones alternately for comparison at the receiving station. If TAPR firmware is used, the CALIBRATE command can be used for this purpose. As mentioned before, the high frequency and low frequency wave forms should be of similar amplitude and relatively undistorted. If the high frequency signal component is of lower amplitude than the low frequency component, either decrease the input series capacitance or the input parallel resistance. Idealy tones should be of equal amplitude but decoding can occur with up to about 20% difference. If good equalisation is attained at both ends of a link, good results will follow. Optimum signal levels will result in about 150-200 mV signals at the modem chip with no distortion by any input protection diodes or components. This will result in reliable DCD detection and data decoding. Because most audio problems occur on the receive side, due to rather heavy de-emphasis, once a modem/rig combination is set up, it does not usually need changing if the other end of the link changes. The values mentioned in the set-up sections above are the best compromise that work for the 4 receivers I have tested with this modem. Two were commercial amateur radios and 2 were converted PMR radios. In the unlikely event of this combination of components not working due to particularly severe de-emphasis, it *may* be necessary to extract audio from before the radio de-emphasis circuitry or alter components to reduce its severity.

If proper setting up is performed with a 200mV input level, the bit error rate for this modem is 10^{-3} for 12dB S/N, 10^{-4} for 14dB S/N & 10^{-5} for 15dB S/N ratio. On my dedicated 4m internode link using PMR radios, the average retry rate is 2-5 frames per hundred with a maximum sustained data throughput of about 10kBytes per minute.

Appendix 1: Parts List.

Resistors:		Capacitors:		Miscellaneous:	
R1	1M	C1	33p	J1	20 pin female DIL
R2	10k	C2	33p	J2,J3,J5	3 way jumpers
		C3	1µ0	J4	4 way hdr & plug
Semiconductors:		C4	0µ1	X1	4.032 MHz crystal
IC1	FX469J	C5	0µ1	Wire for 5V power lead.	
VT1	2N3904	C6	10µ tant	Shielded cable for audio lead	

Appendix 2: TAPR Modem Disconnect (J1)

Pin 1 Carrier Detect to TNC. TTL signal, normally high. To be pulled low by an open collector circuit when valid data is received.

Pin 2 Carrier Detect from the TNC. Normally connected to pin 1. With the TNC modem removed, this reflects the external DCD input to the TNC.

Pin 3 Special interrupt line to TNC. TTL level signal normally used in TAPR firmware for modem calibration and bypass of state machine. Used by NETROM to allow networking on serial port. Not used my this modem.

Pin 4 Special interrupt line from TNC. Normally connected to pin 3. Not used by this modem.

Pin 5 RTS output from TNC. Normally high TTL signal.

Pin 6 RTS to TNC. Same as Transmitter Key. Connected to pin 5.

Pin 7 Connect Status output from TNC TTL signal. Normally low. Goes high when the TNC enters a connected state. Not used by this modem.

Pin 8 Status output from TNC TTL signal. Normally low. Goes high when the TNC has unacknowledged frames in its transmit buffer. Not used by this modem.

Pin 9 CTS input to TNC TTL signal. Normally high. Pulled low when the modem is ready to accept Data for transmission. Not used by this modem.

Pin 10 CTS from TNC. Normally connected to pin 9. Physically tied to pin 6 on the TNC. i.e. it is pulled low when the transmitter is activated. Not used by this modem.

Pin 11 Transmit clock to TNC. TTL signal. Signal derived from this modem oscillates at the transmit clock rate, not at 16x transmit data rate.

Pin 12 Transmit clock (16x) from TNC. Normally connected to pin 11. Signal from the on board HDLC baud rate generator. (Disconnected with this modem.)

Pin 13 Receive clock to TNC TTL signal to SIO Rx clock input. With this modem, this can be a choice between modem generated or TNC generated (pin 14) clock.

Pin 14 Receive clock from TNC. Normally connected to pin 13. Derived from TNC NRZI to NRZ conversion and clock extraction circuit.

Pin 15 TNC digital ground.

Pin 16 No Connection

Pin 17 Receive data to TNC TTL input. This signal is passed to the TNC NRZI to NRZ conversion and clock extraction circuitry.

Pin 18 Receive data from on-board modem. Disconnected with this modem.

Pin 19 Transmit data from TNC. TTL output. Either NRZ or NRZI depending on the position of jumper 11. Passed to modem.

Pin 20 Transmit data to TNC. Disconnected with this modem.

Appendix 3: Audio/PTT connector (J4)

Pin 1. Transmit Audio. This is taken DIRECT from the MODEM chip and needs to go via a 0µ1 capacitor to a level setting potentiometer. On the BSX2, these components exist on board.

Pin 2. Receive Audio. This goes directly to the Audio input pin of the modem chip anmd should therefore be AC coupled off board. The maximum input voltage is ±2 Volts. Minimum input resistance to ground 100kΩ.

Pin 3. Ground. Connected to signal ground. Connect this pin to the shielding on the audio input and output wires.

Pin 4. +5V. Supply voltage for the Modem chip.

Addendum:
If you wish to use the modem with EXTERNAL State Machine DCD, do the following. Remove the modem chip. On the underside of the PCB solder pins 12 and 13 of the modem socket together. Re-insert the modem chip but with pin 13 bent out. This has the effect of taking the RX data from pin 12 instead of pin 13. Set J3 to the EXTERNAL setting. EXTERNAL sync usage is essential if you use this data source.

Good Luck! Let me know how you get on.
Any problems, please give me a shout.

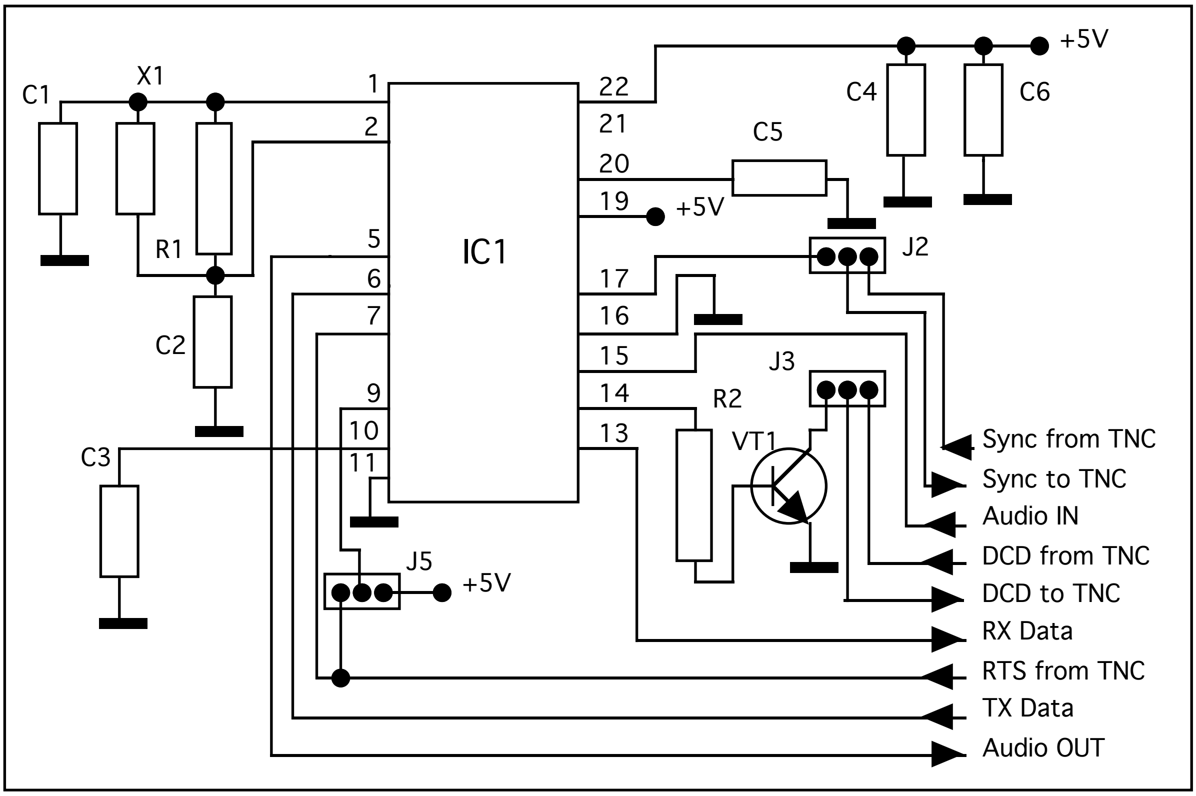
Peter Meiring
18 Slayleigh Lane, Fulwood,
Sheffield, S10 3RF.

Telephone: 0114 230 9478 (after 8pm please)

Email: p.d.meiring@sheffield.ac.uk

AX25:

Appendix 4: Circuit Diagram



Appendix 5: Component Layout