MODIFYING THE HAMTRONICS EM-5 FOR 9600 BPS PACKET OPERATION

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Abstract

Within the last year considerable attention has been given to level three linking of local area packet groups across the country. Experiments using virtual and datagram circuits are under discussion. This paper presents an interface board and the necessary modifications to the Hamtronics FM-5 220 MHz transceiver allowing operation at 9600 bits per second (bps) to provide a high speed link between the local area networks.

Radio Selection

The purpose of this project was to provide a high speed radio modem as a testbed for the level three linking experiments. A minimum data rate of 9600 bps with minimum modifications to an existing radio were the main objectives. In order to send 9600 bps data with minimal overhead a radio with fast transmit to receive and receive to transmit turnaround time was desirable. This implied a crystal controlled transmitter with pin diode antenna switching. Since the ARRL band plan for 220 MHz contains allocations for high speed packet links a 220 MHz transceiver was chosen for the initial experiments. A radio that was still in production and available to all interested groups was also a prime consideration in selecting the Hamtronics FM-5 220 MHz transceiver. This unit contains a crystal controlled receiver and transmitter providing 7 watts of output power and pin diode switching of the antenna.

Receiver Modifications

The EM-5 is a EM transceiver so it contains a discriminator detector in the receiver. Frequency shift keying can be detected using a frequency discriminator so it was chosen as the modulation technique. The maximum data rate that can be sent thru the FM-5 receiver using FSK modulation was tested by frequency shift keying an RF generator with random data at different data rates and observing the received data on an oscilloscope. The pattern generated when the oscilloscope is triggered on the transmitted data clock is called an eye pattern. Figure 1 shows the eye pattern of the transmitted data on the top trace and the received eye pattern in the bottom trace for a 9600 bps data rate. One bit period is approximately two divisions in length. As can be seen in the picture, the received eye is open with minimal jitter at the bit crossings indicating that 9600 bps data can be sent thru the EM-5. Figure 2 shows the eye opening of 12 kbps data. The eye at 12 kbps is beginning to close with increased jitter at the bit crossings but the FM-5 could be used to send 12 kbps data. Figure 3 shows the eye pattern of 16 kbps data. This eye is closed with an unacceptable amount of jitter at the bit crossing. This data limit is due to the bandwidth of the IF filters in the FM-5 and could only be extended by increasing the bandwidth of the IF filters. Since minimum modifications to the radio were desired the maximum standard data rate was set at 9600 bps. The modification to the receiver is simply to connect a shielded wire to pin 9 of U1 (the discriminator output) which is run to post detection filters on the interface board.

The performance of the receiver at 9600 bps can now be tested by measuring the the bit error rate (BER) of the receiver. The BER of a data system is the probability of not receiving the transmitted bit correctly. This is normally expressed in percent or decimal form. For example, a system with a BER of 1 x 10-3 or 0.1% has the probability of receiving the transmitted bit incorrectly once in every 1000 bits. Bit error rate is measured by canparing the transmitted data bits with the received data bits and counting the number of errors. The BER for packet radio is dependent on the input signal strength to the receiver, so a graph of BER versus input power to the receiver is the normal measure of data system performance. Figure 4 shows the BER performance of the FM-5 receiver at 9600 bps. Figure 4 shows that at the 20 dB quieting level of the FM-5 receiver the BER was measured to be 4.5 x 10-3. We can compare this to data taken previously on the TAPR 1200 bps audio modem which was reported in QEX (1). Figure 5 is the BER performance of the TAPR 1200 bps modem. This figure shows that at the 20 dB quieting level of the Motorola Syntor radio the BER was measured to be 1.7 x 10-2. This shows that the 9600 bps radio has a system sensitivity that is approximately 1.5 dB better than the 1200 bps audio modem. The direct modulation of the RF carrier is a more efficient modulation technique than the audio subcarrier modulation of the 1200 bps modem providing a slight improvement in system sensitivity rather than a degradation which might be expected in going to a higher data rate. The QEX article shows that the AX.25 protocol begins to receive packets at the 10-3 BER and it is expected that any linking protocols will also begin reception at the 10-3 BER. We can then say that a EM-5 modified for 9600 bps operation will have a receiver sensitivity about 1 dB better than it's 20 dB quieting sensitivity.

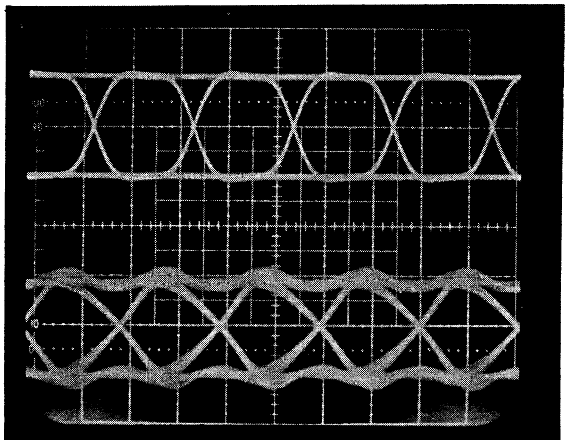


Figure 1
9600 bps Eye Patterns

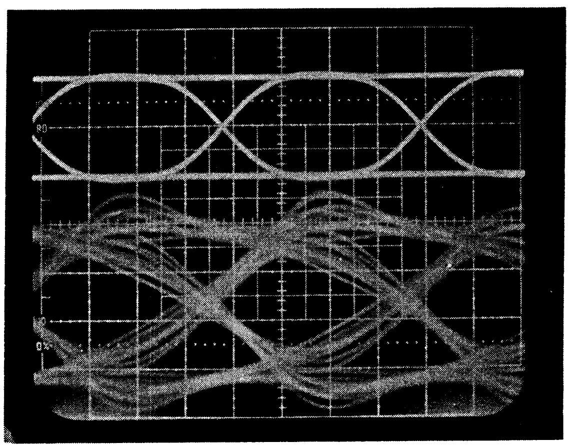


Figure 2
12 Kbps Eye Patterns

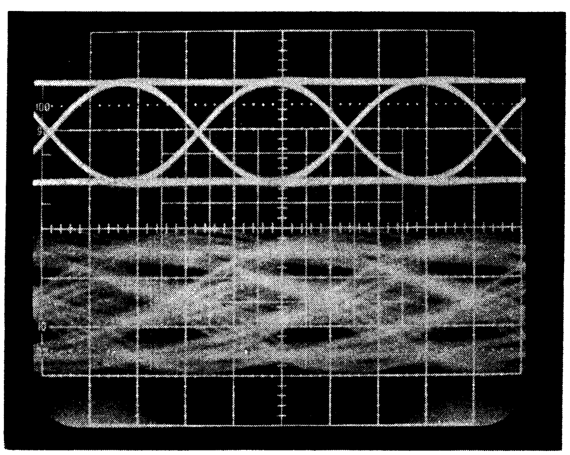


Figure 3
16 Kbps Eye Patterns

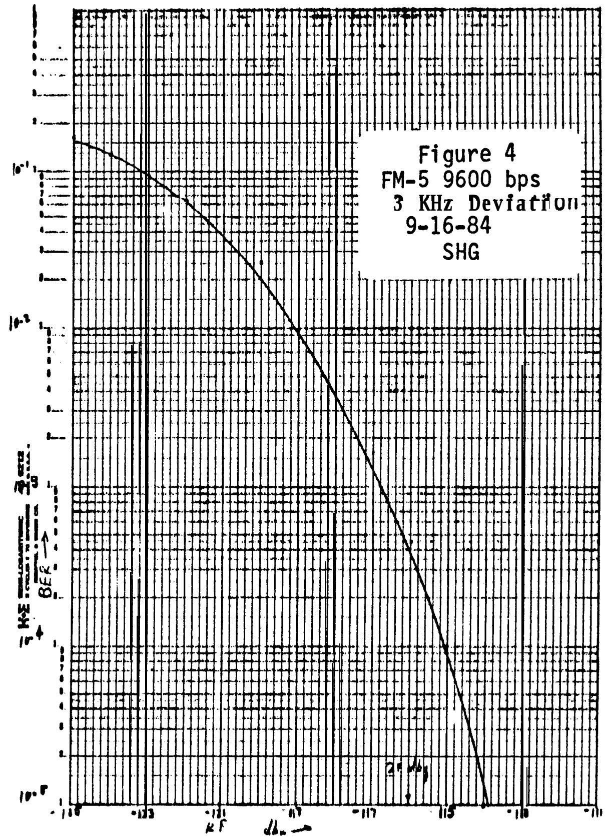


Figure 4
FM-5 9600 bps
3 KHz Deviation
9-16-84
SHG

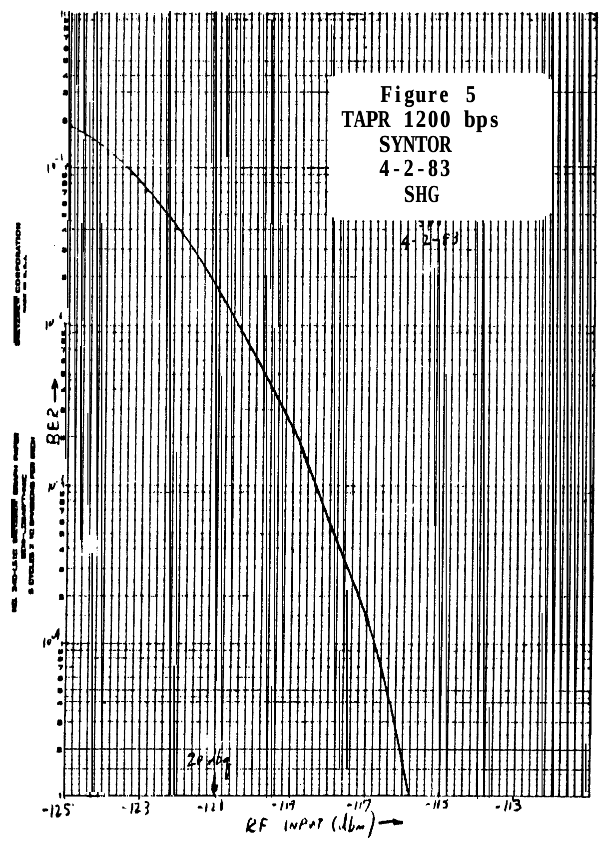


Figure 5
TAPR 1200 bps
SYNTOR
4-2-83
SHG

Transmitter Modifications

The Hamtronics FM-5 uses a phase modulator in the transmitter section. The transmitter was modified to provide direct frequency modulation by removing C25 and replacing it with the circuit shown in Figure 6. The varactor and shunt capacitor were mounted on the bottom of the board. The resistor and capacitor formed a flying connection to which a shielded lead was attached and run to the interface board, The FM linearity of this modulator was tested by measuring the frequency shift at the output of the transmitter with various DC voltages into the modulator. Figure 7 shows the FM linearity of this modulator. As can be seen, the modulator is linear over a 3 KHz range. A linear modulator was used in place of a frequency shift modulator for two reasons. First, since no modifications were made to the receiver IF bandwidth the resulting data system should fit into the present 40 KHz channel spacing 220 MHz band plan. This means that some method of controlling the transmitted spectrum must be provided in the transmitter. Figure 8 shows the resulting transmit spectrum when data is fed directly into a FSK modulator. At 40 KHz spacing there is still considerable energy which can interfere with the users on this adjacent channel. By filtering the data in a premodulation filter and then feeding it to a linear FM modulator the spectrum shown in Figure 9 is produced. This spectrum has greatly reduced energy in the adjacent channel. The second reason for not feeding data directly into a FM modulator without premodulation filtering is that the high frequency components of the data can excite crystal spurs resulting in the transmitter operating at many frequencies, some of which may be out of the Amateur band.

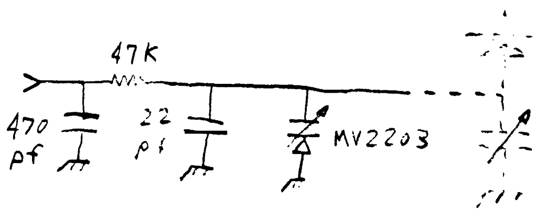


Figure 6
FM-5 Transmitter Oscillator Modification

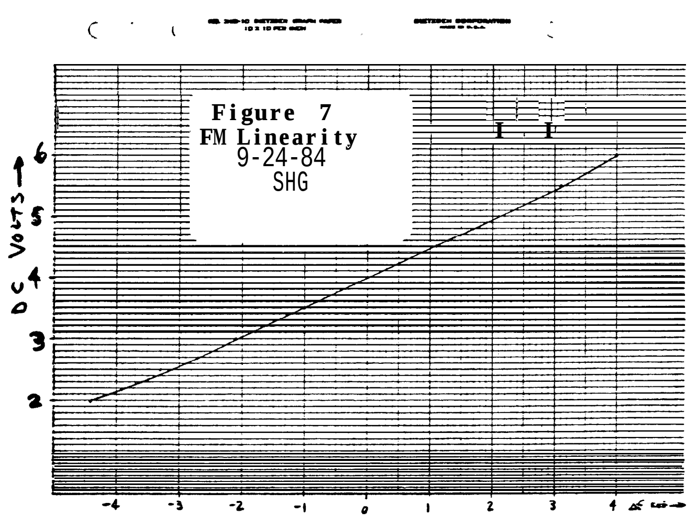


Figure 7
FM Linearity
9-24-84
SHG

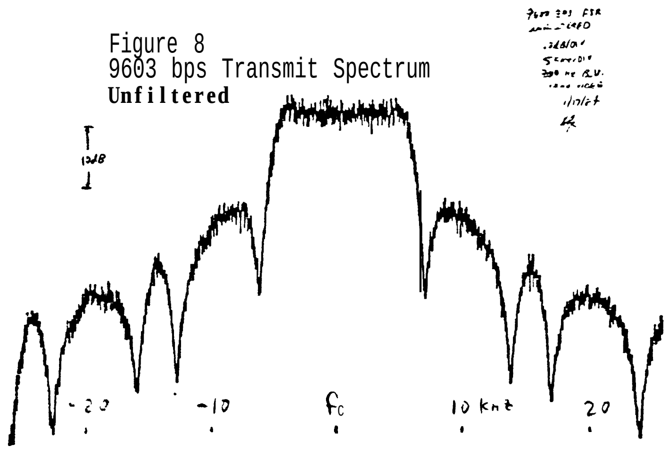


Figure 8
9603 bps Transmit Spectrum
Unfiltered

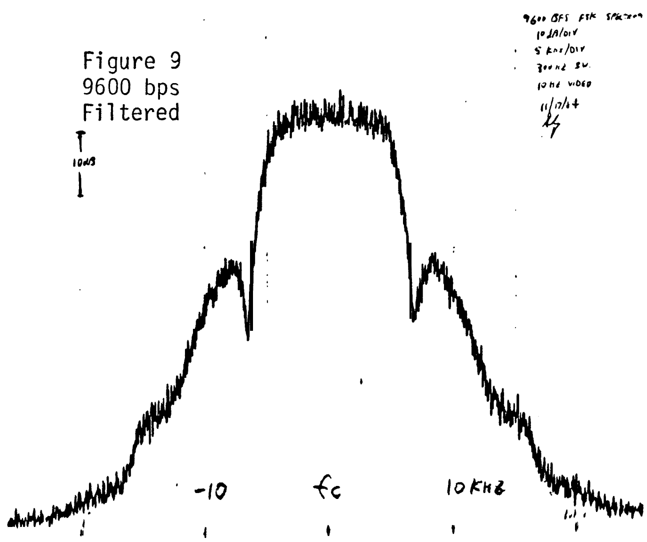


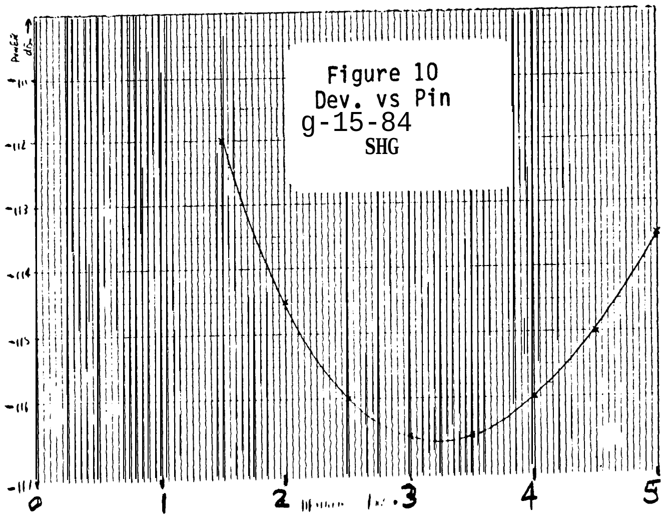
Figure 9
9600 bps
Filtered

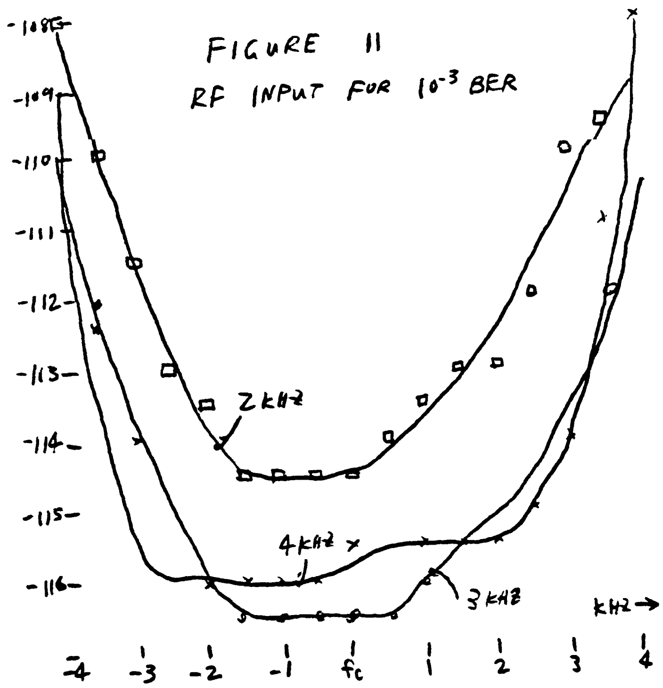
The optimum deviation for the 9600 bps data system was selected by measuring the RF power required for a 10-3 BER at various deviations. Figure 10 shows the RF power required for a 10-3 BER at 1.5 to 5 KHz deviation. Deviation was defined as the peak deviation when sending a 1-0 pattern. From this curve it is seen that the deviation for best sensitivity occurs at 3.25 KHz deviation. Since the data system should work with normal frequency offsets encountered with VHF radios due to temperature, aging and voltage effects, data was also taken measuring the effect of deviation on frequency offset. Figure 11 shows the RF power required for a 10-3 BER at 2, 3 and 4 KHz deviation with up to 4 KHz frequency offset. Taking into account the frequency offset performance of the receiver and the FM linearity of the transmitter the optimum deviation for the system was set at 3 KHz.

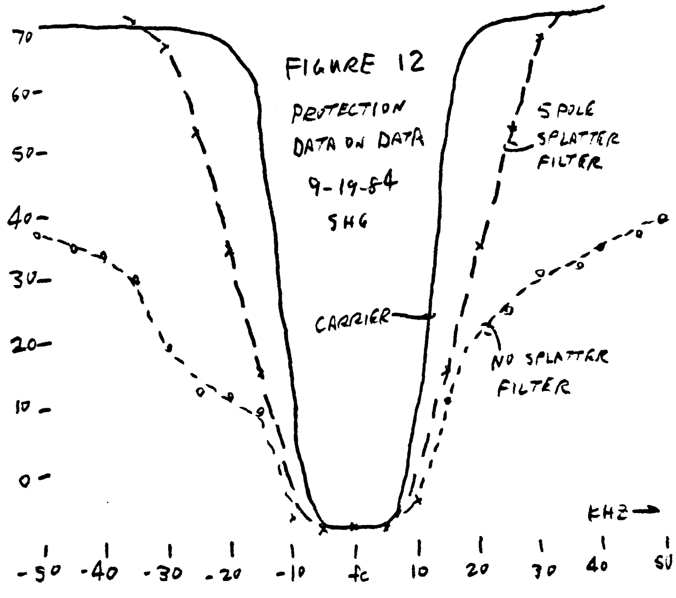
Now that we have defined the system deviation the protection given to adjacent channel users by the transmit splatter filter can be measured. Commercial manufacturers of voice radios measure adjacent channel protection in accordance to an Electronics Industries Association (EIA) specification (2) which requires a minimum of 70 dB protection to the adjacent channel. There are no specifications at the present time for data radios so we will have to make our own definition. The EIA voice spec essentially says to adjust the adjacent channel signal strength to sensitivity, then raise this level by 3 dB and degrade it back to sensitivity by the interfering adjacent channel transmitter. We can run adjacent channel tests by saying that the data system sensitivity is 10-3 BER. The premodulation filtered FSK signal was adjusted to give 10-3 BER and then this level was raised 3 dB. An interfering signal was then placed at various frequency offsets and the protection provided to this interfering signal was measured. Figure 12 shows the protection provided to a carrier, a premodulation filtered system (splatter filtered) and an unfiltered system (no splatter filter) at 9600 bps. As can be seen, 70 dB protection is provided to a carrier which should be similar to the EIA test. 70 dB protection is also provided to the described 9600 bps data system at 40 KHz channel spacing. Without splatter filtering only 34 dB protection is provided which can cause interference to operations on the adjacent channel.

An additional factor which must be considered in packet 'operation is how the transmitter is keyed up and down. Since this is done more often in packet operation than voice operation the frequent key up can produce a spectrum of its own that can be higher in splatter than the data modulation spectrum essentially negating the effect of the premodulation data filter. Once again there are no commercial specs for this frequent transmitter key up but a logical spec to set is that this key up spectrum should be below the data modulation spectrum. The interface board for the 9600 bps radio contains two DC key up switches which control this key up spectrum. The 9.1 volt line to the oscillator is keyed up 5 ms before the 12 volt line to the drivers and stays up for 5 ms after the drivers are turned off. This reduces the key up spectrum to an acceptable level. The modifications to the transmitter require removing C11, R3 and VR1. A separate 9.1 volt regulator with transmit switch is on the interface board and is brought into the radio in place of the removed parts.

A final modification to the transmitter requires removing R24. It was found that the charging of capacitors in the transmitter audio gave a spike at about 30 ms after key up to the phase modulator. This interfered with the data that was being transmitted at that time. Removing the audio from the phase modulator cured this problem.







Data Randomizer

Since VHF radios can have frequency offsets as large as the chosen system deviation for the 9600 bps data system, fixed decision levels for the received data cannot be set. This problem is remedied in this system by assuming a random data input and deriving the data decision level by averaging the received data. Unfortunately the AX.25 protocol does not provide random data so some method must be found to randomize the transmit data and then unrandomize the received data back to the original transmit data. This is provided on the interface board. A 17 stage shift register is configured to provide a self synchronizing data randomizer. This randanizer essentially divides the transmit data by a polynanial at the transmitter and then multiplies the receive data by the same polynomial at the receiver. The polynanial for this randanizer was selected to randomize AX.25 data sufficiently for transmission over the 9600 bps radios. Although this is not a standard maximum length polynomial it does sufficiently randomize AX.25 data with a minimum of extra parts. The randomizer has one drawback in that it requires 17 additional bits to be received correctly for the packet to be received. Since this is 17 bits in addition to the over 1000 bits in a packet this does not significantly change the BER required for the system to begin receiving.

Interface Board

Figure 13 is a schematic of the interface board required for the 9600 bps modifications to the Hamtronics FM-5. U1 is a quad op amp which provides the 5 pole 5 KHz Bessel filter used for the transmit premodulation filter and a 2 pole 5 KHz Butterworth filter used as the post detection receiver filter. The filters were designed to give 70 dB adjacent channel protection at 40 KHz in the transmitter and to provide optimum BER performance in the receiver. U2 and U10 provide the 12 v and 9.1 v key up controls. U5 and U6 form the data randanizer with U7 providing the necessary switching between transmit and receive. U4 and U3 form a clock recovery circuit necessary for proper data randomizer operation. A clock lock output is also provide by U4 and U3 which is used as the data carrier detect function. U8 provides a 1-0 pattern to the transmitter during receive to keep the oscillator on center frequency and ready to transmit. U2 provides a time out timer for the transmitter and the data slicer for the receiver. Channel frequency and deviation of the radio are adjusted by removing jumper 1 and shorting jumper two. C26 in the FM-5 is then adjusted for center frequency. Jumper 1 is then replaced and the deviation on the 1-0 pattern is set for 3 KHz.

Field Tests

An FM-5 transceiver was modified as described in this paper along with a Hamtronics T-51/R-220 exciter receiver pair. The interface board was mounted external to the FM-5 and all control leads were run thru a 9 pin D connector **mounted** on the back of the radio. The exciter/receiver pair used the same interface board as the EM-5 but required the building of a pin diode antenna switch. Field tests were then conducted between K9NG in Palatine, Ill. and W9TD in Hoffman Estates, Ill. which is approximately a five mile path. K9NG used the 7 watt FM-5 and W9TD used the 1 watt T-51/R-220 pair. Two TAPR kit boards were jumpered for twice clock operation and connected via the modem connector. 9600 bps packets were then sent between the two stations. Both stations used a 1/4 wave ground plane antenna. These field tests confirmed the bench tests of the 9600 bps radios. The Txd of the TAPR boards were set to 1 resulting in a 20 ms delay for transmitter key up. 128 byte packets were sent in about 150 ms. These packets just open squelch in a normal FM receiver and sound like noise bursts. 100 Kbyte files were transmitter in approximately one and a half minutes.

Modifying Other Radios

The interface board presented here can be used to modify other radios for 9600 bps packet operation. As was mentioned in the field test results, a Hamtronics T-51 and R-220 exciter/receiver pair were also modified with similar results to the FM-5. One area that may cause a problem with other radios is the transmitter key up. Since other radios may key up differently than the FM-5 or T-51 the method of controlling the key up used for these radios may not work for others. If at all possible, the key up of the intended radio for modification should be observed on a spectrum analyzer and verified to not create a large transmit spectrum when keyed up at an 8 Hz rate.

Comments on Higher Data Rates

The filters on the interface board can be directly scaled for higher data rates when radios with larger bandwidth IFs become available. It should be realized that any increase in data rate from the 12 kbps maximum allowable in the standard 15 KHz bandwidth of an EM receiver will degrade system sensitivity in a direct relationship. For example if a 96000 bps system was desired the IF bandwidth would have to increase by approximately 10 **times** and a 10 dB degradation in system sensitivity would be experienced. This means that link station separation would have to be decrease or transmitter power would have to be increased to make up for this degradation in system sensitivity. The apparent free lunch in system sensitivity that was obtained by going to direct FSK will not be available for higher data rates and the degradation in system sensitivity will be a tradeoff in designing link stations to use these higher data rates.

Conclusions

The necessary interface board and modifications to allow packet operation of the Hamtronics FM-5 transceiver at 9600 bps have been presented. Field tests have proven the design to be workable. Every attempt has been made to design this radio interface to be a good neighbor in the 220 MHz band. Adjacent channel protection ratios were measured for the system and provide a minimum of 70 dB protection to the adjacent channel users.

Since the EM-S provides a maximum of **7** watts of output power, linking groups may be interested in designing a power amplifier. This power amplifier would have to be designed to provide fast antenna switching and proper key up. Future projects could also include a radio designed specifically for 9600 bps packet operation or higher data rates.

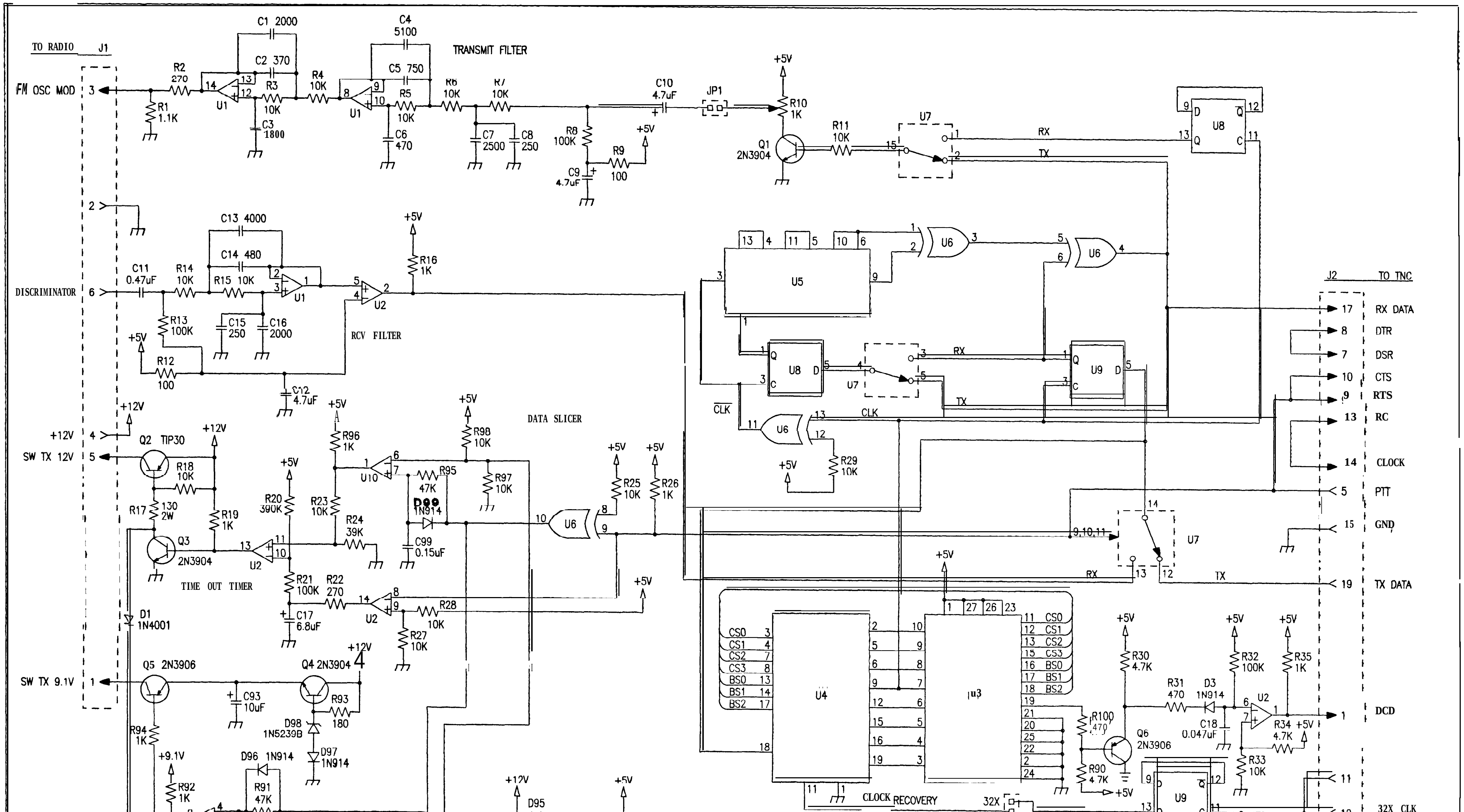
Acknowledgements

I would like to thank Paul Newland, AD71 for providing the state machine code used in U3 which implements clock recovery and data carrier detect. I would also like to thank Gary Kaatz, W9TD for performing the 9600 bps field tests. Finally a large thank you goes to Pete Eaton, WB9FLW for originally suggesting this project and to Lyle Johnson, WA7GXD and the rest of the TAPR gang for their encouragement throughout the project.

References

1) Goode Steve, K9NG, "The Bit Error Rate Performance of the TAPR TNC Modem", QEX 18, August 1983

2) Electronics Industries Association, "Minimum Standards for Land Mobile Communication FM or PM Receivers,25-947 MHz", RS-204C, January 1982



IC	TYPE	+12	+5	GND
U1	MC3303	4	–	11
U2	MC3302	3	–	12
U3	2764	–	28	14
U4	74LS374	–	20	10
U5	MC14006	–	14	7
U6	MC14070	–	14	7
U7	MC14053	–	18	7,8
U8	MC14013	–	–	4,6,7,8,10
U9	MC14013	–	14	4,6,7,8,10
U10	MC3302	3	–	12

NOTE
ALL CAPACITORS ARE IN PICOFARADS UNLESS OTHERWISE SPECIFIED.

TAPR/K9NG 9600 BAUD MODEM

AUGUST 1985