VMSK on the Ham Bands

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Abstract:

VMSK modulation is being experimented with at 431 MHz to transmit digital data at very high data rates, without sidebands. At present it is used for experiments in Computer to Computer linkage (WLAN) at rates up to 4.0 Mb/s. Video, using the Real Player or Windows Video inputs, with better than VHS quality is in the offing. DVD playback can also be used. The transmitted bandwidth is 1 Hz; no that is not a misprint. The receiver noise bandwidth is approximately 2 kHz. The bandwidth efficiency based on receiver Bit Rate/BW is greater than 1,000 bits/sec./Hz. All spurs, sidebands etc. are below FCC minimums for Cellular phone use.

Very Minimum Sideband Keying (VMSK) is an MSB method that has only a J_o Bessel equivalent carrier, but no J_1 sidebands. To understand how this is possible, see the references. The modulation is phase modulation (G1D), +- 45 deviation (actually 0-90, $\beta = .8$). The C/N is better than for BPSK modulation, which has very widespread sidebands. This is due to the very narrow receiver filter bandwidth, which does not change with data rate. Figure 1 shows the transmitted spectrum at 431 MHz, with a data rate of 270 kb/s.

There are several baseband code patterns that can be used with VMSK. The ones chosen for this equipment were WPSK and 3PSK. Straight NRZ data can also be used, with additional filtering. The 2W transmitter and matching receiver employed were produced by Hamtronics, with the modifications shown in the appendix to use a Pegasus 24 MHz VMSK modem. The receiver sensitivity when properly aligned is approximately -120 dBm for a 12 dB SINAD. VMinSK operates down to approximately 6 dB SNR, where the FM knee occurs.

This equipment was operated at 431 MHz in order to make some commercial comparison testing possible, as well as for the Ham band experiment. Any IF frequency can be used, as long as there are enough cycles in the IF section per bit period. It is recommended that at least 50 cycles be used to keep transmitter filtering to a minimum if 3PSK is used, but this is not a firm rule. The only reason for recommending this coding method and ratio is multipath improvement. A data rate of 100kb/s would thus require an IF frequency of 5 MHz. In this T/R setup, the number of cycles has been reduced to as low as 6 per bit period for 4.0Mb/s, which is near the minimum possible. This requires additional transmitter filtering for some FCC applications. With 50 cycles per bit period using 3PSK, it is possible to omit the bandpass filter in the transmitter modem for most low power applications.

Tests conducted by Bell South have shown that VMSK using 3PSK coding has excellent multipath characteristics. Sometime in the future, it is planned to try it on the 40, 20 and 10 meter bands with an E-layer bounce - just for kicks. Naturally, with a Morse identifier between data periods.

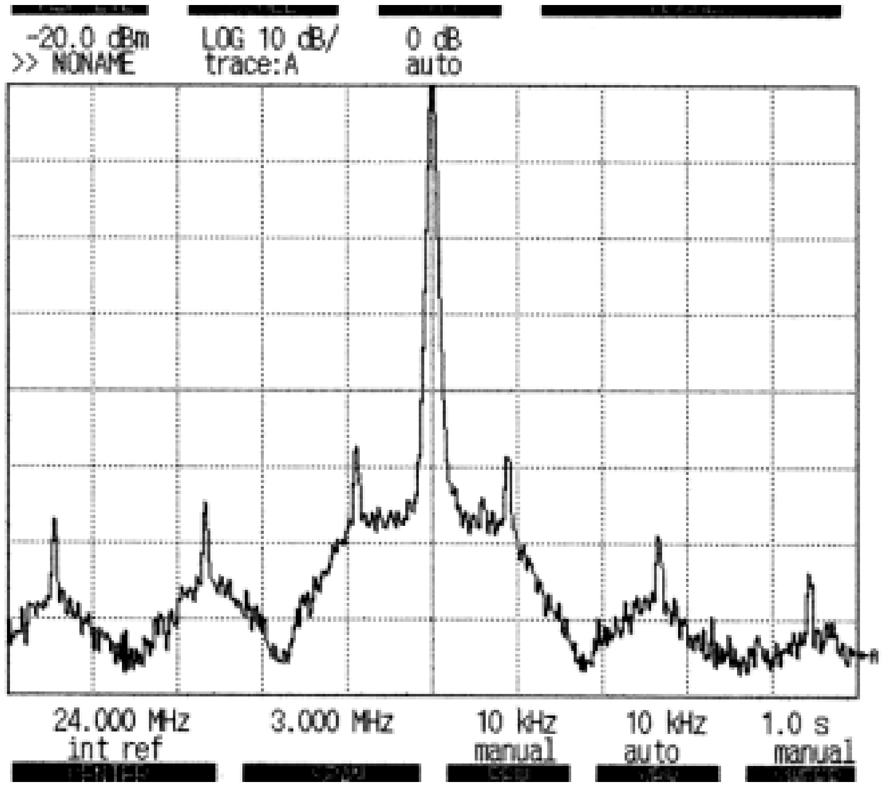


Figure. 1. The Transmitted RF Spectrum for 270kb/s Data Rate Using WPSK.

The equipment described uses a 24 MHz IF for several reasons. The cylindrical filter crystals are about the highest available good quality fundamental cut that can be readily obtained from distributor stock. They can be used in an overtone mode however, for higher IF frequencies. 25 MHz is also the upper fundamental frequency cutoff for most commercial crystals. There is an almost complete lack of commercial limiters for frequencies higher than 25 MHz, which can be a design problem for higher data rates.

24 MHz is also the T/R separation for FCC Part 101 (Fixed Microwave). This IF frequency makes Duplex T/R easier to implement. 431+- MHz is also the frequency range used for Amateur Radio, Business Radio, and in other parts of the world, for Cordless Phones. In Europe, it is the preferred frequency for the equivalent of US Part 15. The Hamtronics transmitter and receiver have frequency synthesizers to enable frequencies other than 431 MHz to be selected.

VMSK modulation cannot use conventional crystal filters (3PSK and WPSK are subclasses). Conventional filters are correlative, or integrating type devices. They operate like an RC integrator and the phase shifted cycles will be completely missed. The Walker Shunt filter is a zero group delay filter that acts as an RC differentiator for a single frequency only. This filter is seen as a monopole filter in the receiver modifications in Fig 7. When parallel resonant tuned exactly at the IF frequency, the input at the amplifying device has all reactances cancelled and appears as a very high resistance driven by the small coupling capacitor. Thus, it is an RC differentiator with no integrating or group delay. The shoulders are typically reduced 20 dB per filter crystal.

Adding a small inductor in series with the crystal lowers the crystal resonance frequency and increases the shoulder rejection.

VMSK modulation creates a strong single frequency with phase modulation and numerous low level Fourier sinx/x products. These sinx/x products are AM products and can be removed by the filters without reducing the detected phase angle. This hardware uses one or two stages of Walker shunt filtering at the transmitter and two stages in the receiver.

Using a WPSK baseband code, the RMS level of any Fourier spikes that are seen is 3dB below the observed peak level. Using 3PSK, the peak level is $-20Log_{10}(T/t)$ and the RMS level is $-40Log_{10}(T/t)$, where (T/t) is the ratio of the number of cycles phase shifted. In Fig.1 the sinx/x spikes are at -48dB peak and -51dB RMS below the phase shifting carrier.

A complete description of Very Minimum Sideband Keying and the required filtering is too voluminous to be included here. The <VMSK.org > web site has all of the necessary schematics for the Modem and a complete theoretical description of the method with applicable math. It does not violate Shannon's Limit and the SNR is better than that for BPSK modulation.

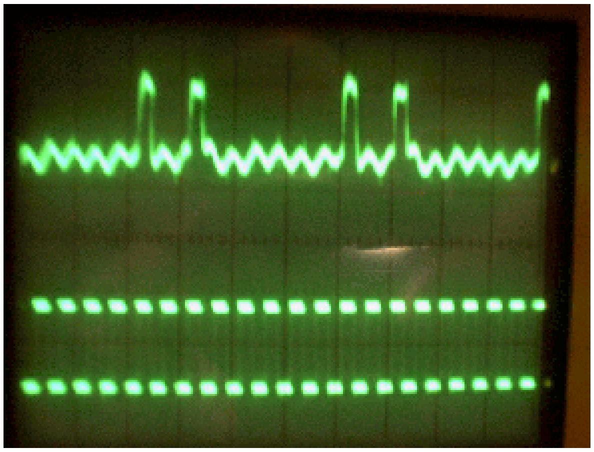
This modulation method can also be used with frequency hopping spread spectrum.

Using a 3PSK code, One or 2 cycles in 14 are altered for 1714 kb/s data rate with a 24 MHz IF frequency. For a lower data rate, the ratio increases.

Using WPSK at 1.71 Mb/s, the IF frequency is on phase 1 for 7 cycles and phase 2 for 7 cycles. The phase is changed for ones only. There is no change for zeros. At 3.0 Mb/s, the time on phase 1 is 4 IF cycles and the time on phase 2 is 4 IF cycles.

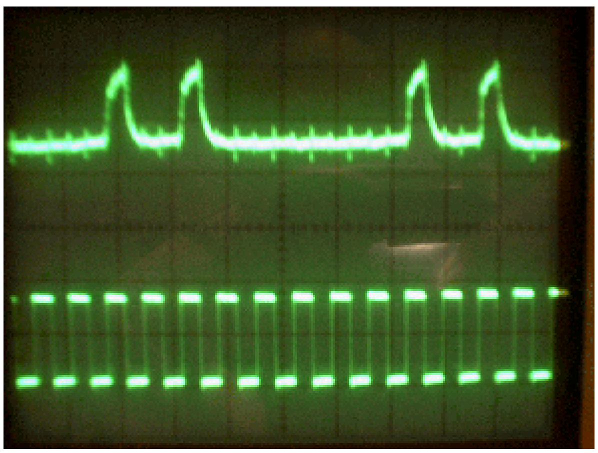
Using NRZ as an input, phase 1, representing a 1, is on 14 cycles and phase 2 is on for 14 cycles for a zero at 1.7 Mb/s. If the bit is repeated, the number of cycles increases by the number of repeat bits.

The detector of the SAE636 IF amplifier has difficulty resolving a 1cycle change, but has no trouble with 2 or more cycles. The rise time of the detector output amplifier is 80 nanoseconds. It is necessary to add a low capacitance FET input amplifier to the output on pin 9 in order to operate at 1.5 to 4.0 Mb/s. An XOR gate used as an amplifier in the analog mode can also be used.



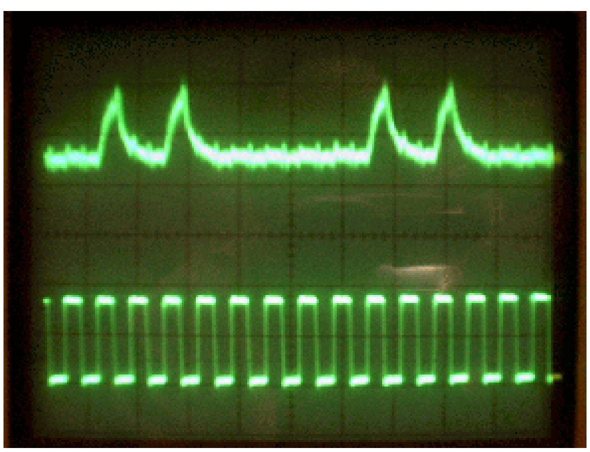
Output of SA636 pin 9 (Data Out)
Data Rate 270 kb/s
Modulation code is WPSK
Detected pulse is 1/2 clock period wide
Data pattern is 10100000

Fig. 2.



Output of SA636 at 812 kb/s (Data Out Pin 9)

Fig.3.



Output of SA636 at 1.7 Mb/s on pin 9.

The capacitive load is from the oscilloscope probe at approximately 18 pf. Note the RC rise time is starting to take effect. The detected data level must be amplified to CMOS levels for the decoder. A low capacity input amplifier (FET) improves this.

Fig. 4.

Although it is not shown, the data rate can be increased to 4Mb/s using NRZ, WPSK or 3PSK. T1 (1.544 Mb/s) and E1 (2.048 Mb/s) are of commercial interest. The circuitry as built will accept and decode a phase change pulse 80 nanoseconds or more in width. Therefor, if the data rate leaves a sufficient number of IF cycles, the higher rates will detect and decode. 4Mb/s detects cleanly with the FET amplifier (Fig. 7) after pin 9.

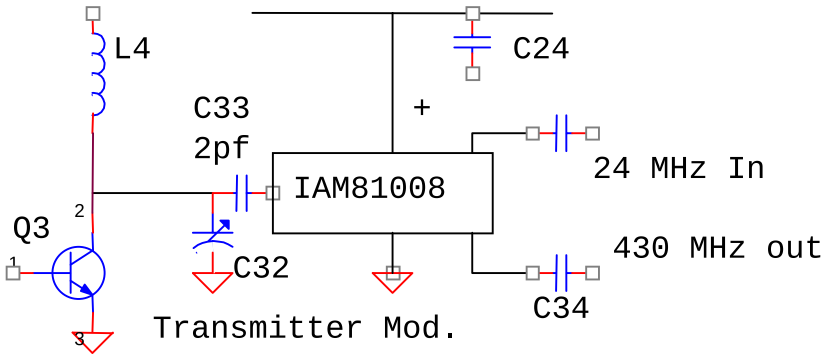


Fig. 5.

The changes made to the transmitter consisted of adding a mixer to mix the 24 MHz IF to the stable transmitter oscillator. The extra components were placed on a small 3/4 inch PC card soldered to the shield plate. A MAR8 (MMIC) was added after C34 to raise the level by the amount necessary to drive the RF amplifier stages to full 2W power. The input to Q3 is 455 MHz.

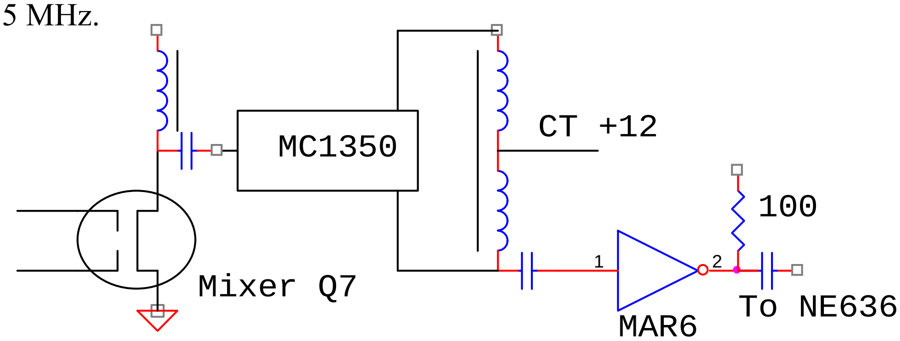


Fig. 6.

Changes made to receiver. The 10.7 IF can at the mixer Q7 is removed and replaced with a 5mm ferrite bead with 6 turns through the hole. The MC1350 and following MAR6 add about 40-45 dB of IF gain. This gain, added to the SA636 threshold, give the receiving unit a threshold level near -120 dBm. See "Demodulating Logamps Bolster Wide Dynamic-Range Measurements", Microwaves and RF, March, 1998.

Fig. 7.

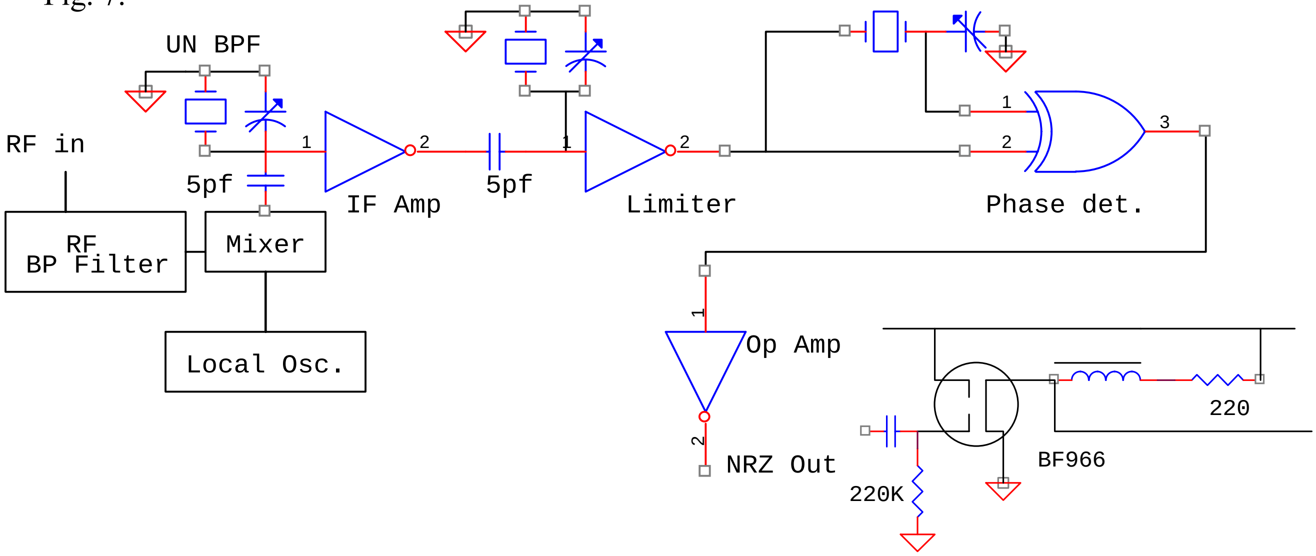


Figure 7 is the equivalent circuit of the SA636 IC used as a complete phase modulation receiver for Ham band and other FCC Part use with minimum sideband modulation. (MSB). The reference crystal is a series mode crystal used in place of the quadrature coil. An XOR gate is shown here as a phase detector. The SA636 uses a Gilbert cell instead. The XOR gate is useful when building the phase detector from discrete parts.

This receiver is built on a surface mount board 2" x 2" laid out for best shielding between sections. The sensitivity measures -88dBm for 30dB quieting. This lower level has been extended by the MC1350 pre-amp in Fig. 6. Photos are appended (Fig. 11).

The crystals used are 24 MHz cylindrical crystals available from Mauser or DigiKey. The frequency trimmers are 4-40 or 5-50 pf ceramic trimmers. Data sheets for the SA636 are available from <philips.com>.

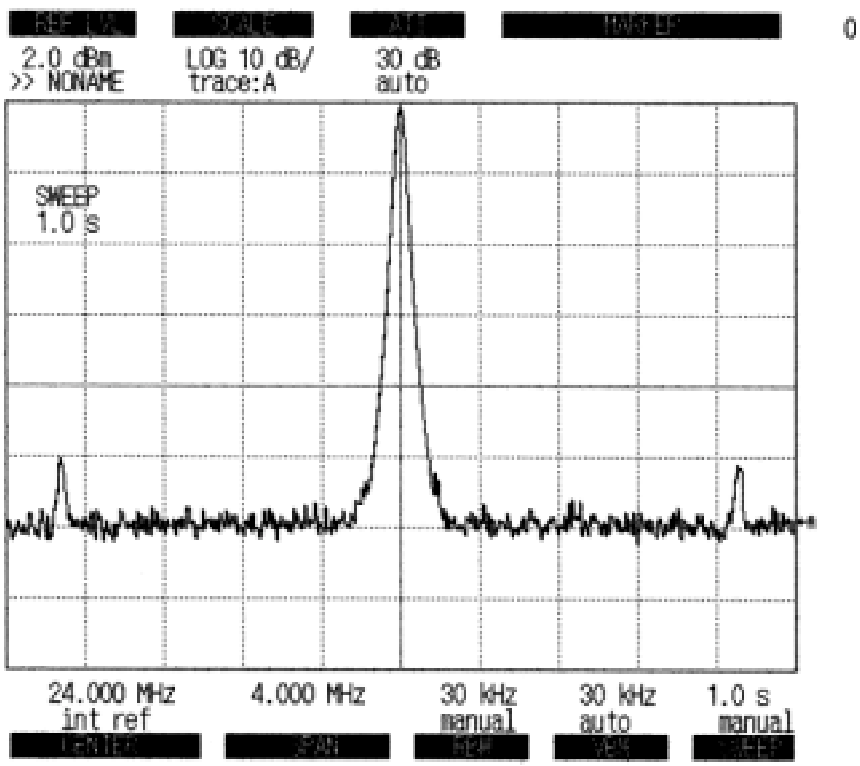


Figure 8.Transmitted spectrum at 1.7Mb/s using WPSK and random data. 2 stages of transmitter filtering were used.

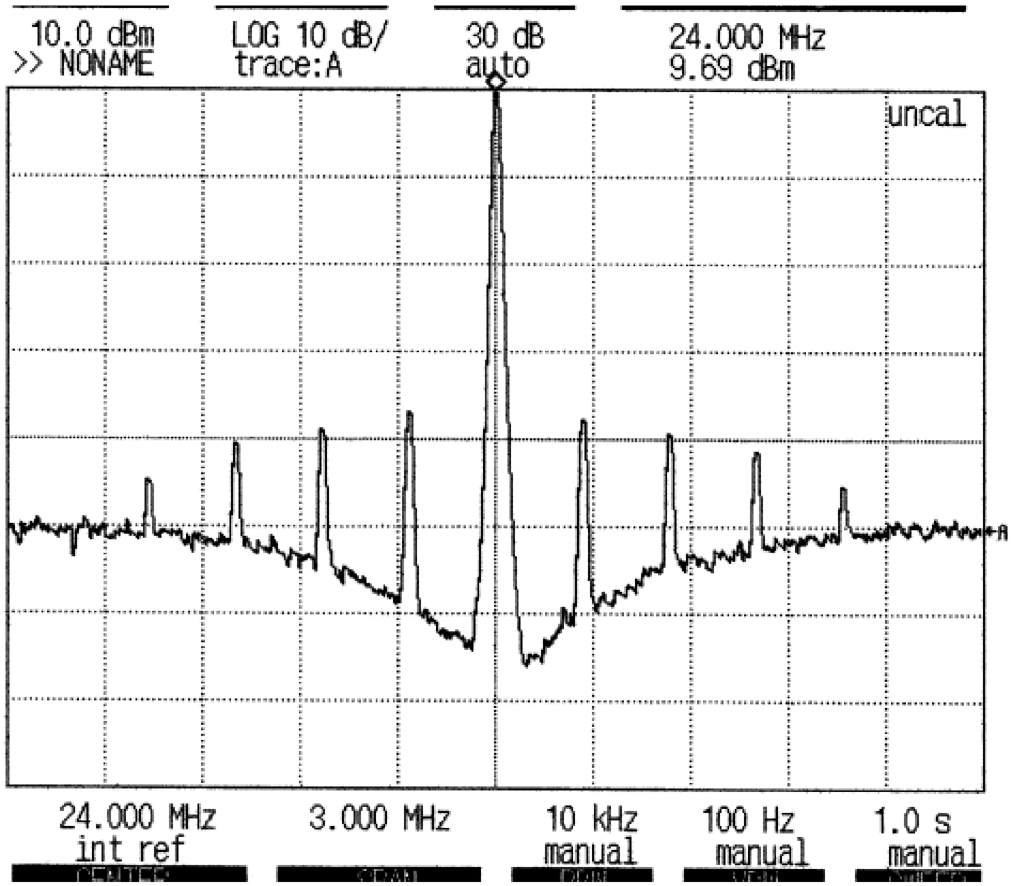
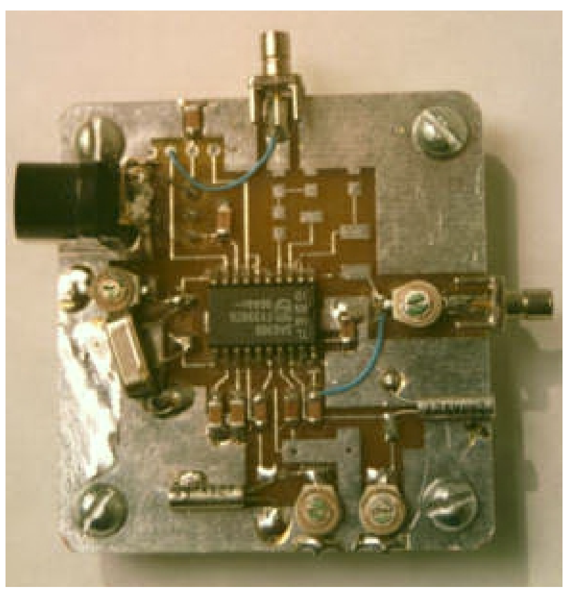


Figure 9. The spectrum using 3PSK at 270 kb/s with 2 cycles phase shifted out of the IF stream. As the data rate increases, the sinx/x spike level rises. At 2.0 Mb/s the peak level would be -18 dB. The RMS level would be -36dB. One stage of transmitter filtering would be required to meet FCC requirements. Using WPSK, two or more filter stages are required. WPSK would have 6 cycles shifted out of 12 for a 2 Mb/s data rate. The detected pulse seen in Fig. 4 would apply.

Using WPSK, the spectrum does not change with data rate, whereas 3PSK has sinx/x spikes at higher or lower levels.

Fig.10. 24 MHz injection jack and 455MHz to 431MHz mixer on Hamtronics T304 Exciter. The 8 pin mixer is Avantek IAM81008.

Figure 11. SA636 IF strip with phase detector. The cylindrical IF filter crystals are tuned with ceramic trimmers. The crystal at left in the HC49US holder is a series mode phase shifter. FET output amplifier is not shown.



The highest data rates are obtainable using NRZ as coding source. Unfortunately, it is more difficult to decode than WPSK or 3PSK. As an experiment, the data rate was raised to 8Mb/s using NRZ. The detected waveform showed that it could be decoded, but no effort was made to do so.