Using VPSK in a Digital Cordless Telephone/Videophone/ISDN Modem

Variable Phase Shift Keying (VPSK) offers increased data rate over simpler modulation types with only a small increase in bandwidth, which enables new applications to be used in the cordless telephone band.

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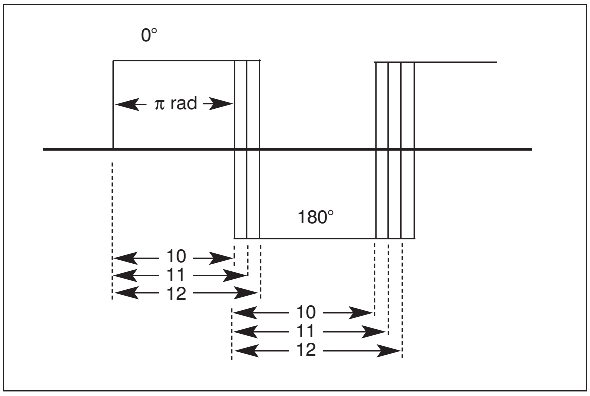
Data transmission at 320 kb/s in the bandwidth allowed for 46/49 MHz cordless telephones makes it possible to provide H320 videoconferencing, two separate 2 B+D channels, or 5 "B" channels over a cordless telephone/wireless link. Provision is made for 2B+D service (U interface) at 160 kb/s to connect to the external ISDN telephone lines currently used for Internet traffic. Within the users' facility, data can be transferred at 320 kb/s for WLAN service, or for videoconferencing using the H320 standard. Most available video equipment at this time operates at 160 kb/s.

This article will discuss only the radio portion of the link. We will assume that all level conversions and protocols are taken care of elsewhere and that normal CMOS level NRZ signals are available from the ISDN equipment to the radio equipment.

VPSK modulation is largely the same as binary phase shift keying (BPSK) or 2 phase shift keying (2PSK or PRK). The difference is that the digital data used to modulate are encoded with an algorithm similar to the MFM algorithm used for double density disk recording. This encoding method results in a varying bit width which, after modulation and processing, results in a phase shift of 30 degrees for 6 VPSK and 18 degrees for 10 VPSK. The signal then assumes some of the characteristics of 12 PSK or 20 PSK, but with a much narrower bandwidth. The actual phase shift depends on the algorithm used, hence the name *Variable* Phase Shift Keying. The coding rules include:

1. No change from previous bit (no phase change)
2. Change from '0' to '1' or '1' to '0 (One unit phase shift)
3. Synchronizing after 4 or 8 changes (Two units phase shift)

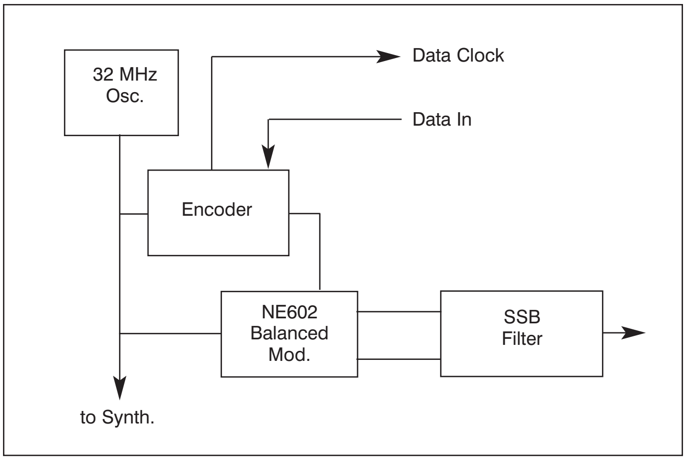


■ **Figure 1. 10VPSK waveform characteristics.**

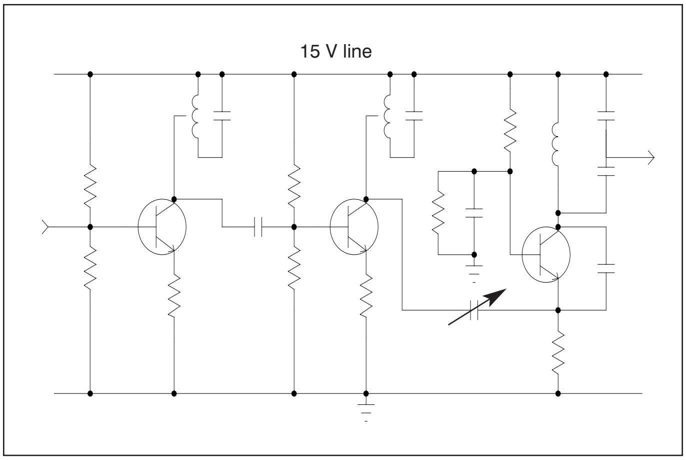
These phase shifts appear at the encoder output as bits which are wider than normal. In the case of 6, 7, 8 Slip Code, the bits are 6/6, 7/6, 8/6 times a normal bit width. For 10, 11, 12 Slip Code the bits are 10/10, 11/10, 12/10 times a normal bit width (Figure 1). There must be a change after each one of these time periods. Because the algorithm causes a '0' to be missed periodically the decoder must reinsert it. The synchronizing bit tells the decoder to insert this '0' and set the next bit to '1', thus correcting for ambiguity. The name Slip Code was adopted because of this missing bit [2].

VPSK modulation is used to compress the RF bandwidth by 15.3:1 (15.3 bits/s/Hz). VPSK is a modified form of BPSK modulation that does not lose signal power as a result of compression. 15.3:1 compression is the equivalent of QAM 40,342 (215.3 = M) which is impossible to achieve.

FCC regulations for cordless telephone service in the 46/49 MHz bands allow 20 kHz of bandwidth using a crystal stability of 100 ppm. Crystal drift either way could thus result in a



■ **Figure 2. The data encoder and modulator.**



■ **Figure 3. The transmitter IF filter.**

bandwidth of 30 kHz.

The FCC allows for this by requiring any radiation drift ±10 kHz outside the nominal 20 kHz center to be at least –26 dB below the peak value after allowing for crystal accuracy and frequency drift. Signal strength is limited to 10 millivolts per meter at 3 meters from the transmitter, which rules out the use of any other high compression method.

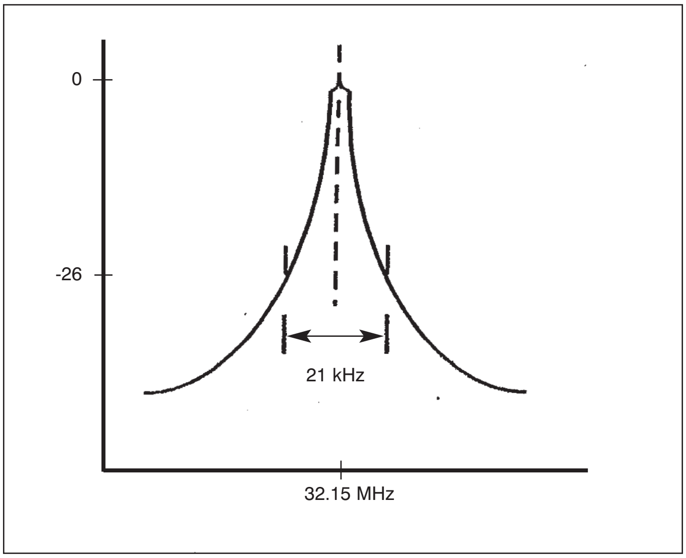
By using crystal oscillators with a stability of better than 10 ppm and using 10 VPSK with its 15.3 to 1 compression, the radiation can be confined to the permitted FCC limits while transmitting data at 320 kb/s. 6 VPSK with 10:1 compression would occupy 32 kHz at –26 dB, which would comply with a liberal interpretation of the rules. If 2B+D is used, compressing 10:1 uses only 16 kHz of bandwidth. VPSK can compress 7.4:1, 10:1, 12.6:1 or 15.3:1 depending on the algorithm used.

Figure 2 shows a block diagram of the VPSK encoder. A crystal oscillator with compensation to better than 10 ppm supplies a clock frequency to the data source, a modulation IF frequency to the balanced BPSK modulator and a clock frequency to the synthesizer that selects the channel.

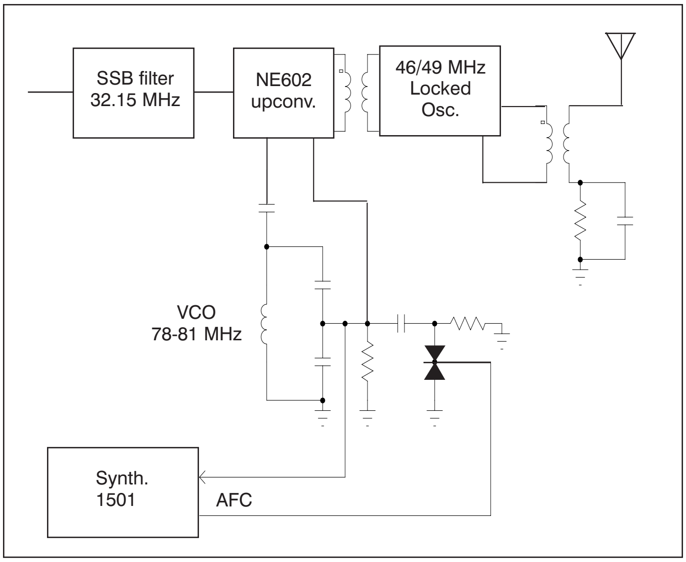
VPSK encoded data is end-to-end pulse width encoded prior to the BPSK modulator. In the case of 10 VPSK, the bits supplied to the BPSK modulator are stretched 1/10 and 2/10 bit width. The resulting Fourier frequencies cover a band 1/15.3 the data rate, or 20.9 kHz for 320 kb/s [1].

The upper sideband filter is a simple two-pole LC filter followed by a locked oscillator to further narrow the bandwidth as shown in Figure 3. The transmitted spectrum, which is –26 dB at the ±10 kHz points, is shown in Figure 4.

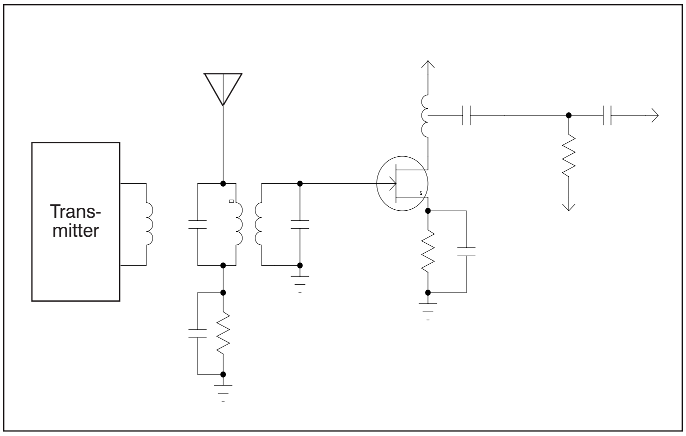
The upper sideband of the modulated IF signal is mixed with a local oscillator signal to provide the 46 or 49 MHz output. A locked oscillator at the mixer output passes only the desired signal, rejecting the two mixer input signals. This oscillator also drives the diplexer. Because of the strong drive signal to this oscillator, it should be categorized as a regenerative IF amplifier and



■ **Figure 4. The spectrum for 320 Kb/s digital modulation using VPSK.**



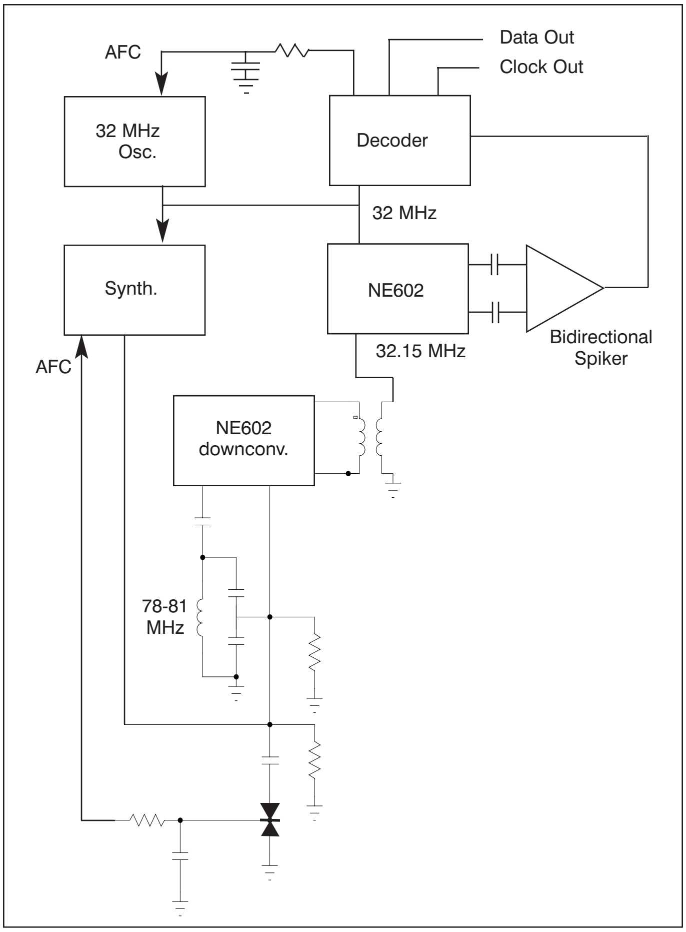
■ **Figure 5. Mixer and output amplifier.**



■ **Figure 6. Receiver input circuit.**

is not to be considered a free running oscillator, which the FCC would not permit. Figure 5 shows the mixer and output amplifier along with the diplexer [3]s.

The diplexer is a typical hybrid transformer circuit. If the antenna and the dummy load at the ends of the hybrid are balanced, the output to the receiver tap is a null at the transmitter frequency. Additional trapping can be used. This circuit requires a fixed antenna length shorter than 1/4 wavelength. A 36” antenna represents



■ **Figure 7. Receiver IF and VPSK detector.**

a load of approximately 1800 ohms and 10 pF of capacitance, which is balanced by the dummy capacitor and ferrite bead. The ferrite bead has a resistive component of 1800 ohms with little or no inductance at 49 MHz.

The oscillator output level is nearly +20 dBm. This must be attenuated to comply with the power output regulations. The necessary reduction is accomplished by varying the coupling distance between the coils. Power loss of 3 dB or more occurs in the hybrid.

Figure 6 shows the RF input circuit. Low noise FET amplifiers are used to raise the signal above the background noise of the following stages as much as possible to prevent additional losses in the mixer and IF amplifier.

The resistive noise (background noise) is approximately –128 dBm for a bandwidth of 30 kHz. Assuming a receiver noise figure of 8 dB, a noise level of –120 dBm remains. The signal must be above this level by a sufficient margin to give an error free response. The theoretical signal-to-noise at 1×10^{-6} BER for VPSK at all levels of compression is 7.4 dB, which is 3 dB better than QPSK. In practice, filter nonlinearity and detector uncertainty result in a value of 14 to 15 dB. After adding the expected losses and receiver input noise the data should be recoverable at –95 to –100 dBm input level.

Substituting a signal generator for the antenna, with impedances matched, the measured input signal level required for 20 dB S/N was –85 dBm. The losses in the hybrid and the input NF were not as low as expected. The VPSK modulated signal was close to error free at –90 dBm.

The same two pole LC filter used in the transmitter IF is used in the receiver, except that an NE605 limiter is used ahead of the locked oscillator. A interesting feature of the locked oscillator in this circuit is that it typically offers more than 6 dB processing gain. The noise bandwidth of the locked oscillator is less than 10 kHz, while the tracking range is approximately 100 kHz [3].

Figure 7 shows the receiving circuit following the down conversion. The 1x clock and the data are restored at the decoder output. VPSK modulation is single sideband FM requiring coherent carrier reinsertion. The AFC circuitry in the decoder chip makes it possible to lock the 100x oscillator exactly in phase and frequency with that of the originating transmitter.

BPSK modulation (and VPSK) can be detected as either AM or FM. The circuit used here is that of a single sideband (SSB) AM product detector with the reinserted carrier exactly the same as the suppressed transmitter carrier.

The output of the detector is a series of square waves of varying widths. A zero crossing detector is required to produce a spike at each zero crossing for use by the decoder chip. A bi-directional one-shot is used for this purpose.

The only other modulation method known at this time that can compress data more than 5 or 6 to one is QAM. To compress 10 to 1, QAM requires 39 dB S/N [7]. 6 VPSK compresses 10 to 1 with S/N values of 13 dB for the same BER. The reason for the difference is in

Shannon's Limit. VPSK is BPSK modulation, with 1 bit per symbol, not 10 bits per symbol as would be required for 1024 QAM. Shannon's Limit for VPSK is the same as that for BPSK, 0 dB. Shannon's Limit for 1024 QAM is 20 dB. By using VPSK there is an immediate power gain improvement of 30 dB (Shannon's Limit plus the 10 dB QAM would be needed to obtain the CNR value). And, 1024 QAM is not a reality at this time.

VPSK, as used here, compresses 15.3:1, hence is the equivalent of 40,342 QAM ($2^N = M$), which is an impossibility. If it were possible, the CNR required would be 55 dB or more (Figure 8). Add this to the input noise plus losses and the transmitted power needed would be 40 dB greater than that required for an analog phone in order to achieve a $1{\times}10^{-6}$ BER. The range of such a system would be 1/100 that of an analog phone, or approximately the distance across a room.

VPSK, on the other hand, offers better post detection signal-to-noise than analog FM at the same signal strength. Those unfamiliar with the concept may disagree with this claim, insisting you cannot compress without losing signal power. VPSK equipment in the field repeatedly has proven that you can compress with post detection S/N as well or better than analog FM.

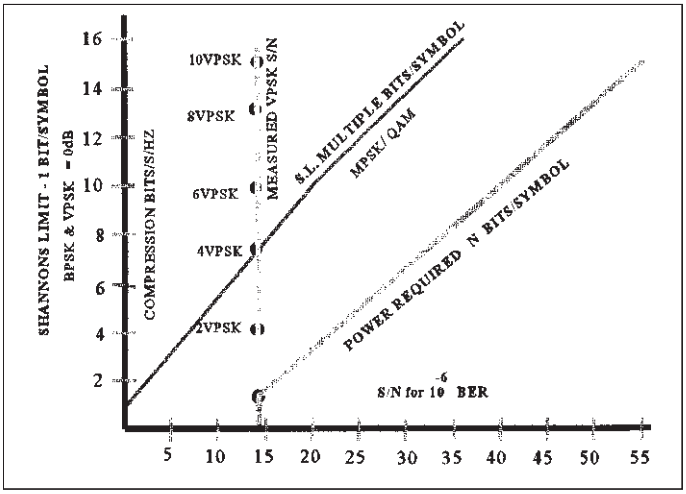
Figure 9 shows the performance of a VPSK receiver using 10:1 compression, compared to analog FM using the same receiver, which could be operated in a dual mode [1].

This equipment is operating well below Shannon's limit for the equivalent QAM, yet it does not violate Shannon's Limit, as shown in Figure 8. Shannon's limit rises as the number of bits/symbol rise. 1024 QAM uses 10 bits/symbol. VPSK is always 1 bit per symbol regardless of compression, hence has the same characteristics as other 1 bit/symbol methods [6].

The frequency synthesizer method used is shown in the figures above, where it will be noted that the synthesizer clock and data clock are the same. The IF frequency from the modulation section of the transmitter and to the receiver detector is 32 MHz. This must be mixed to provide a signal at 46 or 49 MHz. Since a frequency of 14 or 17 MHz cannot be used, (lower than the IF frequency) the local oscillator frequency is 32 plus 46/49 MHz, or 78/81 MHz. The synthesizer uses the 32 MHz as a reference and locks a VCO at 78/81 MHz as required.

This synthesizer has spurs and phase noise that would be unacceptable for FCC use on licensed frequencies, but which can be permitted under Part 15, where the rules are more tolerant. The VCO is a part of the NE602 up or down converter, so a separate VCO is not required for the mixers.

Operating under Part 15 of the FCC regulations has many advantages and some disadvantages. The advantage is that unwanted signals need to be suppressed by only 26 dB, thus simplifying filtering. The disadvantage is the low power that is permitted, which limits range. In this narrow band service at 46/49 MHz, VPSK modulation offers the only acceptable means of passing a higher data rate within the allowed bandwidth and is satisfactory at office distances.



■ **Figure 8. VPSK Eb/n for 10-6 BER.**

Figure 8 shows the S/N values required for 10^{-6} BER when using VPSK modulation for various degrees of compression in bits/s/Hz. Unlike the other compression methods, the power required does not increase with compression. Various degrees of compression from 4:1 to 15.3:1 are shown.

Like all compression methods, the required power for VPSK rises with compression, but the decrease in bandwidth using VPSK cancels the power increase. As a result, the required signal strength CNR for VPSK stays the same, regardless of the bandwidth compression ratio. ■

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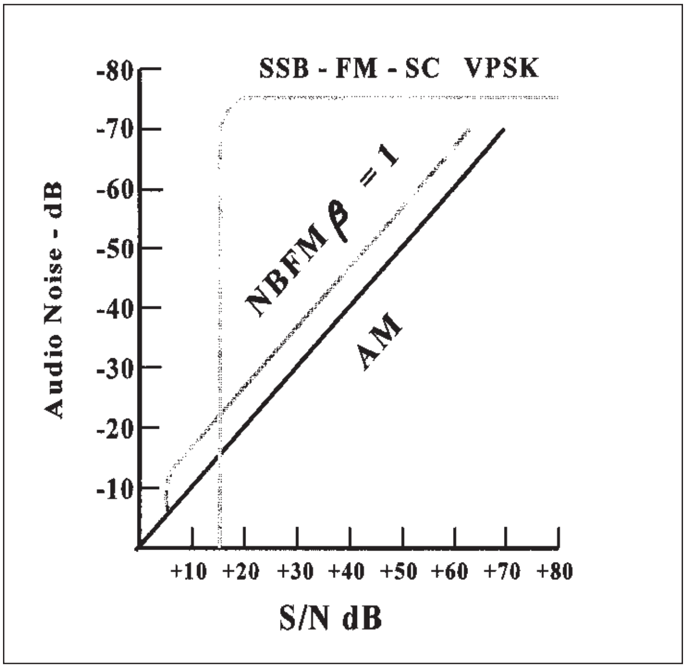

■ **Figure 9. Performance of VPSK vs. FM.**

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