Differential Audio Phase Shift Keying with Phase Transition Shaping

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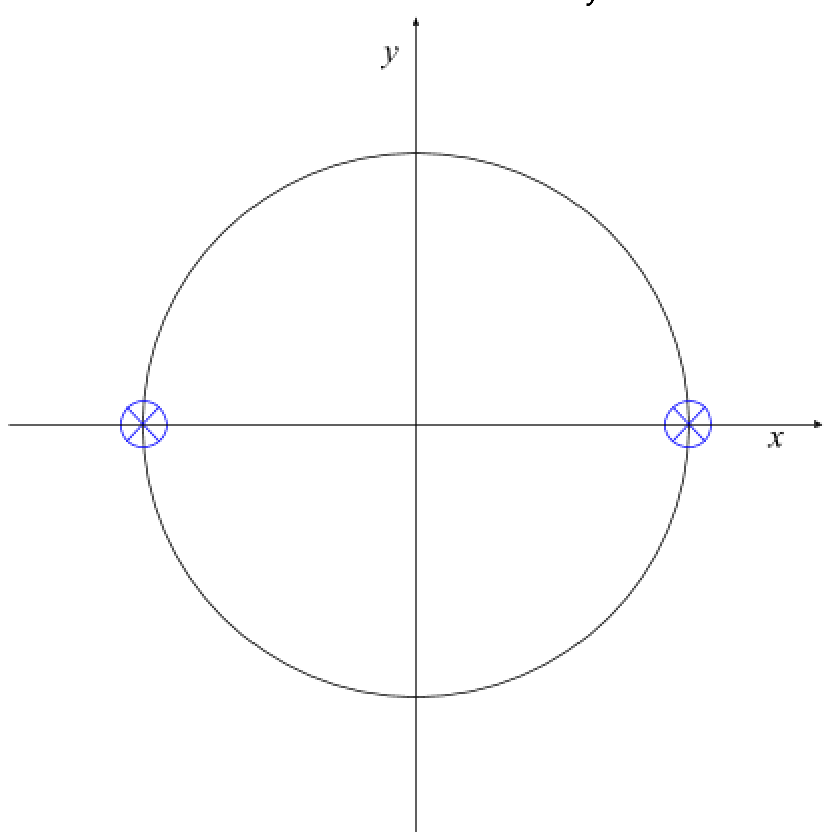
As an alternative to traditional 1200 baud audio frequency shift keying (AFSK), N9600A terminal node controllers also implement a new experimental audio mode capable of 2400 baud. This differential phase-shift key method transmits data by modulating the ***phase*** of a 2400 Hz audio tone. This mode is designed for compatibility with widely available voice-grade VHF and UHF FM communication radios through microphone and speaker connections, made possible by phase transition shaping.

Data Modulation of Audio Tone

Data is modulated onto the audio carrier tone as phase changes. A binary ‘0’ in the data stream is modulated as a 180 degree phase change, and a binary ‘1’ is modulated as no change in phase. One bit of data is encoded per carrier wavelength.

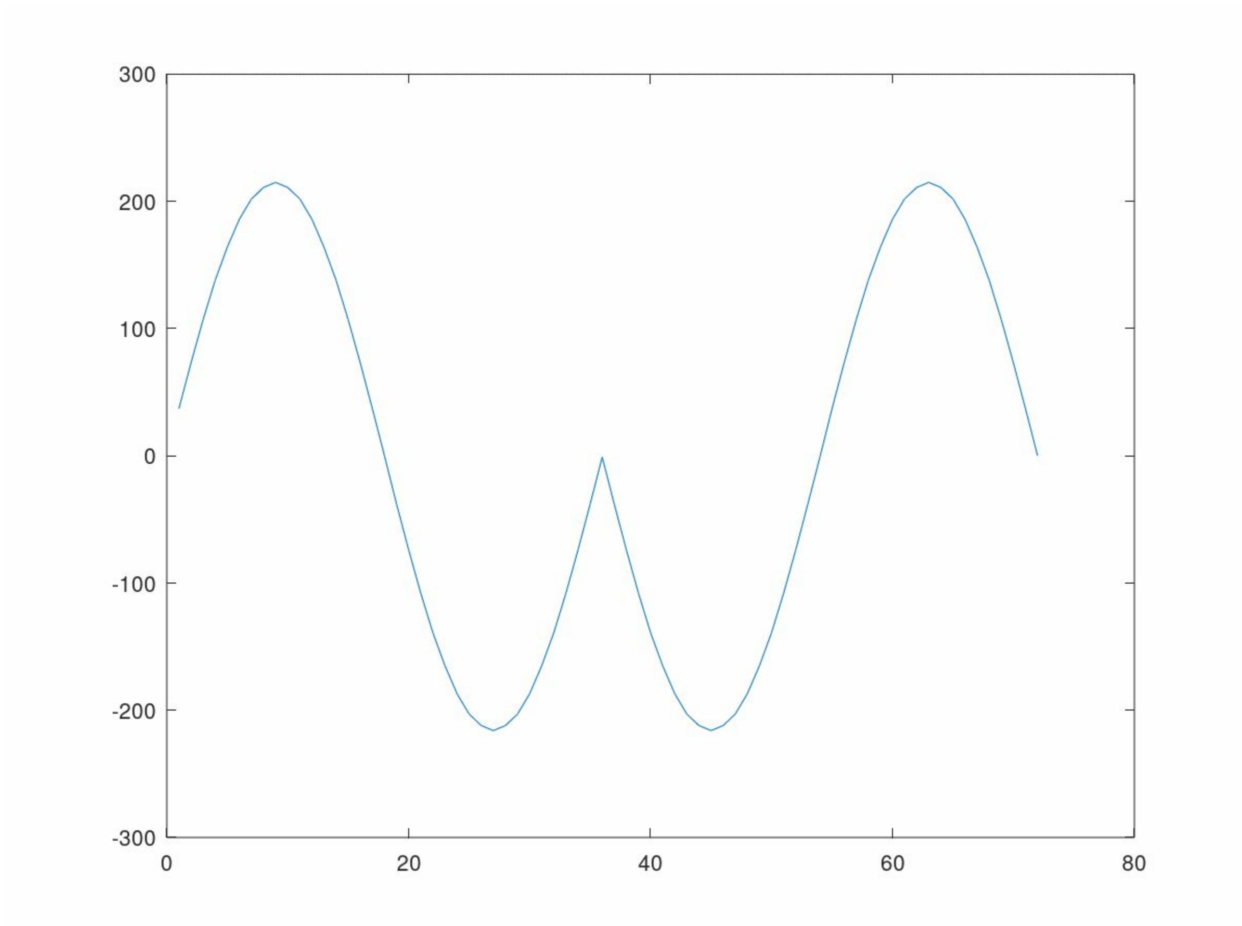
Fig 1. 2400 Baud Differential Audio Phase Shift Key Constellation Diagram



Phase Transition Shaping

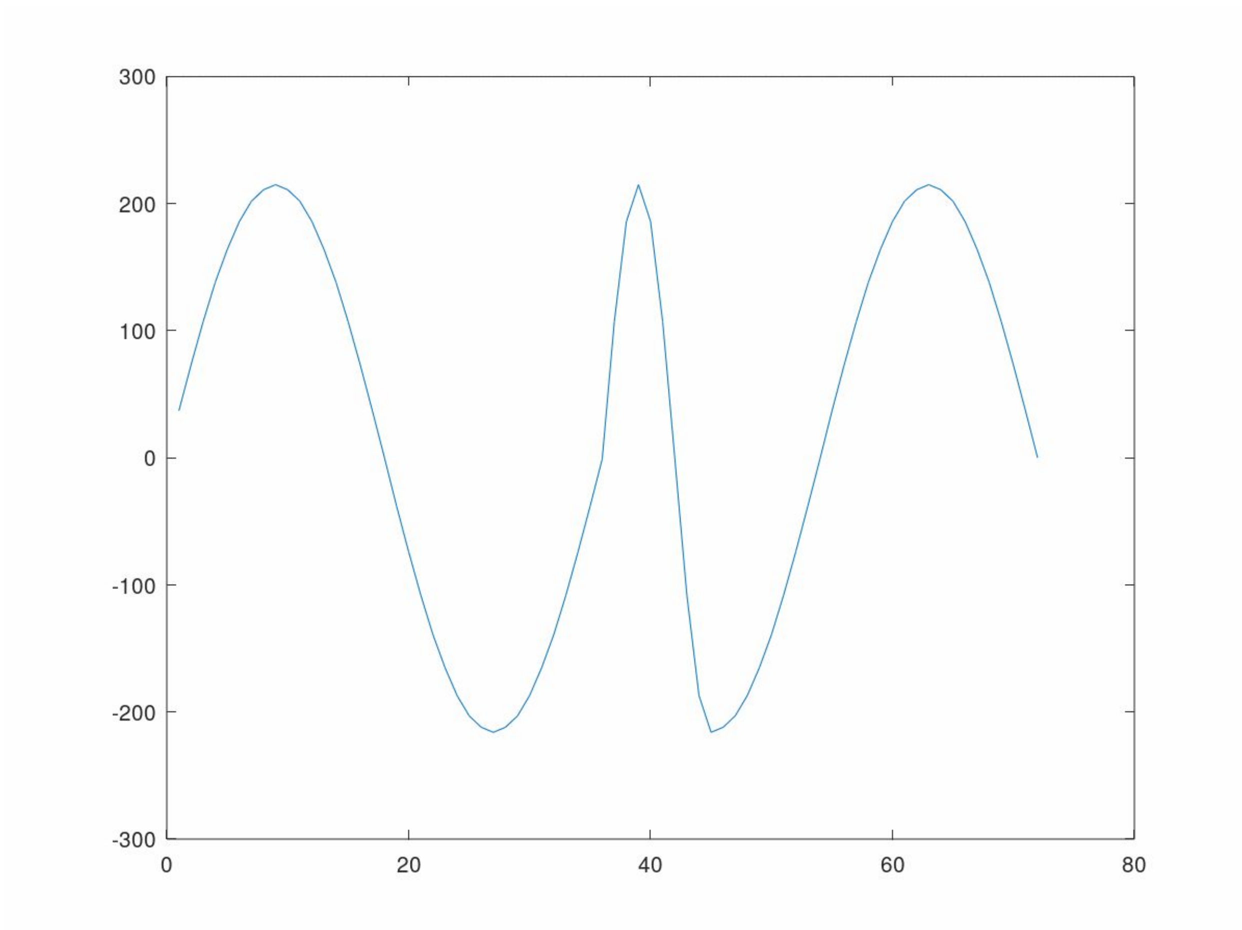
Abrupt phase reversals in a sinusoidal signal introduce asymptotic transitions that are undesirable when that signal is intended for modulation into a voice-band channel. These abrupt phase reversals are band-limited by the low pass filters in the transmit and receive circuitry of voice radios. This can result in large unintended low-frequency distortion, and loss of audio phase information in the recovered signal. Figure 2 shows an unmodified phase reversal in a sinusoidal signal. Note the sharp transition at the midpoint, this is a result of an immediate transition between phase states in the constellation diagram shown in Figure 1. The signal passes through the origin of the unit circle instantly.

Fig 2. Phase Reversal in Sinusoidal Carrier Wave



One way to avoid “passing through the origin” is to deliberately shape the phase transition around the unit circle. This can be accomplished by advancing the phase of the carrier wave through 180 degrees over a fixed amount of time (a fraction of the bit period). This progressive phase change yields a signal that is DC-balanced within each bit period, allowing for effective transmission of information over a bandwidth-limited channel. Figure 3 demonstrates a 180 degree phase advancement over ¼ wavelength of carrier. This can be visualized as a clockwise rotation around the unit circle between phase states, over a fixed amount of time.

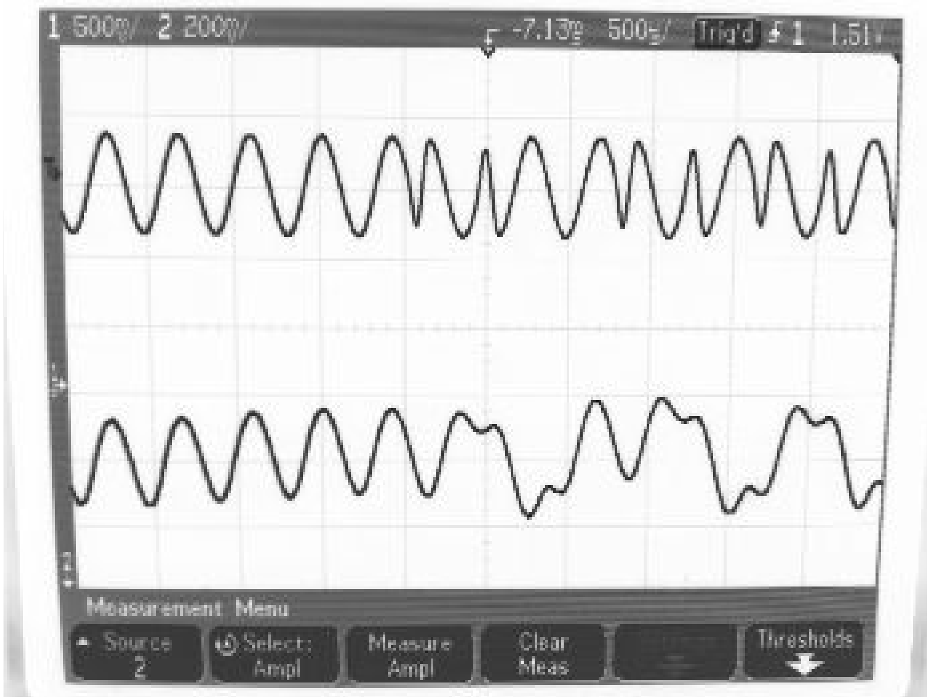
Fig 3. Shaped 180 degree Phase Transition over ¼ Wavelength



The resulting modulated audio signal contains audio components at the carrier frequency and at three times the carrier frequency. In the case of a 2400 Hz carrier, the phase transition frequency is 7200 Hz. The high frequency component is attenuated by the audio channel, without loss of ability to recover payload data. The modulated data is carried by the phase reversal, not the transition frequency.

Figure 4 represents a real-world signal generated by an N9600A3 TNC, transmitted by a Maxon SD-125 UHF transceiver, and received by a Yaesu FT-60R handheld. The top trace is the transmitted signal, the bottom trace is the received signal. Note that this channel appears to introduce about 500uS delay. The high-frequency phase transitions undergo intentional attenuation by the low-pass filtering in the transceiver's audio input. Also, note that the received signal is symmetric around the time axis, which enables very straightforward differential demodulation.

Figure 4. Transmitted and Received Signal over Audio Channel



Differential Demodulation by Bit Delay Multiplication

Data is recovered at the receiver in a straightforward manner. After sampling, filtering, and decimation, the receive processor multiplies the signal by a 1-bit delayed version of the same signal. Assuming the received signal is sampled such that it is centered around 0, and handled as a signed value, then the result of this operation is a positive signal when the phase has not changed and a negative signal when the phase has reversed. Note that this data recovery method also performs differential demodulation in the same step. This processed signal is low-pass filtered, then sliced for clock and data recovery.

References:

General description of phase shift keying theory and techniques:
https://en.wikipedia.org/wiki/Phase-shift_keying accessed 5/31/2020

Demodulation of differential phase shift keying:
https://www.tutorialspoint.com/digital_communication/digital_communication_differential_phase_shift_keying.htm accessed 5/31/2020