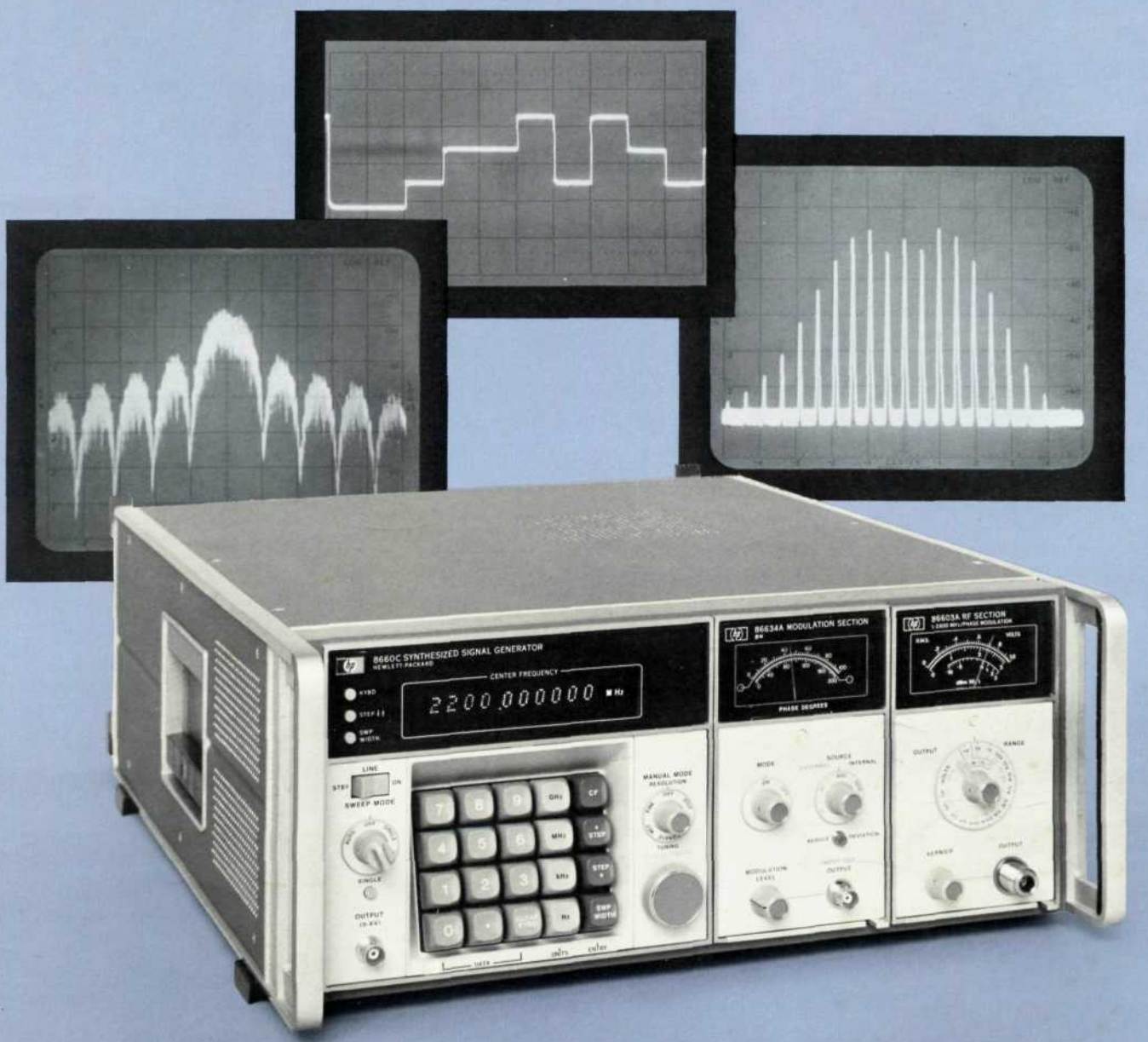
APPLICATION NOTE 164-4

Digital Phase Modulation (PSK) and Wideband FM...

Using the 8660A/C Synthesized Signal Generator



August 1975

HEWLETT hp PACKARD

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Introduction

The HP 8660A/C Synthesized Signal Generator family offers the stability, frequency resolution, and programmability of a synthesizer along with a variety of modulation forms—Pulse Modulation, AM, FM, and Phase Modulation. These features make the 8660A/C an extremely versatile instrument for a wide range of applications.

With phase modulation the 8660A/C offers unique possibilities in the generation of modulation formats that may not be immediately apparent. With either the 86634A or 86635A Modulation Sections and either the 86602B Option 002 or 86603A Option 002 RF Sections, the 8660A/C is capable of high performance phase modulation. The 86634A Modulation Section allows phase modulation at rates from dc to 10 MHz, while the 86635A Modulation Section allows FM as well as phase modulation at rates from dc to 1 MHz. Both modulation sections are capable of deviations up to 100° at output frequencies below 1300 MHz and 200° above 1300 MHz.

This application note illustrates several modulation formats that can be generated with phase modulation—included are digital phase modulation and high rate FM simulation. It also briefly describes how these formats can be generated.

Digital Phase Modulation

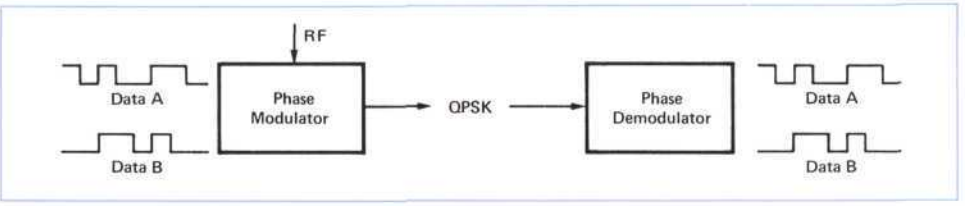


Figure 1. Basic Block Diagram of a Typical QPSK Transmission System.

Digital communication systems are becoming more widely used because of their system versatility and reduced sensitivity to transmission line noise, especially in long transmission systems with numerous regenerative repeaters. Digital phase modulation is gaining in digital communications because in many instances it has better spectral efficiency than other digital modulation methods.

Digital phase modulation, commonly called Phase Shift Keying (PSK) allows only discrete phase angles instead of the continuous functions that occur with analog phase modulation. In phase shift keying the instantaneous phase difference of the modulated carrier with respect to an unmodulated carrier determines the digit being transmitted.

PSK systems usually have 2^n discrete phase states with two-phase (Biphase, BPSK), four phase (Quadraphase, QPSK), eight phase, and sixteen phase being the most common. The greater the number of phase states the greater the information that can be transmitted on a carrier but the lower the noise immunity. Generally, biphase (BPSK) carries one data stream; quadraphase (QPSK) carries two data streams; eight phase carries four data streams; etc.

Usually the phase states are as widely separated as possible in order to reduce noise sensitivity, i.e., 180° separation for BPSK and 90° separations for QPSK (see Figure 2). Other angle separations are quite common though, since those with states 180° opposite each other result in carrier nulls. This increases receiver complexity because the carrier must be regenerated in order to demodulate the PSK signal.

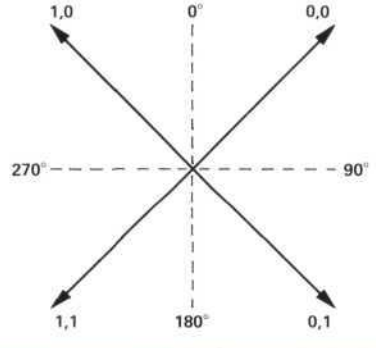


Figure 2. Typical QPSK Phase States.

8660 DIGITAL PHASE MODULATION CAPABILITY

The basic modulation capability of the 8660 has been optimized for accurate, linear, and wideband analog phase modulation. This does not impair its use in digital systems but provides great versatility in generating digital phase modulation—Phase Shift Keying (PSK). By simple signal conditioning between the digital signals and the 8660A/C modulation input, many different variations of digital phase modulation can be generated. Because the actual phase modulator is analog, each discrete phase angle in the generated digital modulation can be chosen to be almost any angle. This provides much greater flexibility than with a completely digital system where phase angles are either fixed or difficult to vary.

When using an 8660A/C for digital phase modulation, all that is necessary is to input the required waveform to the modulation input. This eliminates the problems involved in designing modulation circuits at RF or microwave frequencies. This makes system construction much easier. Also, it is usually easy to change the modulating waveform in order to vary the resulting digital phase modulation format. Since the phase modulation characteristics of the 8660A/C are almost completely independent of carrier frequency, any system assembled would also have great center frequency flexibility.

The phase modulation capability of the 8660A/C allows a wide investigation into unique modulation formats. Because the phase modulation is analog, techniques such as varying the rise and fall times of the data stream, even varying the rise and fall time independently of each other, can be evaluated. Similarly the modulating waveform could be bandwidth limited or otherwise modified. Techniques such as these could be easily evaluated as to their possible effects on bit error rate and transmission bandwidth.

The 8660A/C also offers low incidental AM when used in digital applications. This is a decided advantage over certain techniques where the carrier disappears during switching. When used with certain types of receivers that require a continuous RF signal to maintain lock, a large AM component is extremely undesirable.

Another important consideration in digital applications is the slew rate of the system, how fast the phase can be changed from one state to another. The 8660A/C phase modulation capability is generally not bandwidth limited but rather slew rate limited. The 86634A offers slew rates in excess of 1.2×10^4 degrees/μs (see Table 1).

Table 1. 8660A/C Phase Modulation Slew Rate.

Modulation Section	Slew Rate	
	Carrier <1300 MHz	Carrier >1300 MHz
86634A	>6.3 x 10^3 deg/μs	>1.26 x 10^4 deg/μs
86635A	>6.3 x 10^2 deg/μs	>1.26 v 10^3 deg/μs

BIPHASE MODULATION (BPSK)

As previously described, BPSK is digital phase modulation with two discrete phase states. To generate BPSK all that is necessary is to drive the 8660A/C modulation input with the desired bit stream at the required peak-to-peak voltage level.

At RF frequencies below 1300 MHz, peak phase deviations of ±100° are possible; this represents a total range of 200°. At RF frequencies above 1300 MHz maximum peak deviation is increased to ±200° for a total range of 400°. A data stream that is symmetrical with respect to ground can thus use the total possible phase deviation while a data stream with one level at ground would have one half of the total possible range. These phase swings are more than adequate for BPSK where 180° shifts are usually the maximum used.

Setting Phase Deviations

The modulation meters on the 86634A and 86635A modulation sections are peak responding and sample the most negative portions of the waveform. The meters are calibrated to indicate the peak deviation. For data streams that are symmetrical with respect to ground the meters read one half of the phase shift between states. For data streams that vary between ground and a negative voltage, the phase shift between states is directly indicated on the meter.

For positive going and non-symmetrical data streams, it is still possible to use the modulation meter to calibrate phase states if the data stream has constant bit width and equal numbers of ones and zeros. The phase shift between states can be set by temporarily switching the modulation mode to External ac while adjusting the phase shift. This has the effect of eliminating any dc component in the waveform and essentially converts the waveform to a symmetrical one for setting the phase deviation. The modulation meter then indicates one half of the peak-to-peak deviation. This is effective for all but the slowest clock rates.

If more accuracy is desired when 180° shifts are used, a bit pattern of alternating ones and zeros can be used and the modulation level adjusted for a carrier null by monitoring the output on a spectrum analyzer (see Figure 3).

The best 8660A/C phase modulation frequency response is obtained with the modulation level vernier set at its maximum clockwise position (maximum sensitivity). When operating at high bit rates it is desirable to set the modulation level vernier at its maximum position and set the phase deviation by adjusting the input level of the data stream.

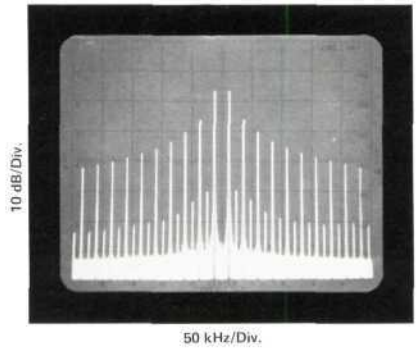


Figure 3. >50-dB Carrier Null With 180° Phase Shift and Square-Wave Modulation.

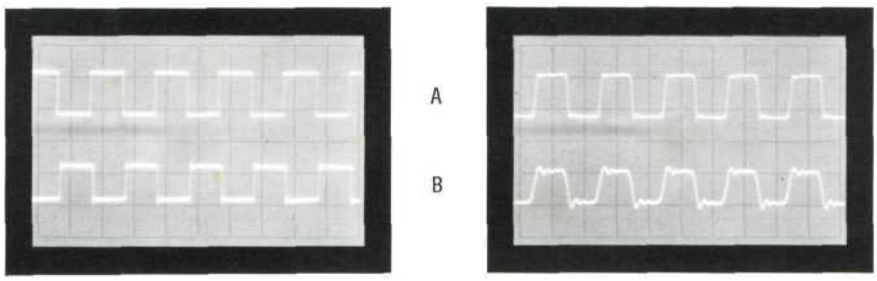


Figure 4. Modulation Section Input (A) and Demodulated Output (B) When Modulating at 1 Mbit Rate BPSK.

Figure 5. Modulation Section Input (A) and Demodulated Output (B) When Modulating at 10 Mbit Rate BPSK. Note Ringing That Can be Eliminated With Filtering (see Page 6).

BPSK Performance

Figures 4 through 7 indicate the type of performance that can be expected when using the 8660 to generate BPSK.

With BPSK phase angles of 0° and 180° the carrier is nulled. In order to detect the data stream the receiver must be able to regenerate the carrier. This is often done by passing the signal through a frequency doubler which results in a signal with phase angles of 0° and 360°, a constant phase signal. This signal is filtered and its frequency divided by two, thus regenerating the carrier.

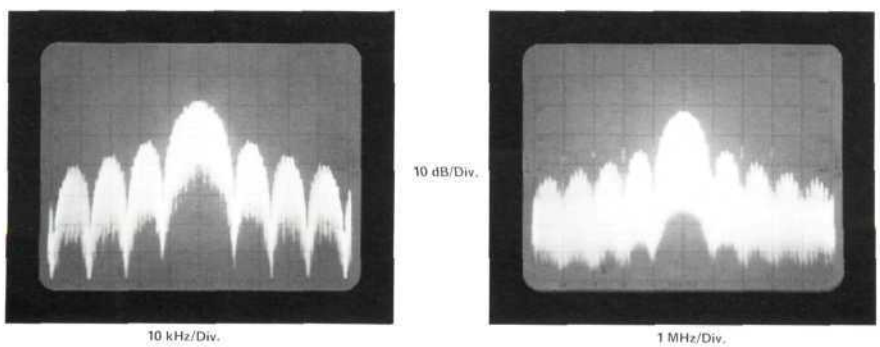


Figure 6. RF Spectrum at 1.5 GHz With $\Delta\phi$=180°, 12 kbit/s Pseudo-Random Bit Stream BPSK.

Figure 7. RF Spectrum at 1.5 GHz With $\Delta\phi$=180°, 1 Mbit/s Pseudo-Random Bit Stream BPSK.

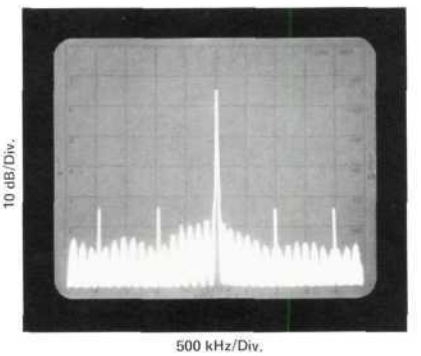


Figure 8. RF Spectrum of 1 Mbit/s Pseudo-Random BPSK Signal After Passing Through a Frequency Doubler.

A measure of the quality of the BPSK is the level of the resulting carrier above the noise (see Figure 8).

Short rise times can possibly cause ringing in 86634A modulation plug-ins. This effect can be minimized by reducing the level of modulation input components above 40 MHz by using longer rise times or low-pass filters before the modulation input.

QUADRAPHASE SHIFT KEYING (QPSK)

QPSK is only slightly more difficult to produce than biphase modulation (BPSK). To generate QPSK with an 8660A/C the input must be converted into a four-level signal. A simple circuit such as that shown in Figure 9 can be used to generate a four-level signal from two TTL data lines. A circuit such as this has the advantage of great flexibility because all phase states can be independently set.

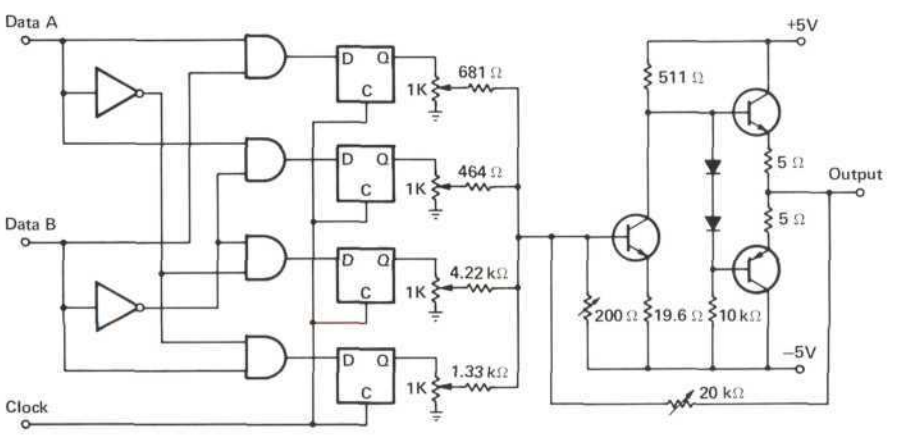


Figure 9. Circuit for Generating a Four-Level Signal from Two TTL Data Lines.

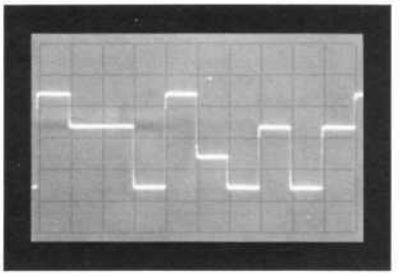


Figure 10. Four-Level Signal Used to Generate QPSK.

If phase states with 90° separation are desired a peak phase deviation of 135° is required. This amount of phase deviation is well within the specified deviation range for the 8660A/C above 1300 MHz and can typically be attained by overdriving the modulation section for frequencies below 1300 MHz.

Setting Phase Deviations

Setting the phase states for QPSK is more difficult than for BPSK. Several techniques are available, though. One method that gives reasonably accurate results is to use dc coupling and adjust the input waveform to be symmetrical with respect to ground and then use the modulation meter on the 8660A/C to determine the total phase shift from the peak negative shift the meter indicates.

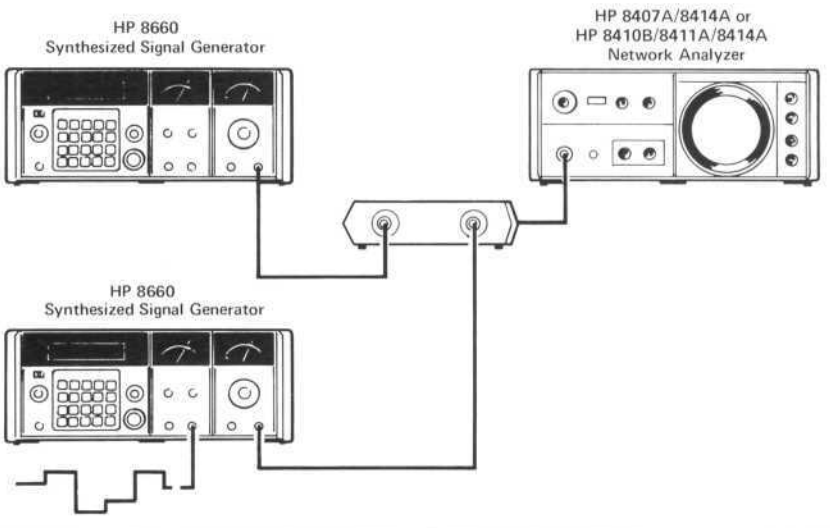


Figure 11. Using a Network Analyzer to Set Phase States for QPSK.

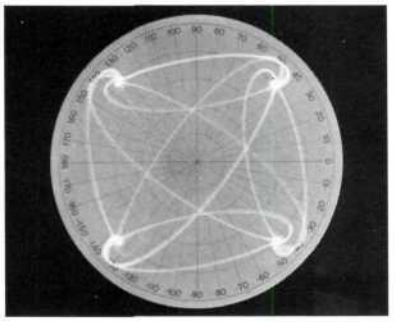


Figure 12. Network Analyzer Display for 90° Separation QPSK. The Trace Passes Through Center of Display Due to the Bandwidth of the Network Analyzer.

For greater accuracy a calibrated phase detector or a technique such as that shown in Figure 11 could be used. This technique involves the use of a second synthesizer and a network analyzer. The two synthesizers are connected to the same reference and set to the same output frequency. The network analyzer then indicates the relative phase and amplitude of the two signals. When one 8660 is phase modulated with a four-level signal the relative phase states are indicated on the network analyzer display (see Figure 12). When using a network analyzer the clock rate must be slow enough to accommodate the bandwidth of the network analyzer, usually 5 kHz or less.

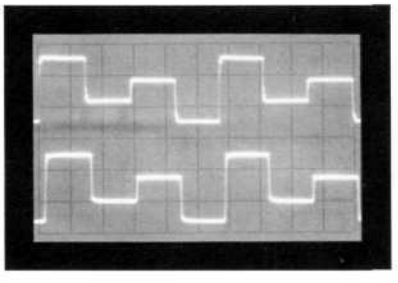


Figure 13. Modulation Section Input (A) and Demodulated Output (B) at 1.5-MHz Clock Rate QPSK.

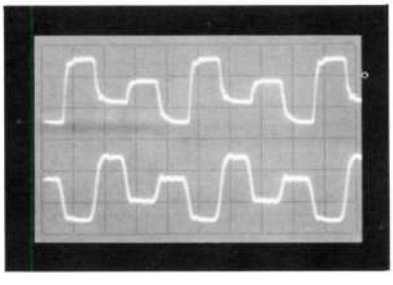


Figure 14. Modulation Section Input (A) and Demodulated Output (B) at 10-MHz Clock Rate QPSK.

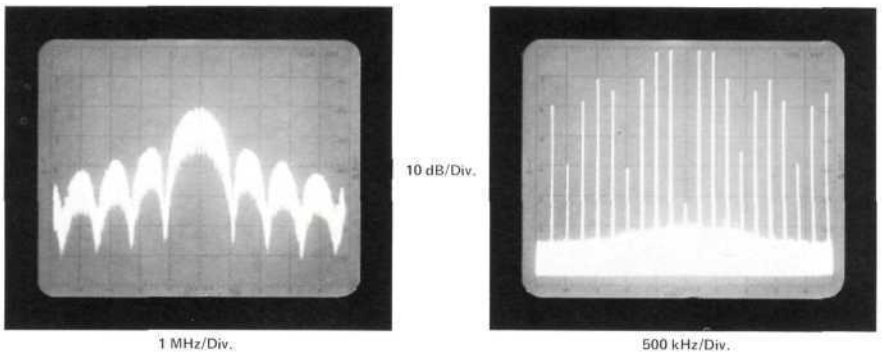


Figure 15. RF Spectrum at 1.5 GHz With $\Delta\phi=90°$, 2 Mbit/s Pseudo-Random Bit Stream QPSK.

Figure 16. >50 dB Carrier Null With Repetitive QPSK Bit Pattern at 90° Phase Shift and 1-MHz Clock Rate.

QPSK Performance

Figures 13 through 16 indicate the type of performance that has been obtained using the 8660A/C to generate QPSK. The simple circuit shown in Figure 9 was used in generating these pictures.

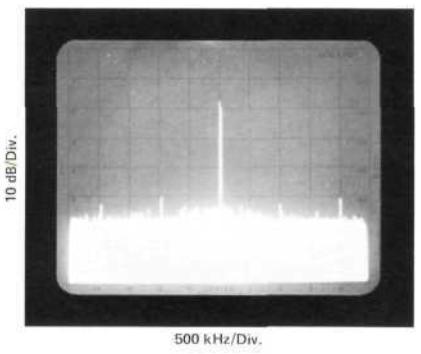


Figure 17. RF Spectrum of 2 Mbit/s Pseudo-Random QPSK Signal After Passing Through a 4X Frequency Multiplier.

High Rate FM Simulation

The 8660A/C is capable of producing low distortion FM directly using the FM modulation mode. There are applications that require rates and deviations that exceed the capabilities of the 8660A/C and most other signal generators. For many of these applications phase modulation can be used to simulate FM. With ϕM rates up to 10 MHz, the 8660A/C offers much higher rates and deviations than might otherwise be possible.

Phase modulation is very similar to FM. A carrier modulated with a sine wave of constant frequency will have the same resultant signal properties (i.e., the same spectrum display) for frequency and phase modulation when the modulation indices are the same. It is impossible when modulating with a single tone to distinguish between FM and ϕM without a direct comparison of the signal to the modulating wave in the time domain.

This great similarity between ϕM and FM allows the use of the 8660A/C with phase modulation to simulate high rate FM. The difference between the two is primarily the effect modulation rate has on the modulation index for a constant amplitude modulating signal. The modulation index is independent of rate in ϕM, while it varies inversely with rate for FM. ϕM, then, appears like 6 dB/octave pre-emphasized FM. For tests requiring an FM signal with 6 dB/octave pre-emphasis, phase modulation offers the advantage of requiring no special shaping network.

When multi-tone FM without pre-emphasis is desired, a 6 dB/octave de-emphasis network applied to the modulating signal is generally all that is necessary so that ϕM can simulate FM.

Possible Rates and Deviations

In order to use ϕM to simulate single-tone FM it is only necessary to convert the desired peak frequency deviation to its corresponding peak phase deviation. This can be accomplished by calculating the appropriate peak deviations using the formula:

$$\Delta\phi_{\text{peak in degrees}} = \frac{180}{\pi} \quad \frac{\Delta f_{\text{peak}}}{f_m}$$

Rates to 10 MHz can be simulated with the 86634A Modulation Section. Peak frequency deviations of up to 35 MHz can be obtained depending on what modulation rate and carrier frequency are used (see Figure 18).

For example, at a 2.2 GHz center frequency and 8 MHz modulation *rate, deviations* to 27.9 MHz are possible. For a desired FM signal at a 10 MHz rate and a 25 MHz deviation, the 86634A Modulation Section would have to be driven with a 10 MHz signal and the modulation level adjusted for a peak phase deviation of 143°.

$$\Delta\phi = \frac{180}{\pi} \quad \frac{\Delta f_{\text{peak}}}{f_m} = \frac{180}{\pi} \quad \frac{25\ \text{MHz}}{10\ \text{MHz}} = 143^\circ$$

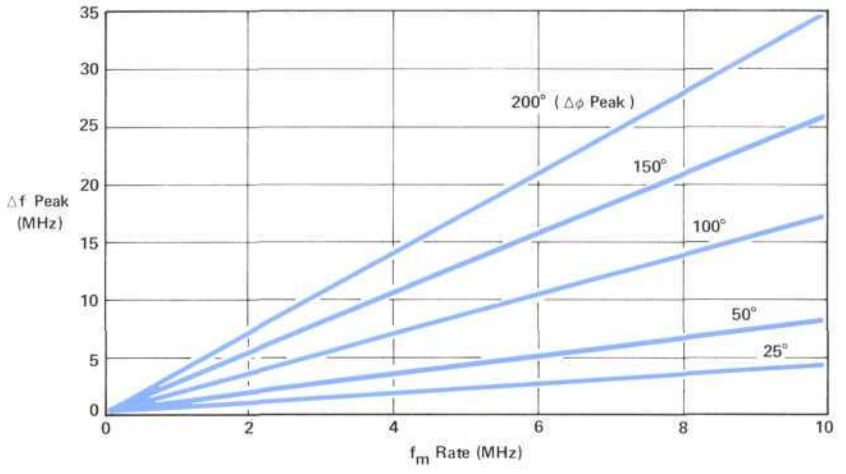


Figure 18. Chart for Converting Peak Frequency Deviation and Rate to the Required Peak Phase Deviation.

Distortion Considerations

When using ϕM to simulate FM, a direct conversion of ϕM distortion specifications to corresponding simulated FM distortion performance cannot be made. This occurs because with constant peak phase deviation the output amplitude of a phase demodulator is independent of rate, while the output amplitude of an FM demodulator is proportional to rate. Thus, when the demodulated output from an FM demodulator is compared with that of a phase demodulator with identical input signals the ratio of fundamental to second harmonic would be 6 dB higher, the 3rd would be 9 dB higher, the 4th would be 12 dB higher, etc. Thus, any conversion from ϕM specifications to the corresponding simulated FM performance would depend on the relative levels of each harmonic. Since higher order distortion products decrease in amplitude quite rapidly as phase deviation is decreased, the lower the phase deviations the better the simulated FM distortion performance. For deviations of 80 percent of full scale or less total harmonic distortion is typically less than 10 percent at 10 MHz. At lower rates distortion is further improved.

Conclusion

Calibrated, analog phase modulation offers great flexibility in the generation of Phase Shift Keying and can be used to simulate high rate frequency modulation.

The applications described here only indicate possible areas where phase modulation is useful. A great number of variations and modifications are possible depending on the needs of any particular application. The relative ease of modifying a modulation format is one of the advantages that the 8660A/C Synthesized Signal Generator offers in these applications. The greatest advantage that the 8660A/C offers, though, is that it is a general purpose piece of test equipment and not a dedicated instrument. This makes it useful in an extremely wide range of applications besides those described.

For more application information on the uses of phase modulation refer to AN 164-3 "New Techniques for Analyzing Phase Lock Loops."



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