ılation
ɪre Modulation
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lulation

ʒnals and Quadrature

Demodulation

ınd why they are advantageous in RF systems.

ɔage on quadrature demodulation. However, before we explore
riefly discuss quadrature modulation. And before we discuss
I/Q signals.

The term “I/Q” is an abbreviation for “in-phase” and “quadrature.” Unfortunately, we already have a terminology problem. First of all, “in-phase” and “quadrature” have no meaning on their own; phase is relative, and something can only be “in phase” or “out of phase” with reference to another signal or an established reference point. Furthermore, we now have the word “quadrature” applied to both a signal and the modulation/demodulation techniques associated with that signal.

In any event, “in-phase” and “quadrature” refer to two sinusoids that have the same frequency and are 90° out of phase. By convention, the I signal is a cosine waveform, and the Q signal is a sine waveform. As you know, a sine wave (without any additional phase) is shifted by 90° relative to a cosine wave. Another way to express this is that the sine and cosine waves are *in quadrature*.

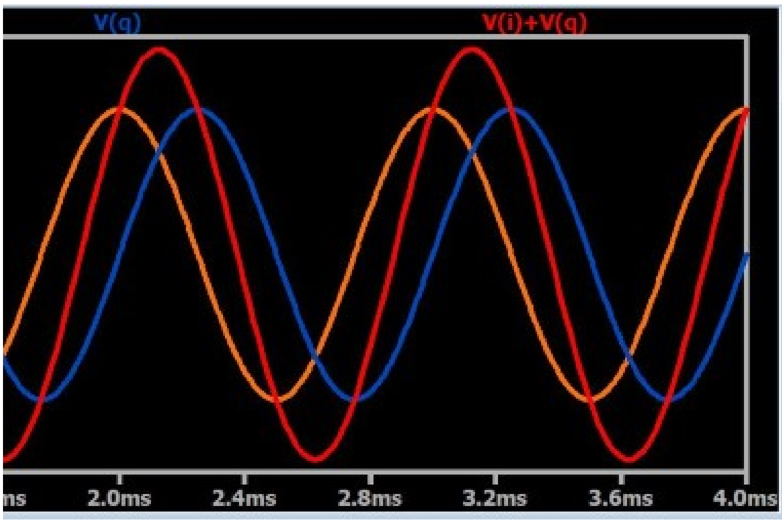
The first thing to understand about I/Q signals is that they are always amplitude-modulated, not frequency- or phase-modulated. However, I/Q amplitude modulation is different from the AM technique discussed in Chapter 4: in an I/Q modulator, the signals that modulate the I/Q sinusoids are not shifted such that they are always positive. In other words, I/Q modulation involves multiplying I/Q waveforms by modulating signals that can have negative voltage values, and consequently the “amplitude” modulation can result in a 180° phase shift. Later in this page we’ll explore this issue in more detail.

What is so advantageous about amplitude-modulating two sinusoids that are 90° out of phase? Why are I/Q modulation and demodulation so widespread? Read on.

Summing I and Q

I and Q signals on their own are not very interesting. The interesting thing happens when I and Q waveforms
tion can be performed simply by varying the amplitude—only
ding them together.

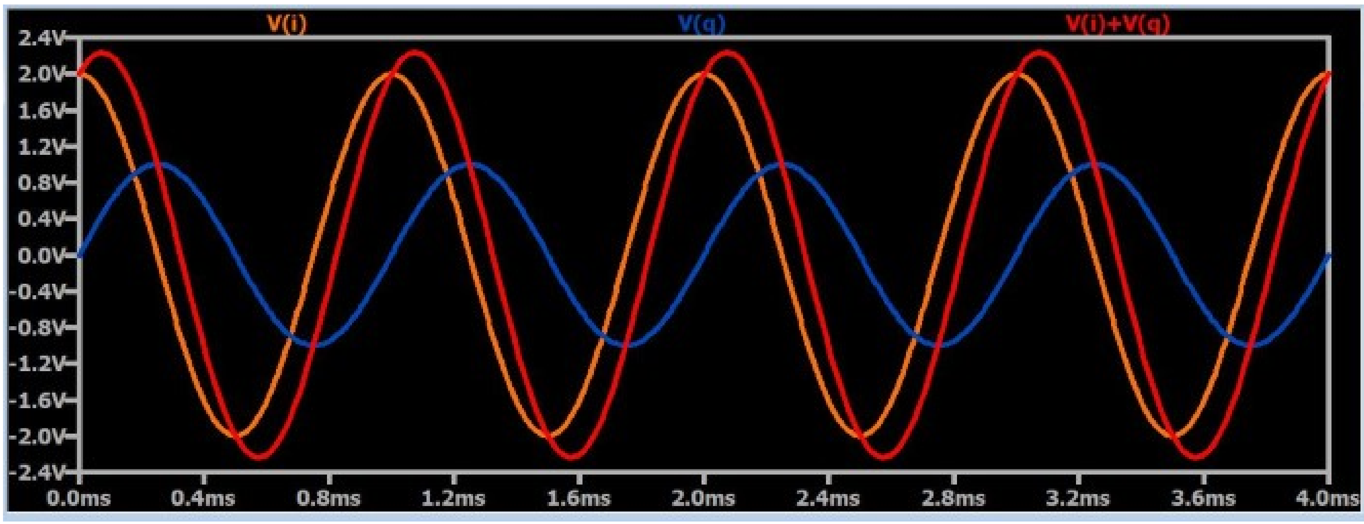
ınd add them, the result is a sinusoid with a phase that is exactly
of the Q signal.

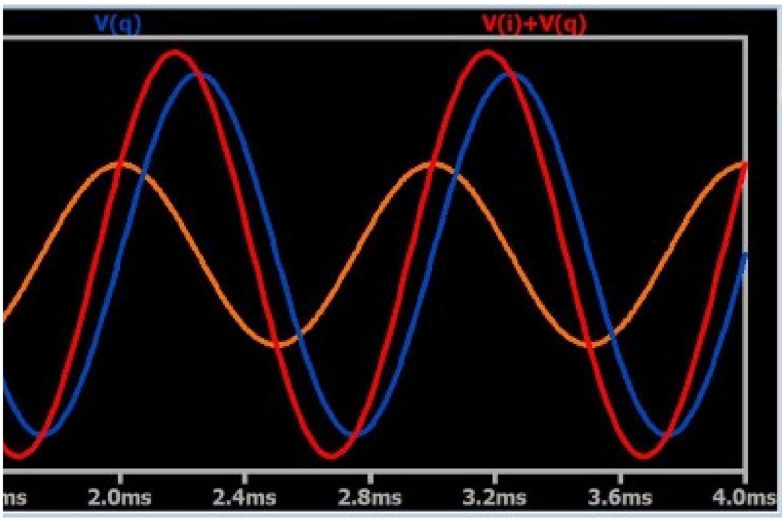


to have a phase of 0° and the Q waveform to have a phase of
45°. If you want to use these I and Q signals to create an
nplitude modulate the individual I and Q signals. Obviously a
it is created by adding together two signals that are both
wever, you must ensure that the amplitude modulation applied to
ıtion applied to the Q signal, because if they are not identical,
the next property of I/Q signaling.

From Amplitude to Phase

Phase modulation, in the form of phase shift keying, is an important technique in modern RF systems, and phase modulation can be conveniently achieved by varying the *amplitude* of I/Q signals. Consider the following plots:

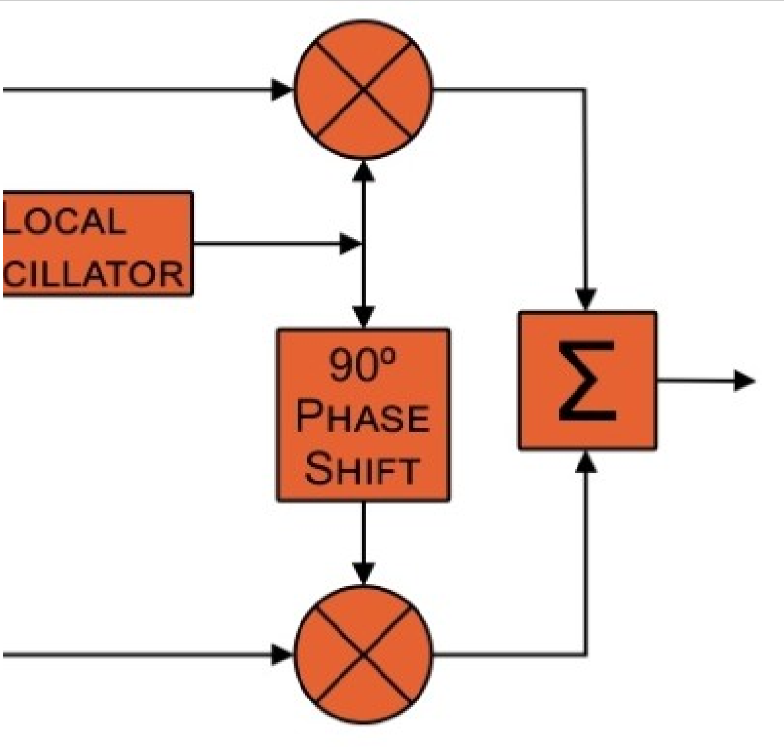




e of the waveforms relative to the other causes the summation
/eform. This makes intuitive sense: if you eliminated the Q
shift all the way over to the phase of the I waveform, because
result in a summation signal that is identical to the I waveform.

/Q signaling can only be used to shift a signal 90° (i.e., 45° in
o zero, the summation goes all the way to the I phase; if the I
oes all the way to the Q phase. How, then, could we use I/Q
e shift keying (QPSK), which uses phase values covering a range

The term "quadrature modulation" refers to modulation that is based on the summation of two signals that are in quadrature. In other words, it is I/Q-signal-based modulation. We'll use QPSK as an example of how quadrature modulation works, and in the process we'll see how amplitude modulation of I/Q signals can produce phase shifts beyond 90°.



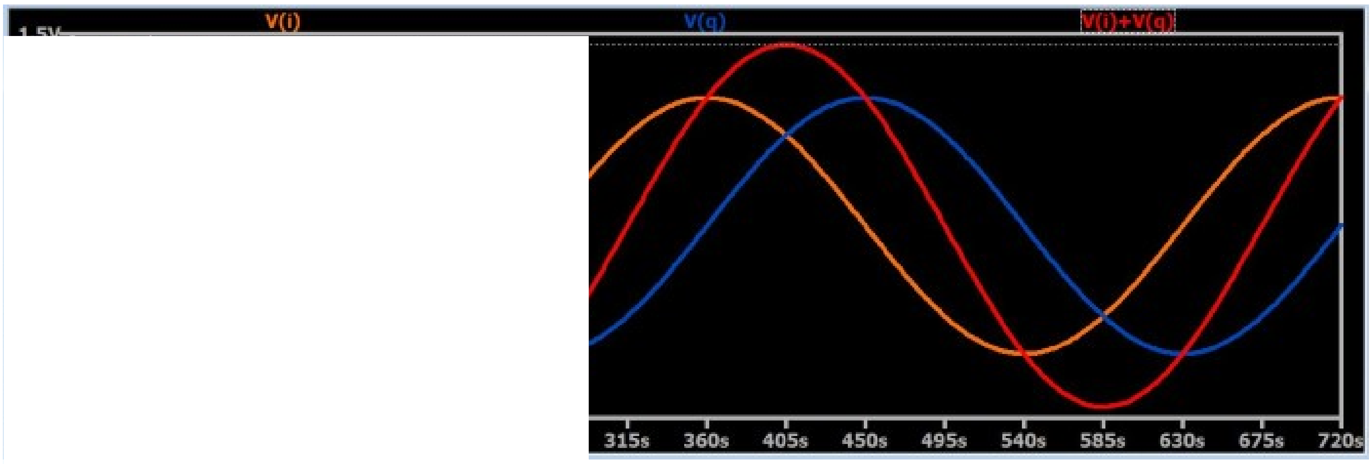
ulator. First, the digital data stream is processed so that two
ı of these bits will be transmitted simultaneously; in other words,
ımbol to transfer two bits. The local oscillator generates the
lf becomes the I carrier, and a 90° phase shift is applied to create
d by the I and Q data streams, and the two signals resulting from
ie QPSK-modulated waveform.

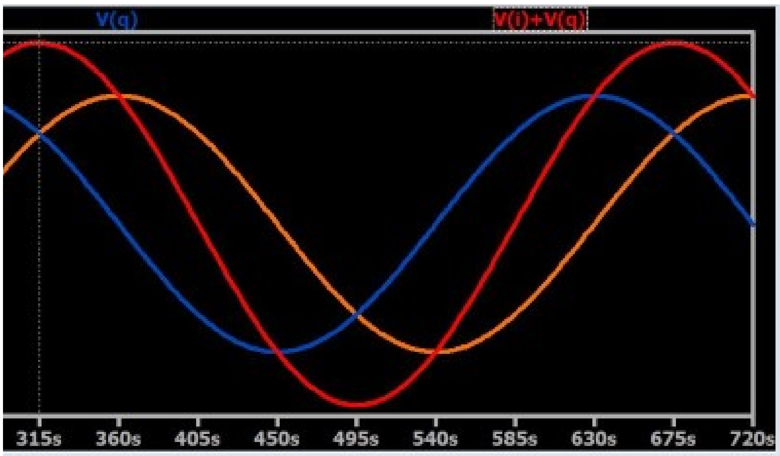
ating the I and Q carriers, and as explained above, these
to produce phase modulation in the final signal. If the I and Q
ling from ground to some positive voltage, we would be applying
on-off keying to the I and Q carriers, and our phase shift would be restricted to 45° in either direction. However, if the I and Q data streams are *bipolar* signals—i.e., if they swing between a negative voltage and a positive voltage—our "amplitude modulation" is actually inverting the carrier whenever the input data is logic low (because the negative input voltage multiplied by the carrier results in inversion). This means that we will have four I/Q states:

- I normal and Q normal
- I normal and Q inverted
- I inverted and Q normal
- I inverted and Q inverted

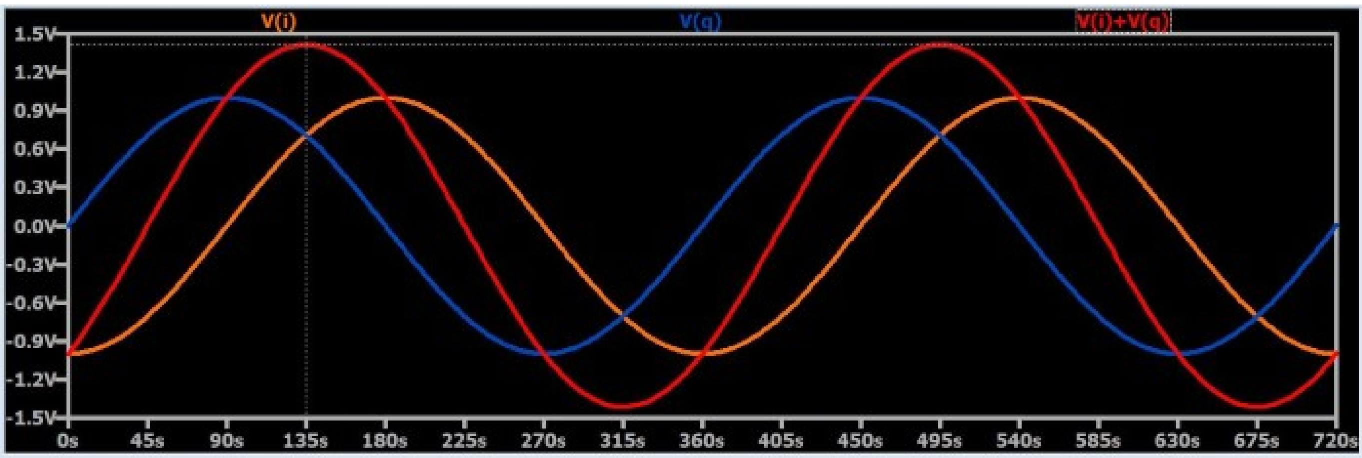
What will summation produce in each of these cases? (Note that in the following plots the frequency of the waveforms is chosen such that the number of seconds on the x-axis is the same as the phase shift in degrees.)

I Normal and Q Normal

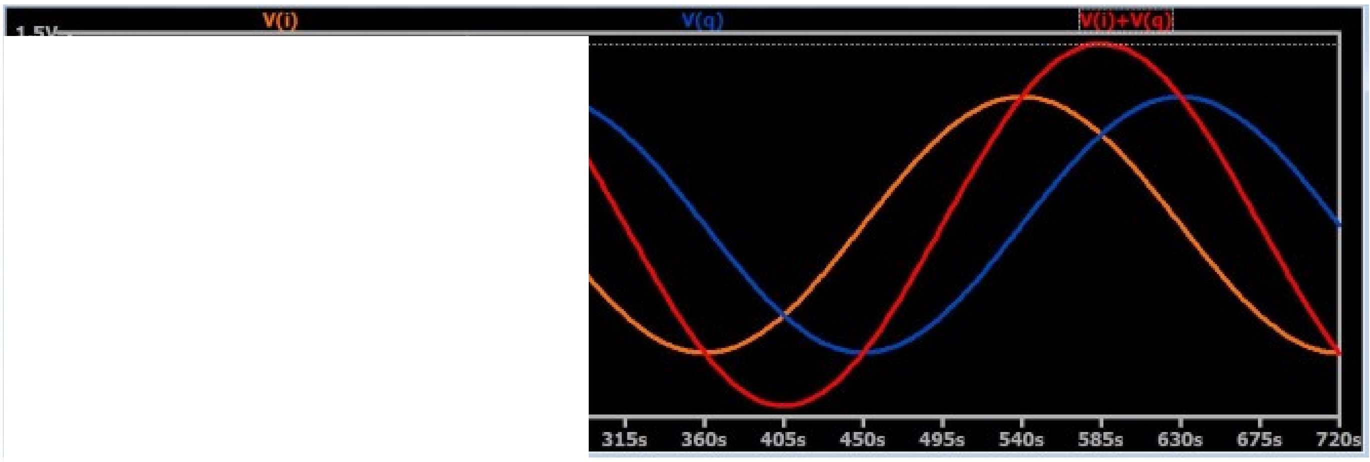




I Inverted and Q Normal



I Inverted and Q Inverted



produces exactly what we want to have in a QPSK signal: phase

usoids that have the same frequency and a relative phase shift of

ation can be performed by summing amplitude-modulated I/Q

ion that involves I/Q signals.
omplished by adding I and Q carriers that have been individually
ing digital data, by +1 or –1.

lation

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