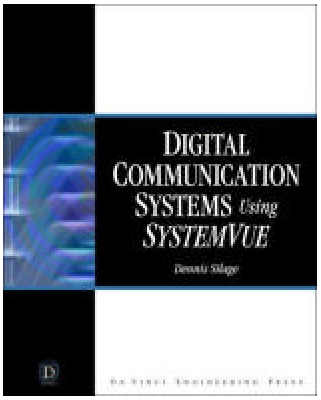
Bandpass Sampling of QPSK in *SystemVue*



Bandpass sampling of a QPSK signal can be demonstrated with the *SystemVue* model shown in Figure 1. The carrier frequency is 29.000 MHz, the data rate r_b = 56 kb/sec and the system sampling rate is f_{sys} = 560 kHz. The bandwidth of this QPSK signal contains 95% of the total power in $2/T_b = 2r_b$ = 2(56 kHz) = 112 kHz (see Table 3.10, page 191).

For this 95% bandwidth the lower frequency f_L = 29.0 – 0.056 = 28.844 MHz and the upper frequency f_H = 29.0 + 0.056 = 29.056 MHz. Bandpass sampling would occur for $f_s = 2(f_H - f_L)$ = 2(112) kHz = 224 kHz and 560 kHz is used here for convenience in decimation and data bit correlation for the bit error rate (BER) with a delay.

The transmitter amplitude is $A = 5/\sqrt{2}$ V = 3.536 V and $E_b = A^2 T_b = (5/\sqrt{2})^2 \times$ (1/56 000) = 2.232 × 10^{-4} V^2-sec.

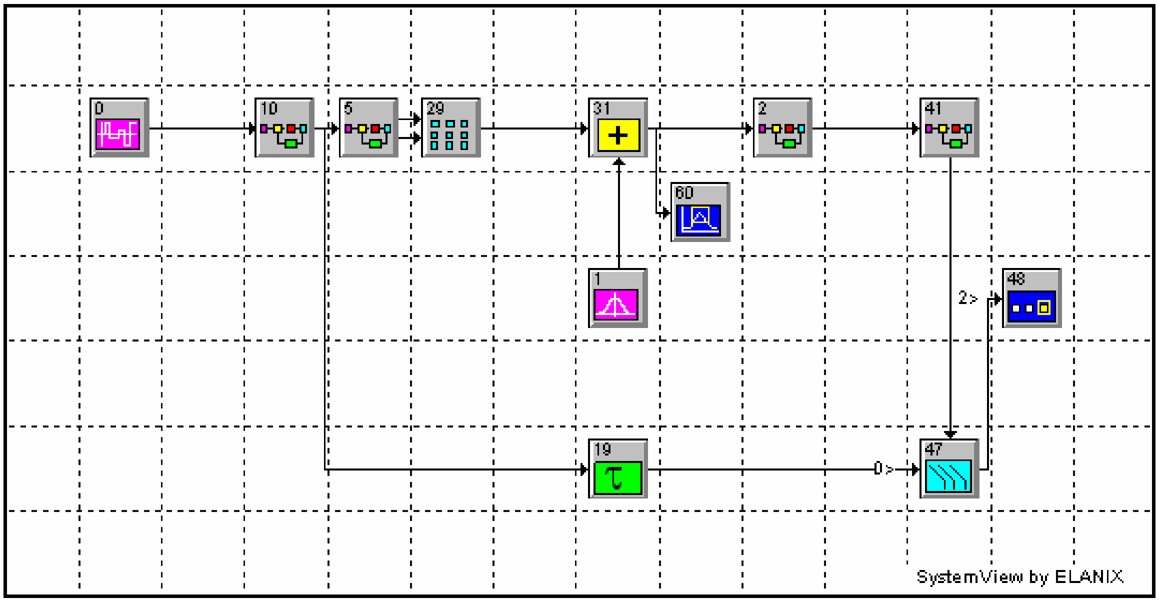


Figure 1

The normalized power spectral density (PSD) is obtained with 1 048 576 (2^{20}) system sample points for a spectral resolution of approximately 0.5 Hz. If conventional simulation system sampling was used a reasonable rate would be 480 MHz (×20 the nominal maximum frequency of the QPSK signal here or 20 × 29 MHz). To obtain a PSD with less than 1 Hz resolution would require over 5.36

× 10^8 points or a simulation that would be over 500 times as long. The resulting PSD using bandpass sampling is shown in Figure 2.

The center frequency of the bandpass sampling PSD is (as expected) f_{alias} = 120 KHz. This is due to aliasing because 52 × 560 kHz = 29.120 MHz and the difference between the nominal center frequency of the QPSK signal here (29 MHz) and 29.120 MHz is 120 KHz. Note that the spectral nulls appear at $f_{alias} \pm r_b/2$ = 120 ± 28 kHz = 92 kHz and 148 kHz as predicted.

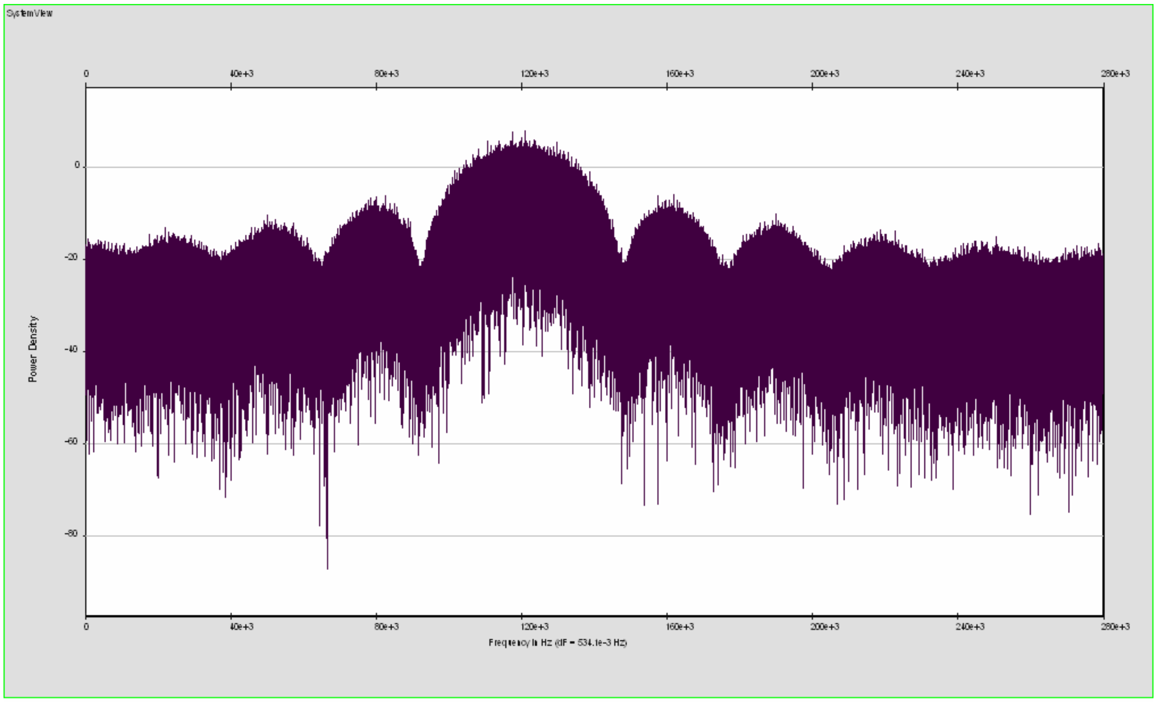


Figure 3

The decimator in the first MetaSystem of the transmitter, as shown in Figure 4, divides by 10 to reduce the sampling of the data at the system rate f_{sys} = 560 kHz then to one sampling point at the data rate r_b = 56 kb/sec (560 kHz/10). The symbol rate r_s = 28 ksymbols/sec and the data is Gray-encoded to improve the bit error performance.

The second MetaSystem in the transmitter and the AWGN channel are unchanged. The first MetaSystem of the receiver is the correlation receiver, as shown in Figure 5. The coherent sinusoidal reference signals are at 29 MHz has the same amplitude of A = 5/v2 V = 3.536 V as the transmitter amplitude.

The decimator in the second MetaSystem of the receiver, as shown in Figure 6, divides by 20 to reduce the sampling of the symbols at the system rate f_{sys} = 560 kHz then to one sampling point at the symbol rate r_s = 28 ksymbols/sec (560 kHz/20). The output data rate of this second MetaSystem is 56 kb/sec (2 bits/symbol) and the symbols are Gray-decoded.

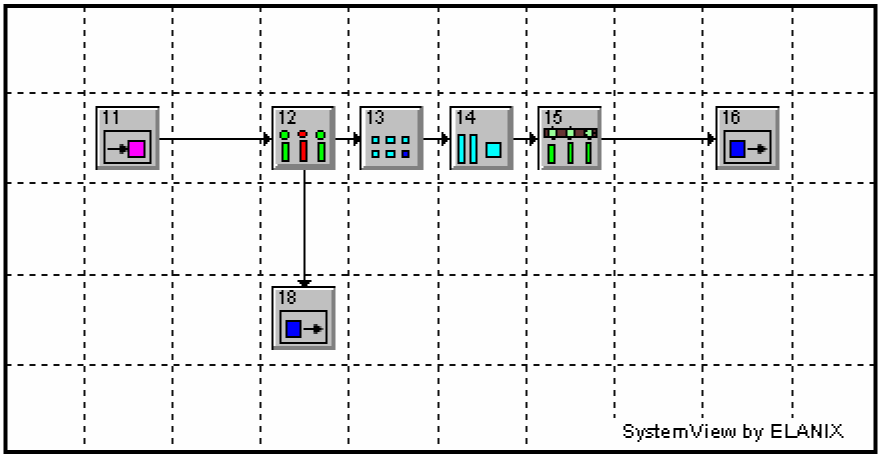


Figure 4

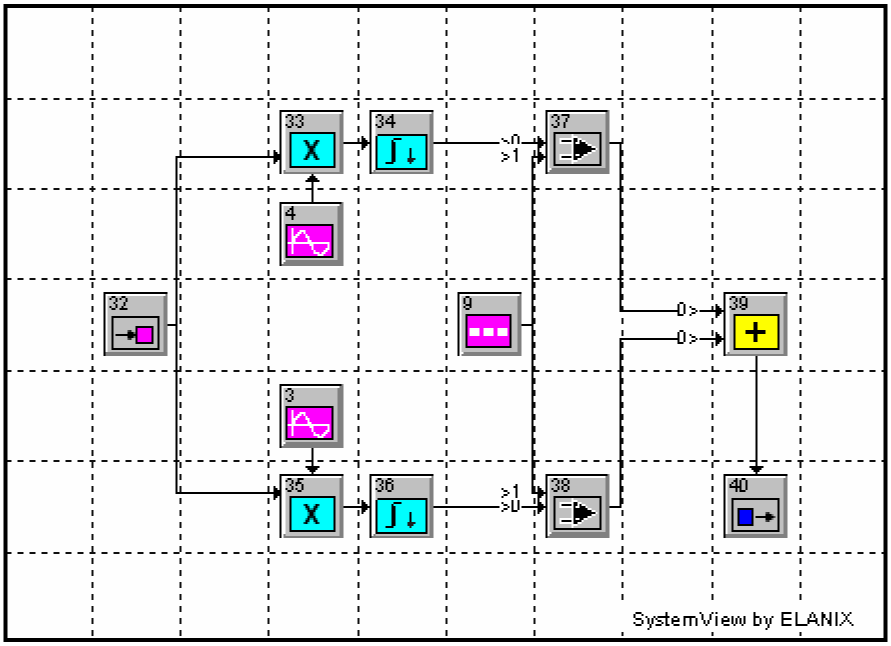


Figure 5

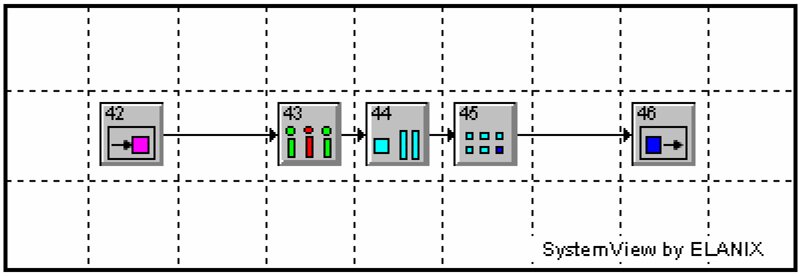


Figure 6

The BER) measurement is performed with a delay of 142.875 µsec (8 bits at 56 kb/sec) for a total of 10 000 data bits. The observed BER with a carrier frequency here of 29.0 MHz and bandpass sampling agrees with the theoretical upper bound of the probability of bit error P_b and the observed BER obtained with a carrier frequency of 20 kHz and conventional sampling (see Table 3.11, page 194 of the text).

E_b/N_o dB	**N_o V^2-sec**	**BER**	**N_o V^2-sec**	**BER**	**P_b**
	f_c = 20 KHz	**r_b = 1 kb/sec**	**f_c = 29 MHz**	**r_b = 56 kb/sec**	
∞	0	0	0	0	0
14	4.98×10^{-4}	0	8.89×10^{-6}	0	~ 0
12	7.89×10^{-4}	0	1.408×10^{-5}	0	$\sim 10^{-8}$
10	1.25×10^{-3}	0	2.232×10^{-5}	0	$\sim 10^{-6}$
8	1.98×10^{-3}	3×10^{-4}	3.54×10^{-5}	4×10^{-4}	$\sim 10^{-4}$
6	3.14×10^{-3}	4.2×10^{-3}	5.61×10^{-5}	4.7×10^{-3}	2.4×10^{-3}
4	4.98×10^{-3}	1.46×10^{-2}	8.89×10^{-5}	1.88×10^{-2}	1.25×10^{-2}
2	7.89×10^{-3}	3.69×10^{-2}	1.408×10^{-4}	5.51×10^{-2}	3.75×10^{-2}
0	1.25×10^{-2}	7.73×10^{-2}	2.232×10^{-4}	1.136×10^{-1}	7.85×10^{-2}

The probability of bit error P_b is a theoretical upper-bound. The observed BER for the conventional and bandpass sampling tracks well until low signal to noise ratios (SNR). The system sampling here (f_{sys} = 560 kHz) does not consistently reproduce the peak amplitudes of either the transmitted signal or the correlation receiver reference signals.

The 20 kHz carrier or reference signals sampled at a system sampling rate f_{sys} = 500 KHz (as in Figure 3.20 in the text) is shown in Figure 7 and the 29 MHz carrier or reference signals sampled at f_{sys} = 560 KHz is shown in Figure 8. Note how the peak amplitudes of the 20 kHz signal ($\pm 5/\sqrt{2}$) are produced consistently which improves the BER performance. This is because the 1 kb/sec (1 kHz) data rate and the 20 kHz reference signal are an integer multiple of the 500 kHz system sampling rate.

However, the 29 MHz reference signal with the same peak amplitude ($\pm 5/\sqrt{2}$) is not completely reproduced and the observed BER at low SNR is compromised. This is because the 560 kHz sampling rate is not an integer multiple of the 29 MHz reference signal.

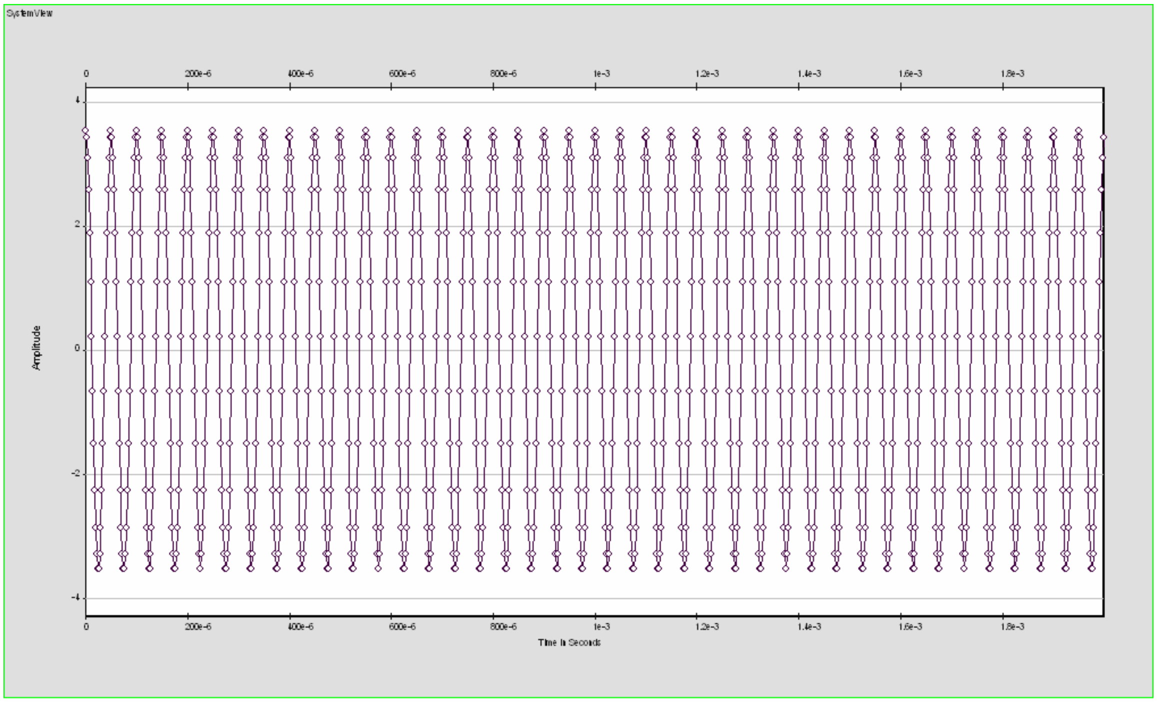


Figure 7

The bandpass sampling rate here cannot be a multiple of the data rate because the correlation reference signal then would be a constant (for example, the sine reference could be 0). However, bandpass sampling allows the simulation of a digital communication system at the intended frequency of operation. This facilitates the replacement of the simple additive white Gaussian noise (AWGN) channel with more realistic channel models (such as multipath) and the investigation of advanced digital communication systems (such as multiple input-multiple output or MIMO systems).

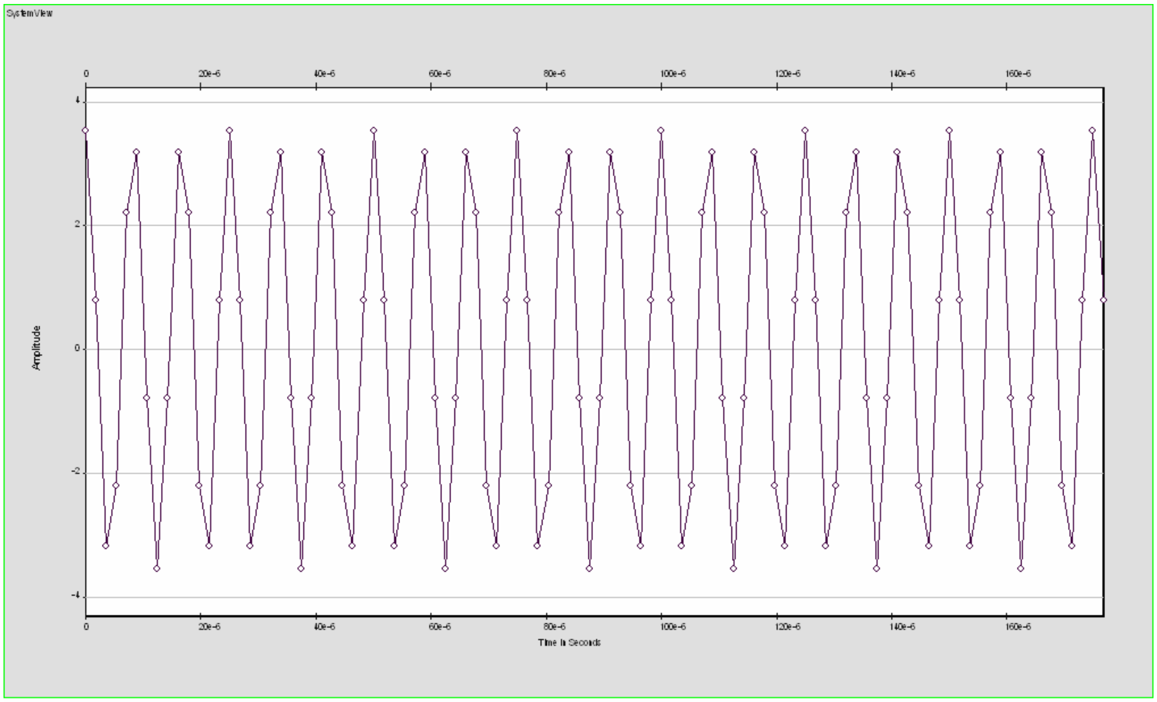

SystemView
0
20e-6
40e-6
60e-6
80e-6
100e-6
120e-6
140e-6
160e-6
4
2
0
-2
-4
Amplitude
Time in Seconds

Figure 8