Demonstrating CDMA, Frequency Hopping, and Other Wireless Techniques with PSPICE

Andrew Rusek, Barbara Oakley
Department of Electrical and Systems Engineering
Oakland University, Rochester, Michigan 48309

Abstract

Wireless communication systems apply various methods of modulation and demodulation. In the literature, these methods are often described very generally in analytical fashion and then illustrated by means of software. However, in the past, neither theory nor simulation have often bridged the gap to show students how general communication functions can be practically implemented in circuitry.

This paper discusses PSpice models illustrating how digital modulation and demodulation can be achieved and applied in support of conventional and spread spectrum communication systems. The PSpice models of PSK and FSK systems described in the article can be directly referred to existing hardware. The most popular spread spectrum methods, CDMA and frequency hopping, have been considered and introduced to demonstrate encoding and decoding processes. The PSpice circuits and simulations discussed here would make excellent additions to the classroom or laboratory of any undergraduate communications system course.

I. Introduction

PSpice is the most venerable of the many circuit simulation packages in common use today, and for good reason–it has a free demo version capable of handling fairly complex circuitry, it provides good connection with circuit level software, and it offers a fast learning curve. Even so, there are many competitors: Matlab/Simulab, ViSsim, and Elanix among them. None of these offer substantive demonstration models, and an additional problem is that one must often know more about the inner workings of the simulation than about the processes being investigated. PSpice offers flexibility in Fourier analysis through automatic scaling, along with the possibility of easy customization. As a consequence, PSpice provides unbeatable advantages in modeling communication-related circuitry and systems.

Table 1: PSpice macromodules discussed in this paper
1. Sampling
2. Phase shift keying
3. Frequency shift keying
4. Frequency hopping
5. CDMA with interfering signal

In this paper we will explore how basic aspects of digital modulation, interference, and system integration can be demonstrated to students through PSpice simulation; Table 1 provides a summary of the topics. Some areas related to source coding, such as pulse width modulation, analog-to-digital conversion, and delta modulation were discussed in previous papers,[1,2] along with other topics such as pulse amplitude modulation, analog correlators, and frequency synthesizers. Many simulations related to voltage controlled oscillators and phase locked loops were also provided, and the interested reader is directed to those papers for in-depth discussions of those topics.

II. Description of the PSpice Modules

1. Sampling

The circuits of Figure 1 illustrate a simple method of sampling a pulsed signal. The input signal with its salient characteristics is shown in blue, while the sampling pulsed voltage with its related characteristics are shown in green. The filters and receivers on the right, in yellow, act as receivers. The three circuits differ only in their sampling frequencies. The top circuit samples at a frequency below the Nyquist frequency, while the middle circuit is somewhat beyond and the bottom is well beyond the Nyquist frequency. Input V(input*x*), modulation V(move*x*), sampled waveform V(sample_out*x*), and output signal V(filt_out*x*) are shown in Figure 2. Here students can clearly see how undersampling distorts the signal past recognition–they can also easily play with the system to explore its limits. A look at the spectra (Figure 3) reveals yet a deeper way of understanding and exploring the problem. Undersampling provides for intertwined spectra (V(sample_out1)) that are too close together to effectively filter, while denser sampling rates separate the spectra into easily filterable sections. The more densely sampled outputs– V(filt_out2) and V(filt_out3)–display markedly different spectra from the undersampled V(filt_out1).

The simulations illustrated here are only introductory trials to show PSpice's ability to investigate sampling. More tests could easily be introduced to show the effects of changing the sampling rate and the demodulation filter bandwidth. An anti-aliasing filter could also be added so that its effects could be shown.

2. Phase shift keying

A PSK system is illustrated in Figure 4. The transmitter is in blue, while the receiver is in yellow. Information bits are sent at a rate of $1/8 \times 10^6$ Hz. This information modulates the phase of the 5 MHz carrier, with +1 producing no phase shift and -1 producing -180° phase shift. The modulated signal is sent to the receiver. Inside the receiver, the PSK modulated signal is split, with the left branch squaring the input signal to produce 2×5 MHz. The resulting signal is applied to a JK-toggle flip-flop to divide the frequency by two. The DC voltage sources and the $\oplus$ produce the necessary DC offset for the carrier, which must be symmetric and bipolar. This reconstructed carrier is applied to the coherent demodulator, where the modulated signal from the transmitter is also applied. The resulting combination yields the original information bits after filtering. Figure 7, which shows the associated voltage waveforms, reveals the slightly distorted relationship between input analog signal into the transmitter and output analog signal from the receiver. The effects of PSK are more clearly seen in the closeup views of Figure 8. Figure 9 shows a simplified PSK more suited to in-depth examination of effects related to variation of the information signal, while Figure 10 shows the (fashionable!) ‘eye’ diagram, often used to examine rise and fall times.

3. Frequency shift keying

Frequency shift keying is shown as a simplified system in Figure 11, and as a more complex system in Figure 13. In Figure 11, a VCO (shown in yellow) acts as a transmitter whose square wave frequency is controlled by the information source shown at the bottom left. The square waves are received by two filters, shown in the top right of the figure. The uppermost filter is designed to detect a ‘1,’ while the filter below it is designed to detect a ‘0.’ The associated voltage waveforms are shown in Figure 12.

Figure 13 illustrates a slightly more complex method of handling FSK. Once again, the input to the system (shown in green) is fed into a VCO (in blue). This time, however, the receiver is essentially a phase locked loop system. The PLL filter output voltage is proportional to the frequency changes, which represent the 0's and 1's of the transmitter. Figure 14 shows the corresponding waveforms.

4. Frequency hopping

Frequency hopping is illustrated in Figure 15. The ‘hopping code’ signal is provided by the two pulsed voltage sources (in green). These provide for several different levels of amplitude, as shown by V(hop-hop) of Figure 16 and 17. These different amplitude levels in turn provide different inputs to the VCO (in yellow), which varies the frequency accordingly. PSK modulation of the input information with the varying carrier is accomplished by the PSK modulator (shown in blue). The carrier recovery system is shown in orange–its chief feature is the divide by two counter that recovers the carrier from the squared input signal. The coherent demodulator is shown in grey, while a low pass filter is shown in dark pink. A closeup of the waveform outputs is shown in Figure 17. Either fast or slow hopping can be demonstrated with this system.

5. CDMA with fast spreading code

In CDMA with fast spreading codes, the rate of the information bits is lower than the rate of the spreading code. An example of such a system is shown in Figure 18. The codes chosen here are very simple so as to clearly reveal the processes involved in modulation and demodulation. The simulation involves two stations operating on the same carrier frequency but having different spreading codes. The carrier sources are modulated in phase (PSK) by the signals marked as Vinfo1 and Vinfo2, which represent the state of the intelligence signals. The upper station, on the left, generates the desired signals, and the lower station, also on the left, produces an interfering signal. The triangular block controls the amount of interfering signal. The spectrum spreading sources, Vencrypt1 and Vencrypt2, ‘chop’ the carrier at high rate, thereby adding more PSK to the signals mod1 and mod2, which were also PSK modulated by the information bits. Both double modulated signals reach the same receiver located on the right. In the receiver, the de-spreading signal (Vencrypt11), which of the same shape as the spreading signal Vencrypt1, is applied to decipher the desired channel (in this case, the upper transmitter signal). The internally generated carrier, Vcarrier11, is then applied to demodulate the original information Vinfo1. The multipliers (circles with crosses) in the transmitters are modulators, while the multipliers in the receiver are coherent demodulators whose coherence is assured by proper alignment of the de-spreading code signal and the internal carrier. The receiver output voltage (Voutdec1) of the desired signal is finally obtained by low pass filtering.

The simulation results show only a basic application of the system. Students can play with the level of interference to show distortions of the received and useful signal. At high interfering signals one may expect total disruption of expected messages. Although not shown here, different delays can be introduced to simulate multipath instead of interference in the second input signal. The effects of both noise and code modification can also be easily examined. One of the chief advantages of CDMA is clearly revealed through these simulations: different coding even while using the same carrier frequency can increase spectrum utilization.

Time domain waveforms illustrating the system operation are shown in Figures 19 and 20, while Figure 21 shows the frequency spectra. Here, the signal V(mod1) is the PSK modulated and desired signal, while V(out1) is the "chopped" or encrypted version of V(mod1). The frequency spectrum of the encrypted signal is clearly broader than the spectrum of PSK modulated signal. Both time-domain and frequency domain representations of V(sum) show no resemblance whatsoever to V(mod1), which is the desired signal.

The spreading codes of both transmitters used in the examples are much shorter than the ones applied in practice in order to present the principles of operation within reasonable simulation times. To make the simulation work, it is assumed that the de-spreading code and the carrier are properly aligned (synchronized) with corresponding signals generated in the desired signal transmitter. In real life, both of these signals must be reconstructed in the receiver. This is done by proper sequencing of the desired signal phases, which is controlled by a protocol. For instance, during one phase the information signal, V(info1), is not applied–only the spreading code signal is present in the desired signal. The code is demodulated in the receiver, as in regular PSK, compared with built-in signature of this code in the receiver through correlation, and aligned. During the same phase the carrier is also reconstructed, as in PSK. Then the code is activated and the desired information is demodulated as shown above.

Figures 22 and 23 show a simplified method to decipher the spreading code of the desired transmitter and reconstruct the carrier. The authors of this paper are currently developing more complete simulation models of spread spectrum units with synchronization systems that would include correlators, noise sources, and PLL systems. (Detailed simulations demonstrating these concepts were presented in the previous papers.[1,2])

III. Conclusions

Frequency hopping, CDMA, and other wireless techniques are sometimes difficult concepts for students to grasp, and even more difficult to obtain practical experimental experiences with. Demonstrating these concepts through PSpice simulations, allowing students free rein to play with these simulations, and encouraging them to devise their own experiments based on these simulations can provide invaluable educational opportunities. Simulations such as those shown in this paper could very profitably be used in many courses related to this cutting edge area of technology.

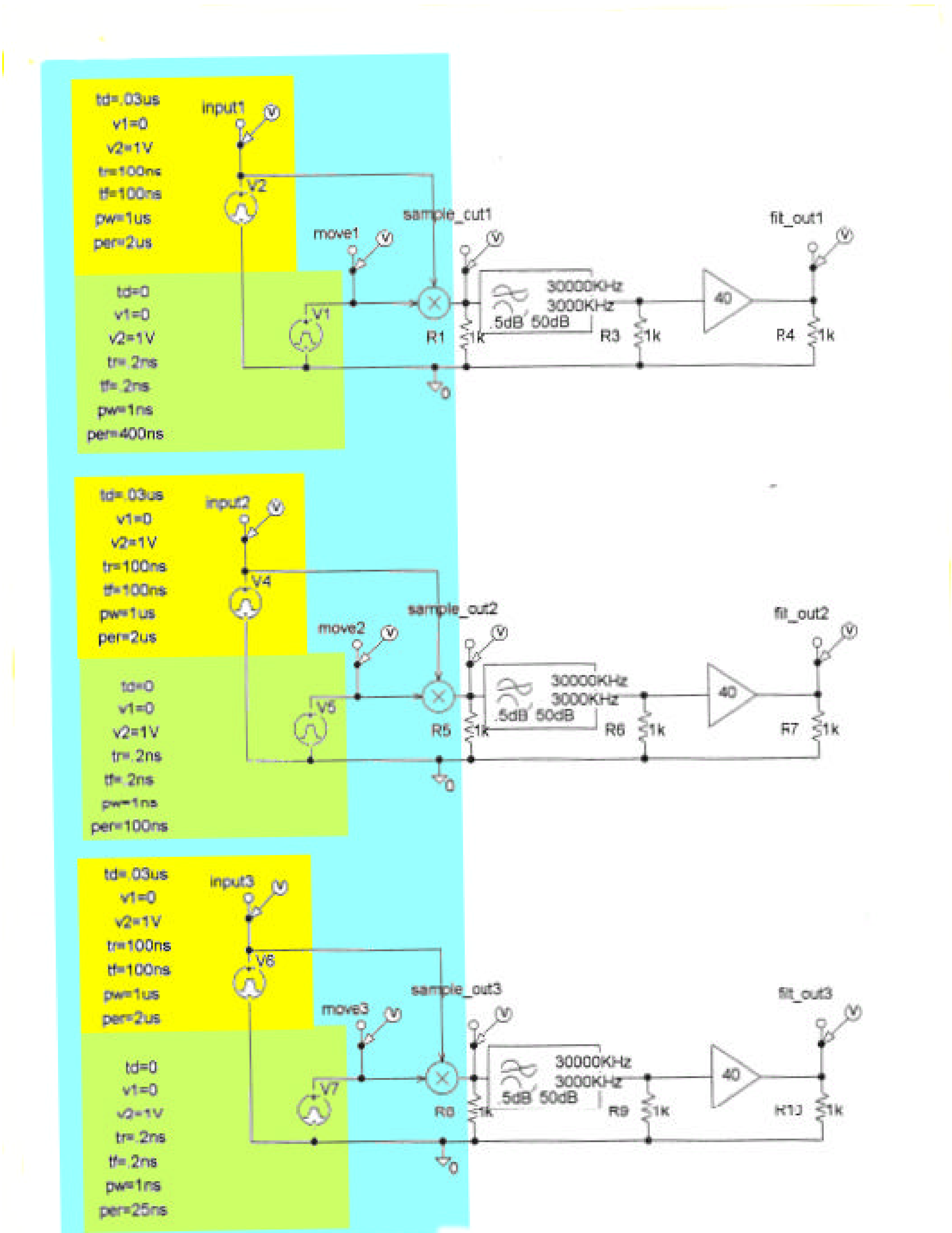

Figure 1: Three virtually identical sampling circuits, which differ only in the rate of sampling. The information to be sampled is shown in yellow, while the signal doing the sampling is shown in green. The top circuit, with a pulse width of 1 µs and a period of 2 µs, is undersampled. The lower two circuits show more appropriate sampling of the information signal. The portions of the circuit outlined in blue are acting as transmitters, while the filter and amplifier on the right hand portion of each circuit (in white) are acting as receivers.

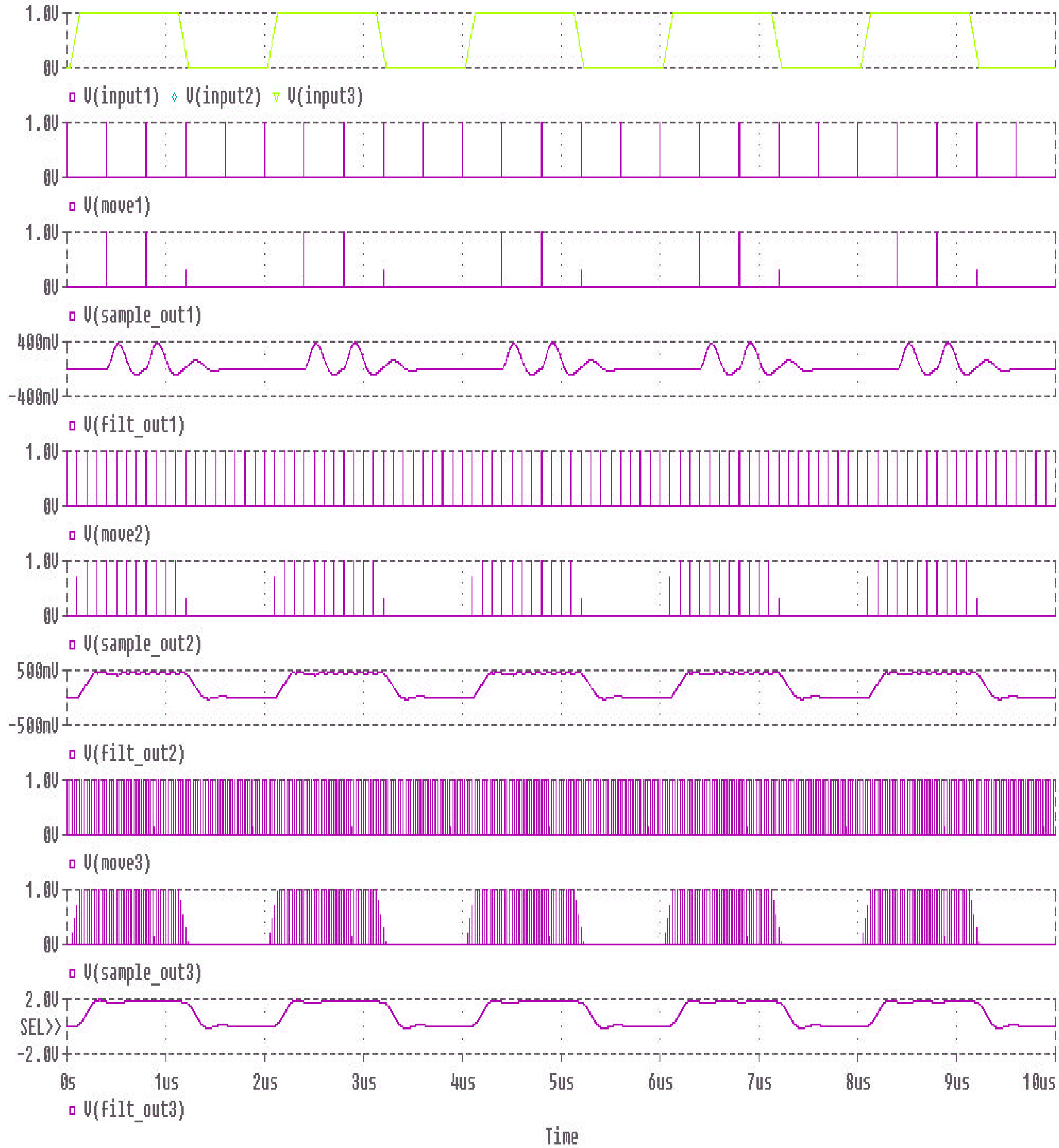

Figure 2: Voltage waveforms affiliated with Figure 1. An index of 1 indicates that the waveforms are associated with the undersampled circuit shown at the top of the previous figure, while indices 2 and 3 indicate the waveforms of the more densely sampled circuits in the middle and at the bottom respectively of Fig. 1.

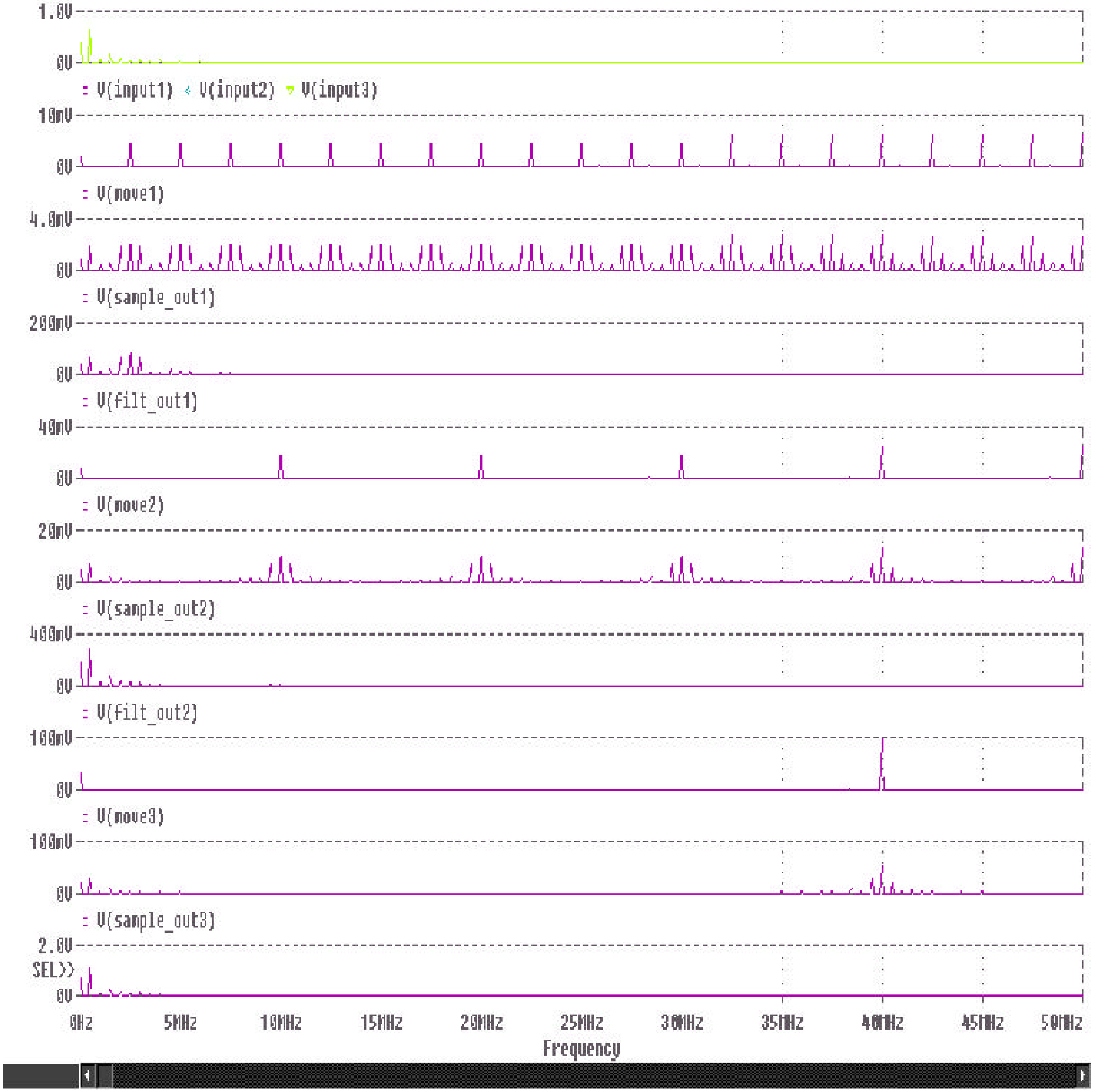

Figure 3: Spectra of sampled circuits of Figures 1 and 2. An index of 1 indicates that the spectra are associated with the undersampled circuit shown at the top of Figure 1, while indices 2 and 3 indicate the spectra of the more densely sampled circuits in the middle and at the bottom respectively of Fig. 1. Undersampling provides for intertwined spectra (V(sample_out1)) that are too close together to effectively filter, while denser sampling rates separate the spectra into easily filterable sections.

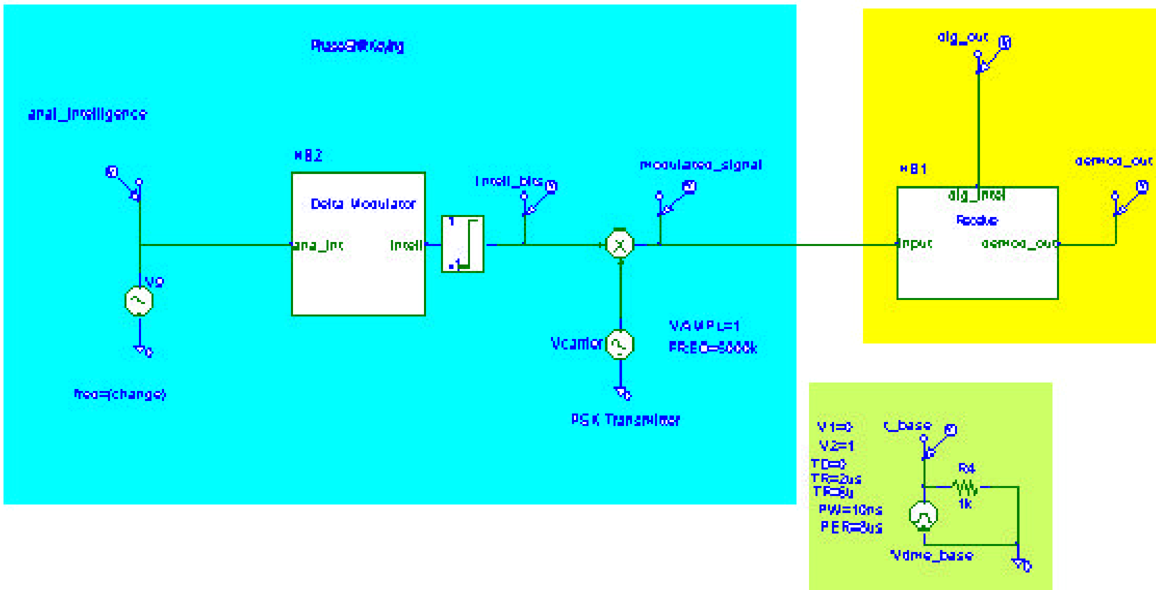

Figure 4: PSK system. The transmitter is in blue, the receiver in yellow, and the time base used for the 'eye diagram' is in green.

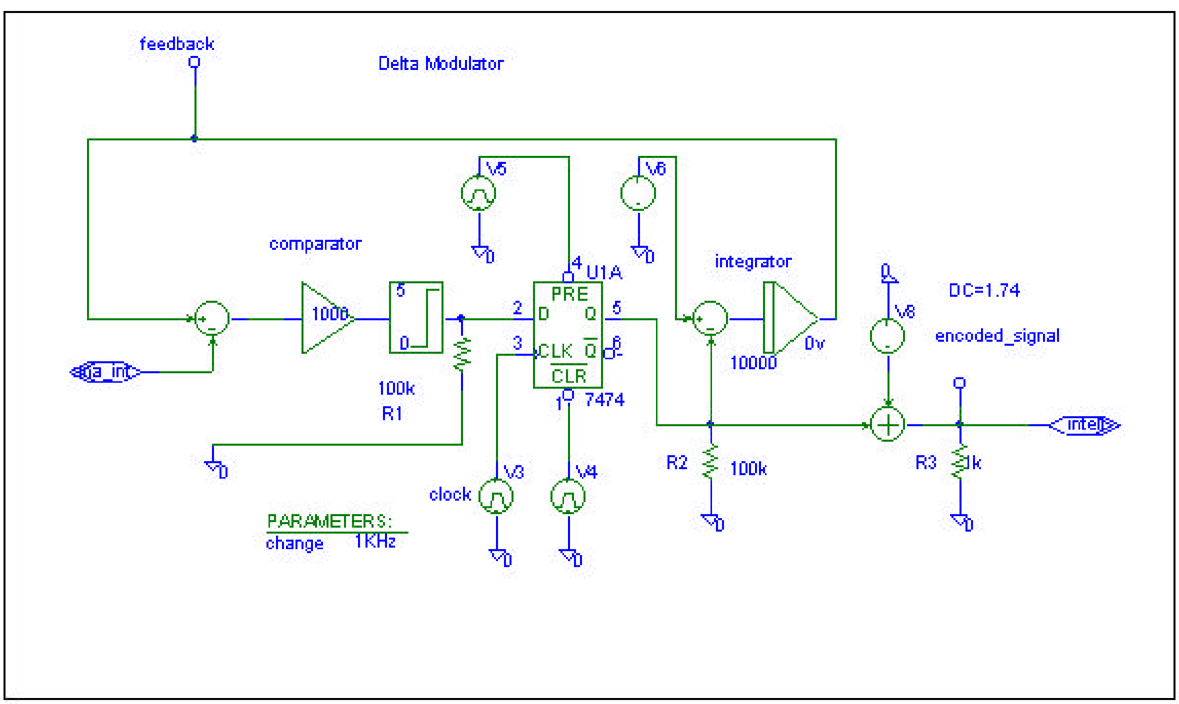

Figure 5: Delta modulator (described in detail in Rusek, Oakley, 2001, Communications). The output signal is bipolar, since it is intended to be applied to modulate the carrier for PSK.

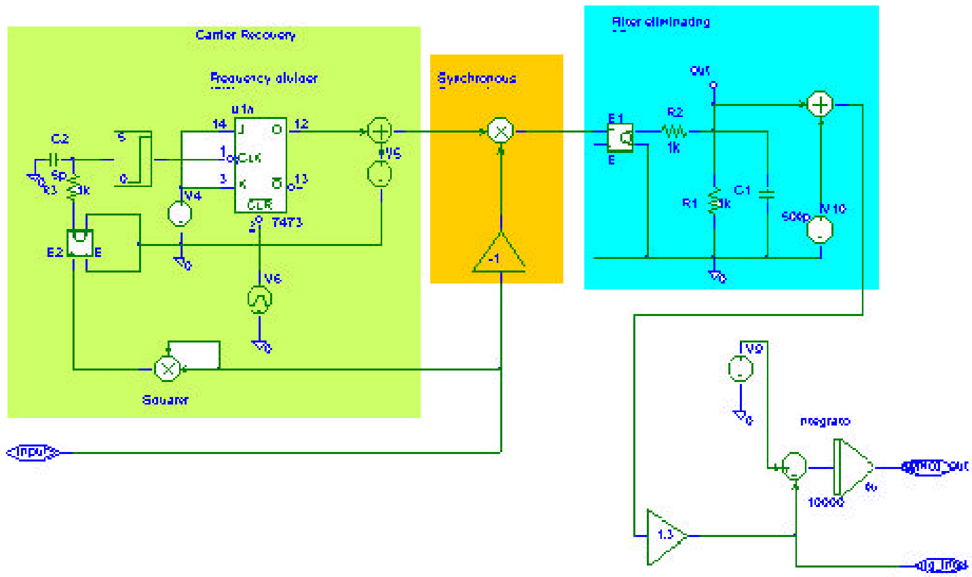

Figure 6: PSK receiver that includes the carrier recovery system in green (a squarer and frequency divider), a coherent demodulator (multiplier, in orange), a low pass filter (in blue), and a delta demodulator with integrator on bottom right.

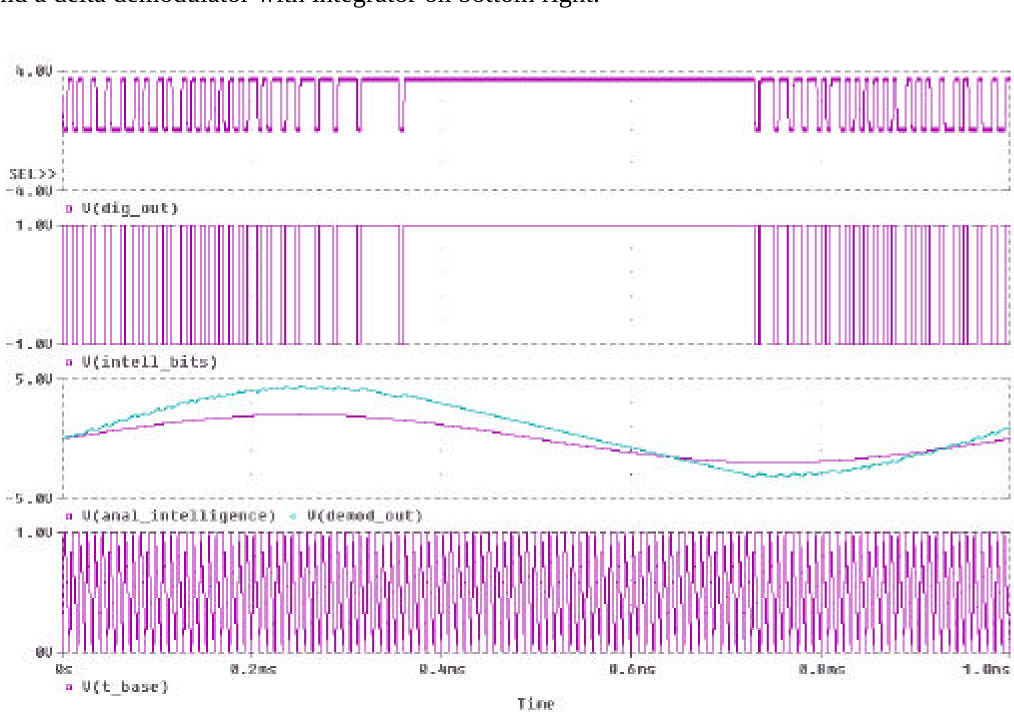

Figure 7: Signals corresponding to voltages of the PSK system. The top shows digital signals available from the output of the receiver, second from top shows the digital signals just rpior to their insertion onto the carrier, third from top shows the original signals provided as input into the transmitter (V(anal_intelligence)) and the demodulated output signal–a close, but not perfect approximation of the original signal. The bottom waveform illustrates the triangle waveform of the time base used for the 'eye' diagram.

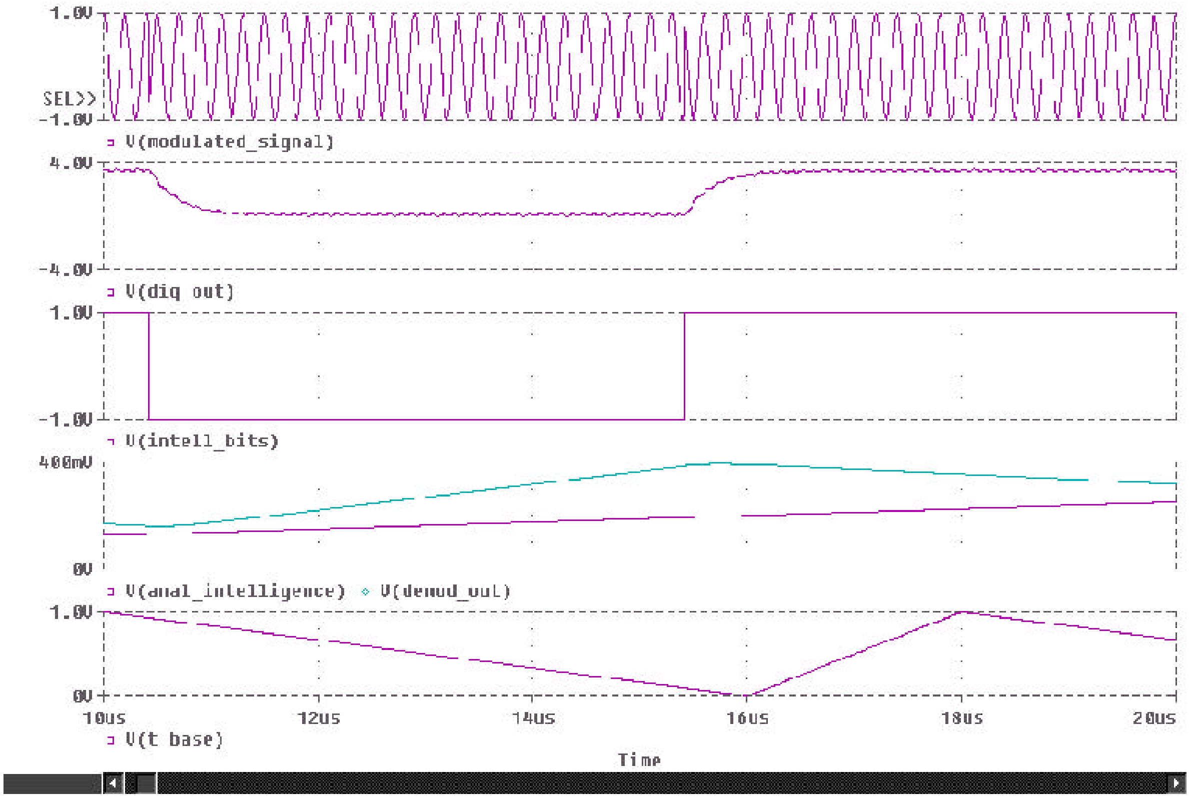

Figure 8: Closeup of waveforms related to PSK system. The uppermost waveform clearly reveals the effect of the phase modulation, which are directly related to the change in state of the intelligence bits that were input into the system.

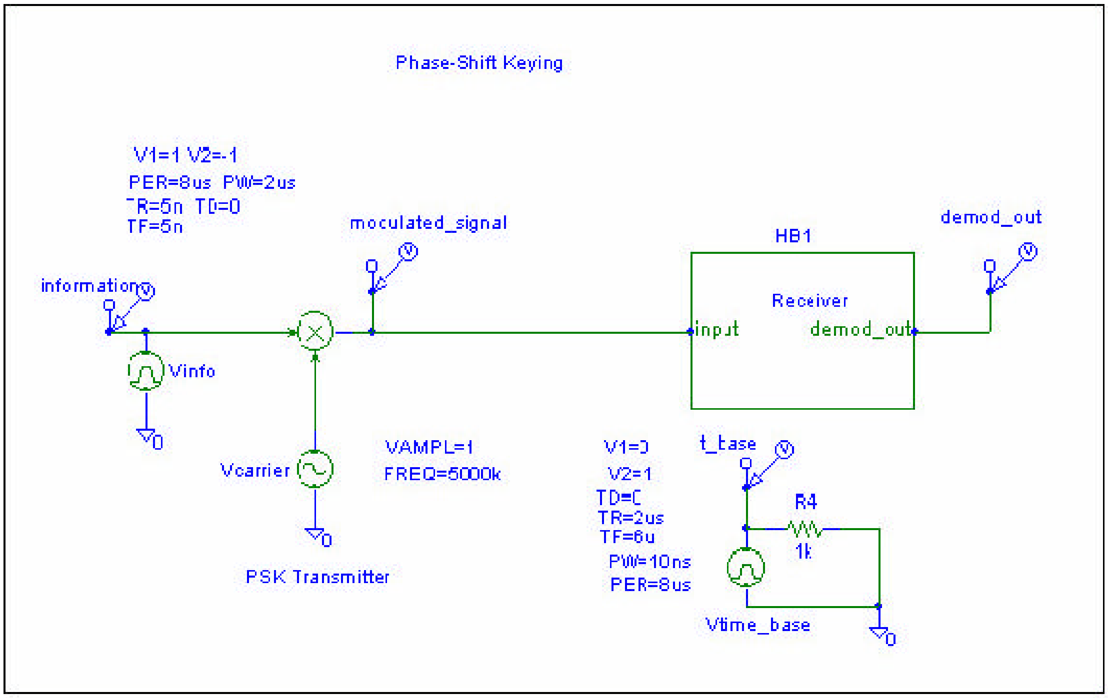

Figure 9: Simplified PSK system which can be used to demonstrate the effects of transmitting high frequency information signals.

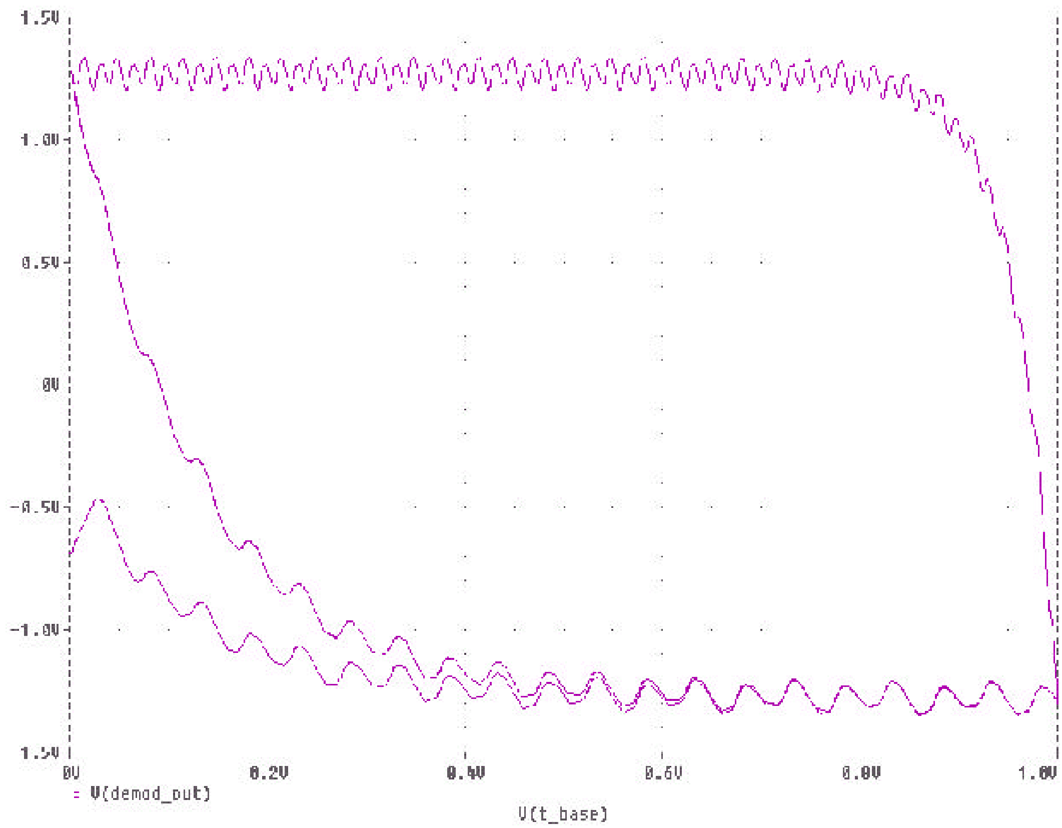

Figure 10: 'Eye' diagram, used to quickly visualize and relate effects related to rise and fall times.

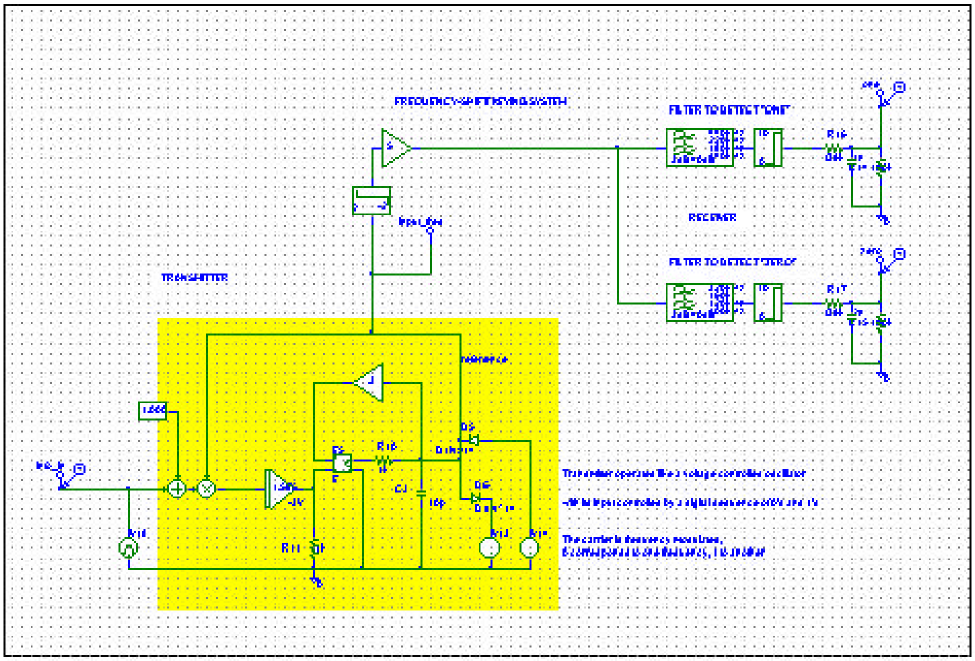

Figure 11: Simple FSK system. The transmitter is in actuality a VCO (in yellow). The frequency of the VCO is controlled by the 0's and 1's of the input signal. 0 then corresponds to one frequency, while 1 corresponds to another. The top filter on the right detects '1,' while the filter beneath it detects '0.'

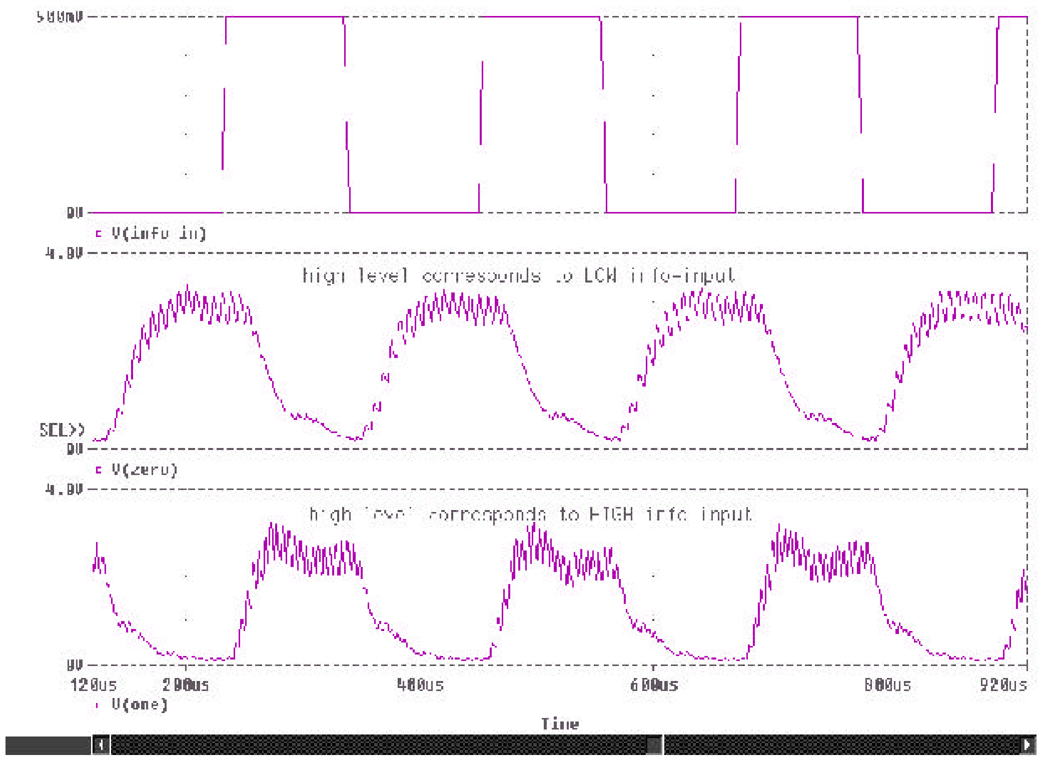

Figure 12: Voltage waveforms affiliated with the previous figure.

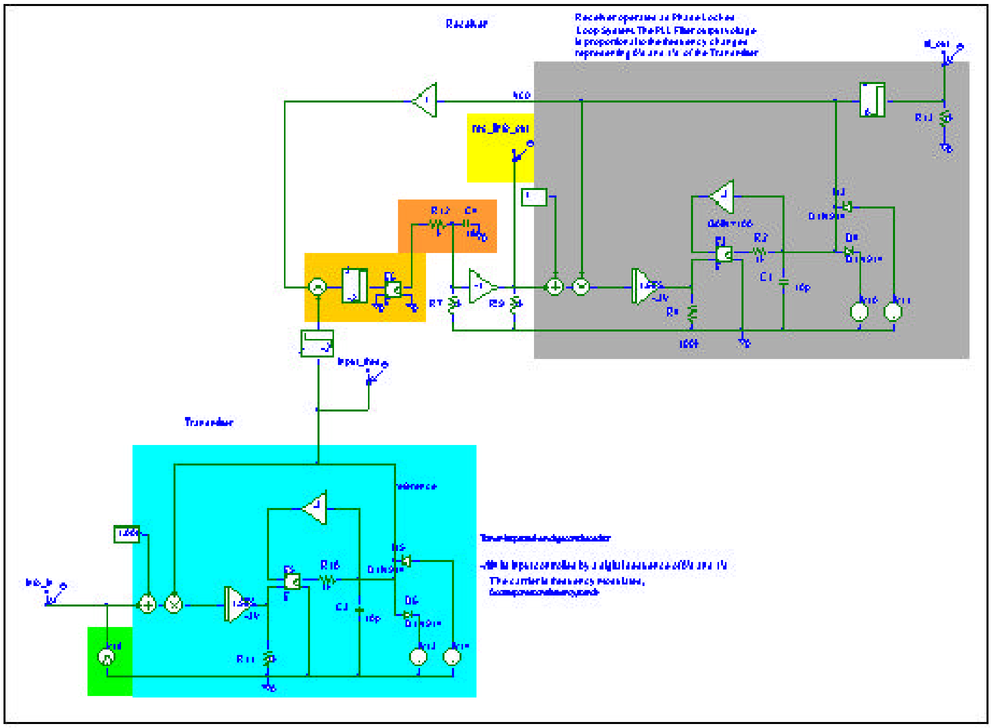

Figure 13: FSK system. The intelligence input are pulses provided by the voltage source shown in green. This input modulates a VCO (in blue) that produces a square wave output. The phase detector is shown in light orange, a low pass filter in dark orange, the other VCO in dark grey, and the output in yellow.

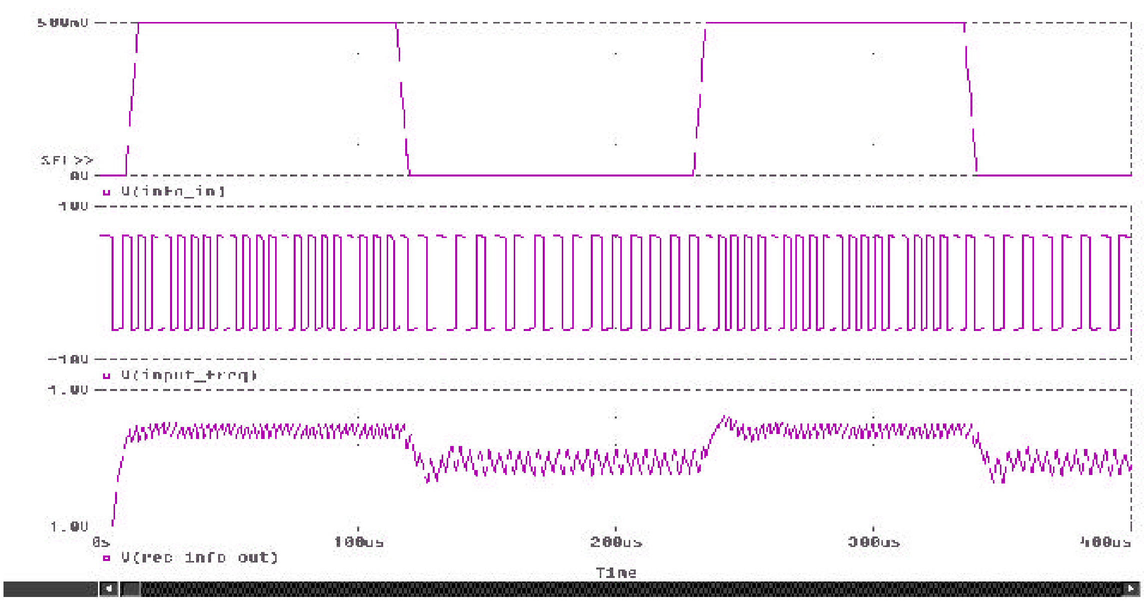

Figure 14: Voltage waveforms affiliated with the previous figure.

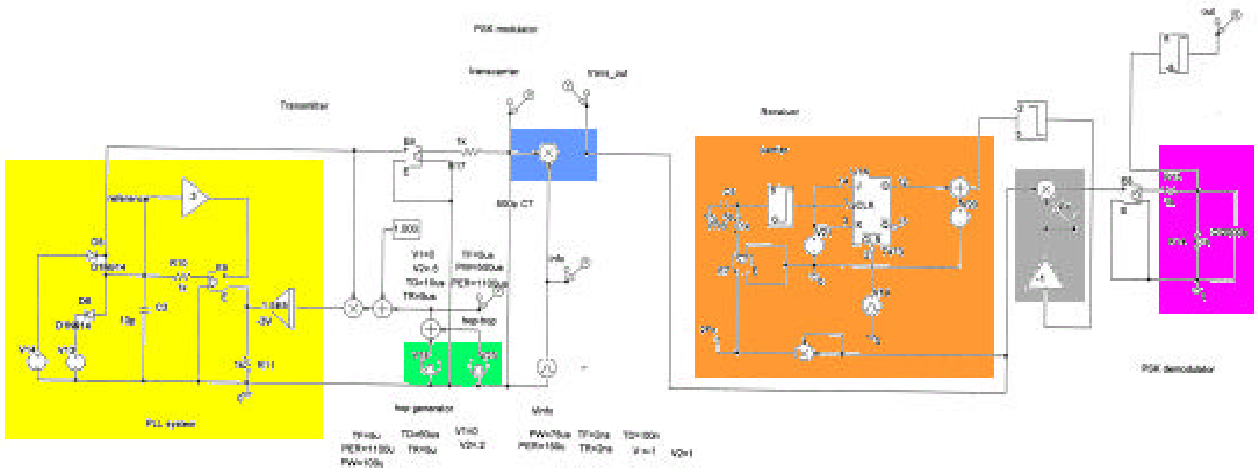

Figure 15: Frequency hopping scheme. The signal is encoded in phase (PSK), the 'hops' are those of the carrier frequency.

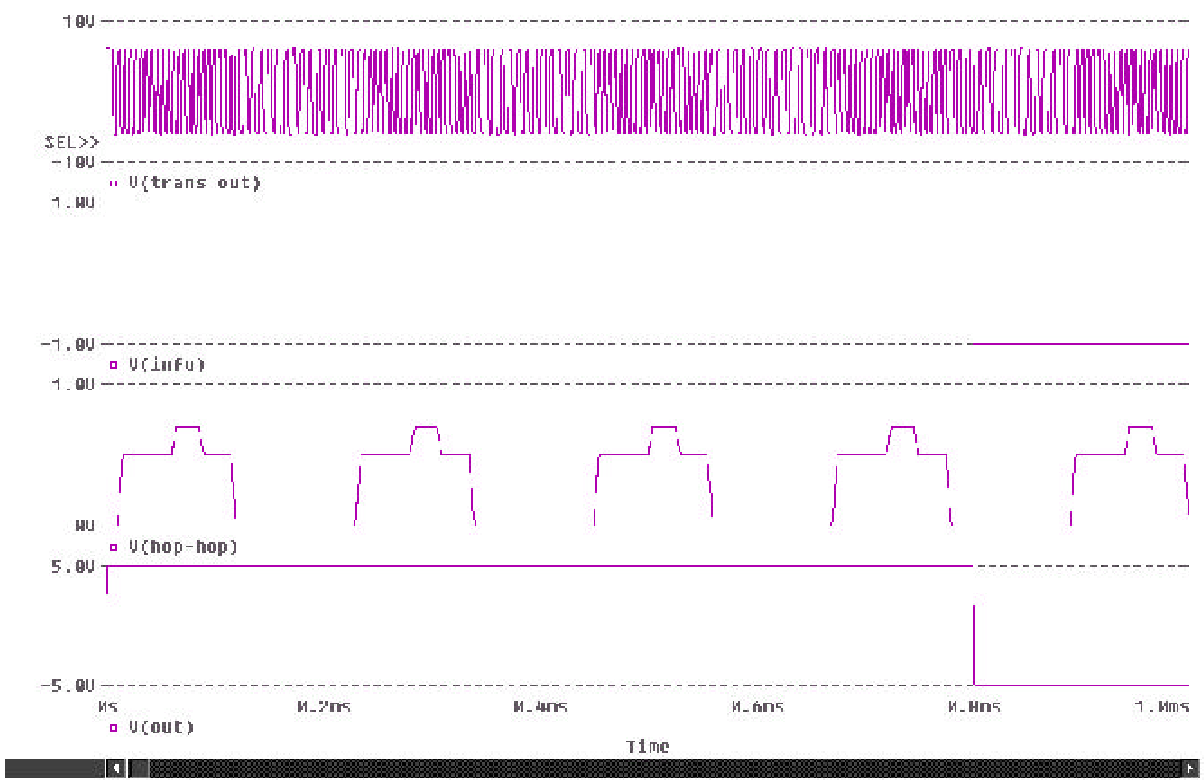

Figure 16: Information signal is encoded into phase changes (PSK); V(hop-hop) reveals the 'hopped' changes in the frequency of the carrier; V(trans_out) of the top wave is the output signal of the transmitter that includes the triple change in frequency as well as the changes of phase.

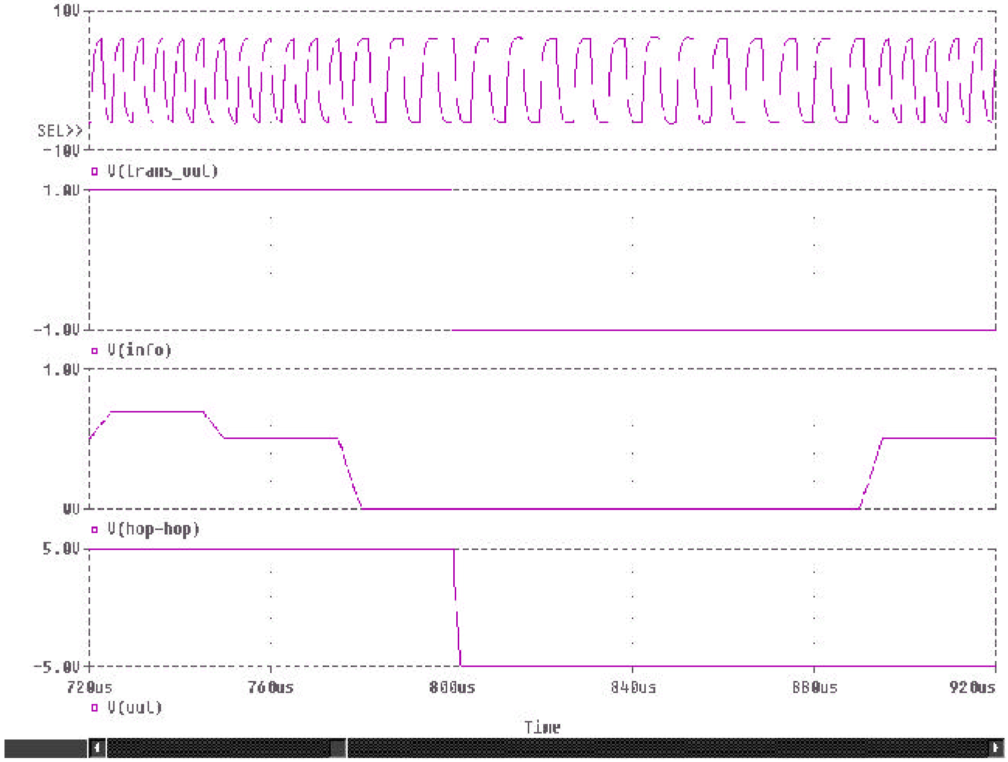

Figure 17: Expanded waves of the previous figure. The top wave shows the phase change when V(info) changes its level. Frequency changes of the carrier are imposed by V(hop-hop).

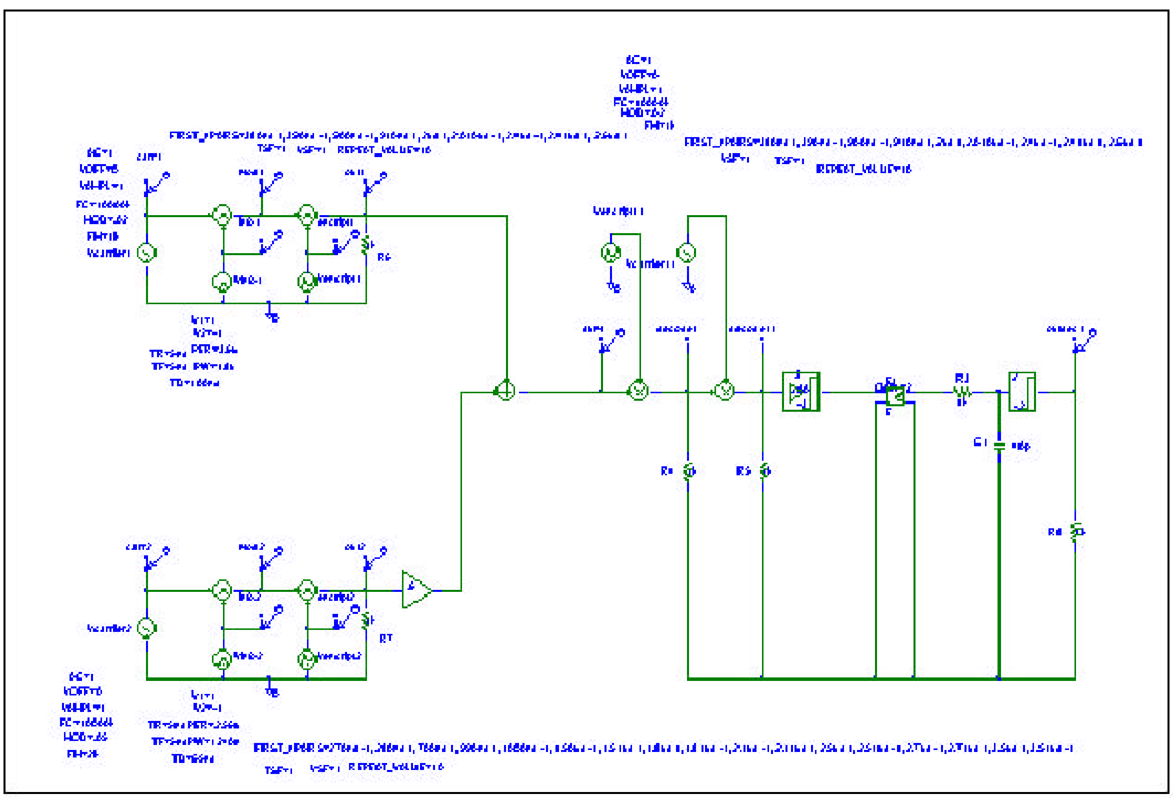

Figure 18: CDMA with fast spreading code.

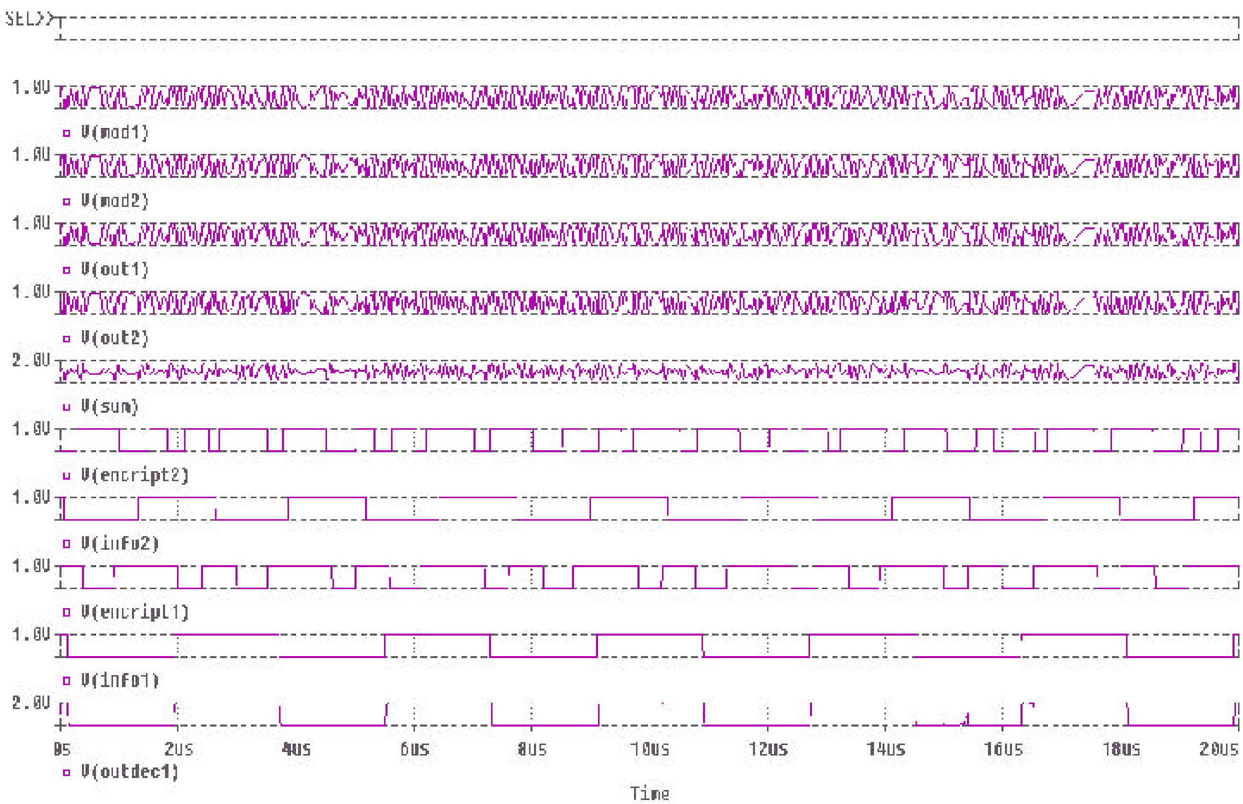

Figure 19: CDMA time domain waves. Encript1 and encript2 are the spreading waves, whose rate is higher than the info bits (this is shown with a bit higher than the information bits, info1, info2, to demonstrate all waves within a reasonable scale).

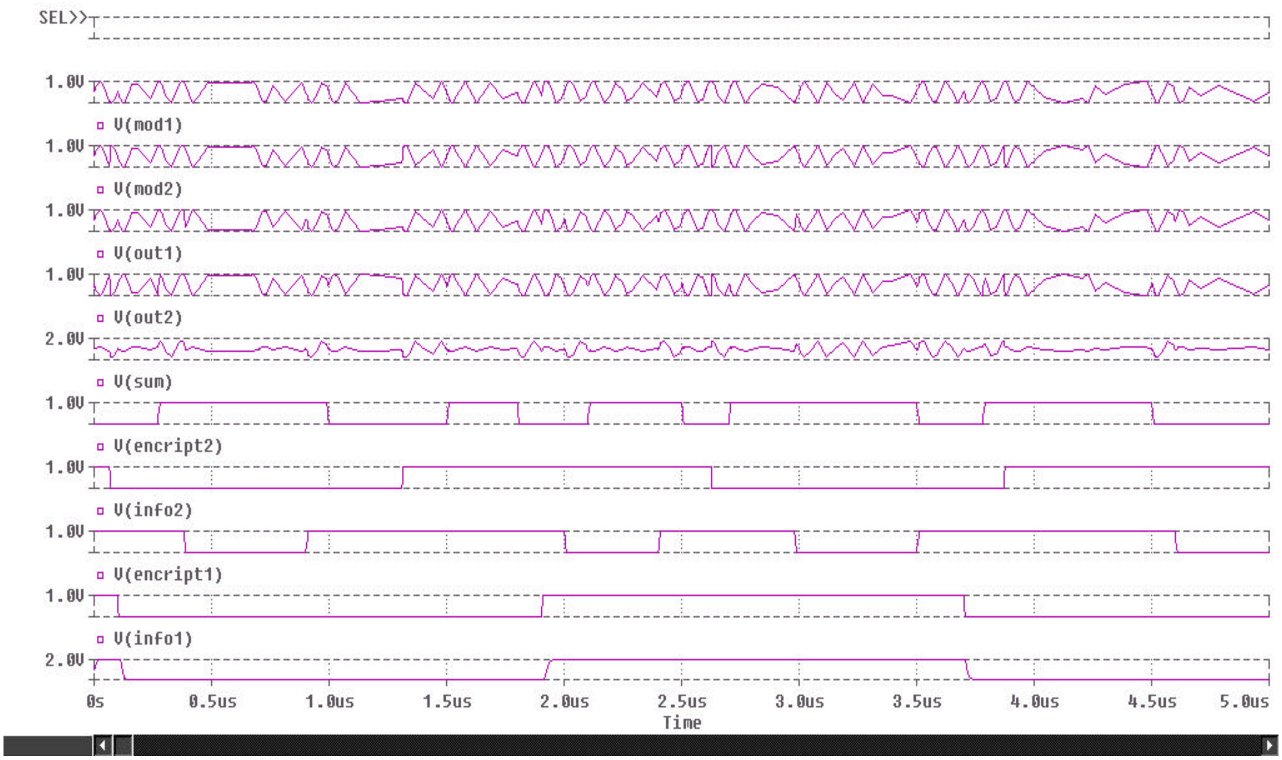

Figure 20:CDMA waves as above but with a different time scale to show the differences between mod1 and out1, and mod2 and out2 (that is, the non-encrypted and the encrypted waves).

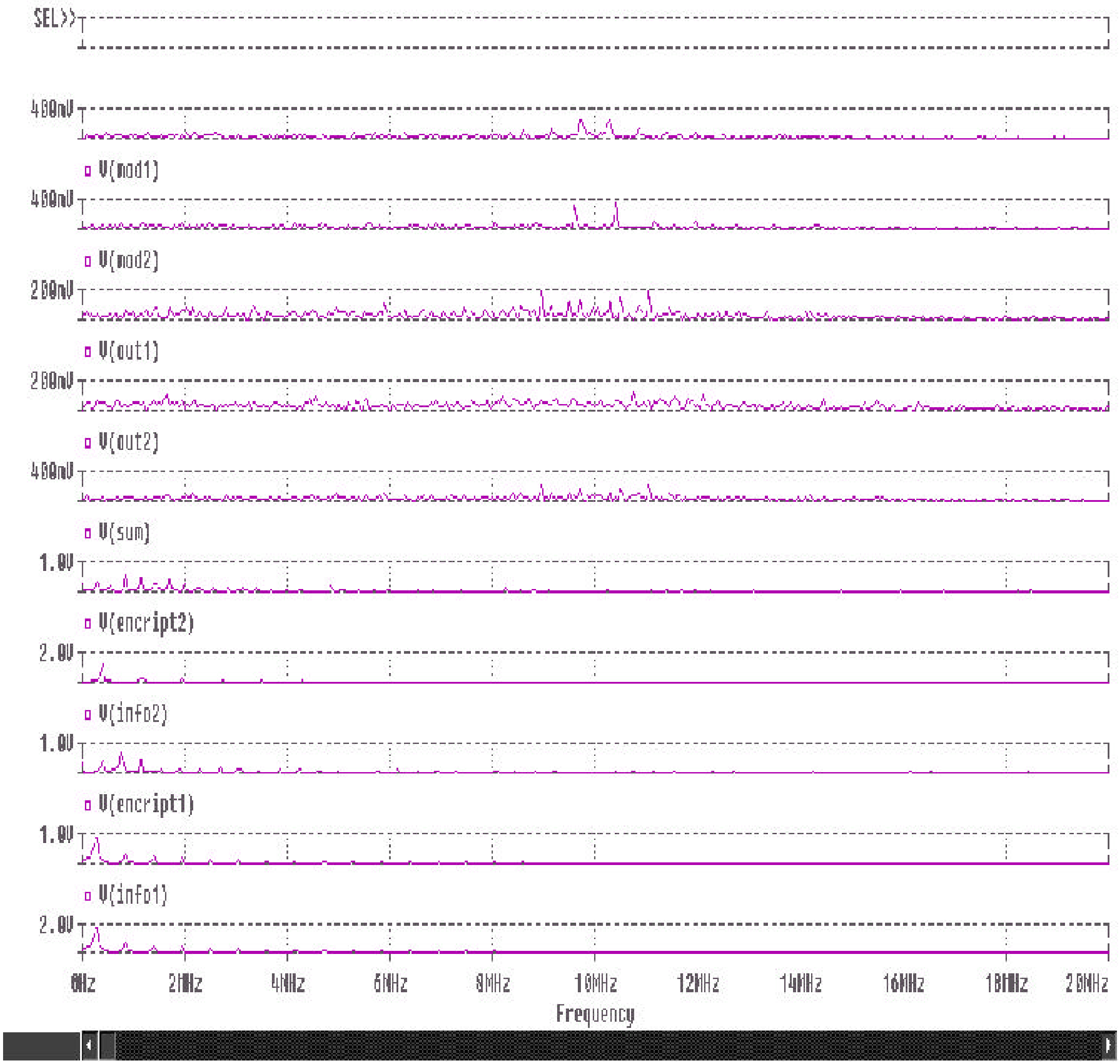

Figure 21: Spectra for CDMA. Out1, out2 represent the final spectra of the transmitted signals. Mod1, mod2 are PSK modulated carriers. Sum is the composite signal reaching the receiver. Encript1 and encript2 are the spreading code spectra. Info1 and info2 are spectra of the information bits. Out1 and out2 spectra are broader than PSK mod1 and mod2. They have also smaller amplitudes, which illustrate the effects of spreading

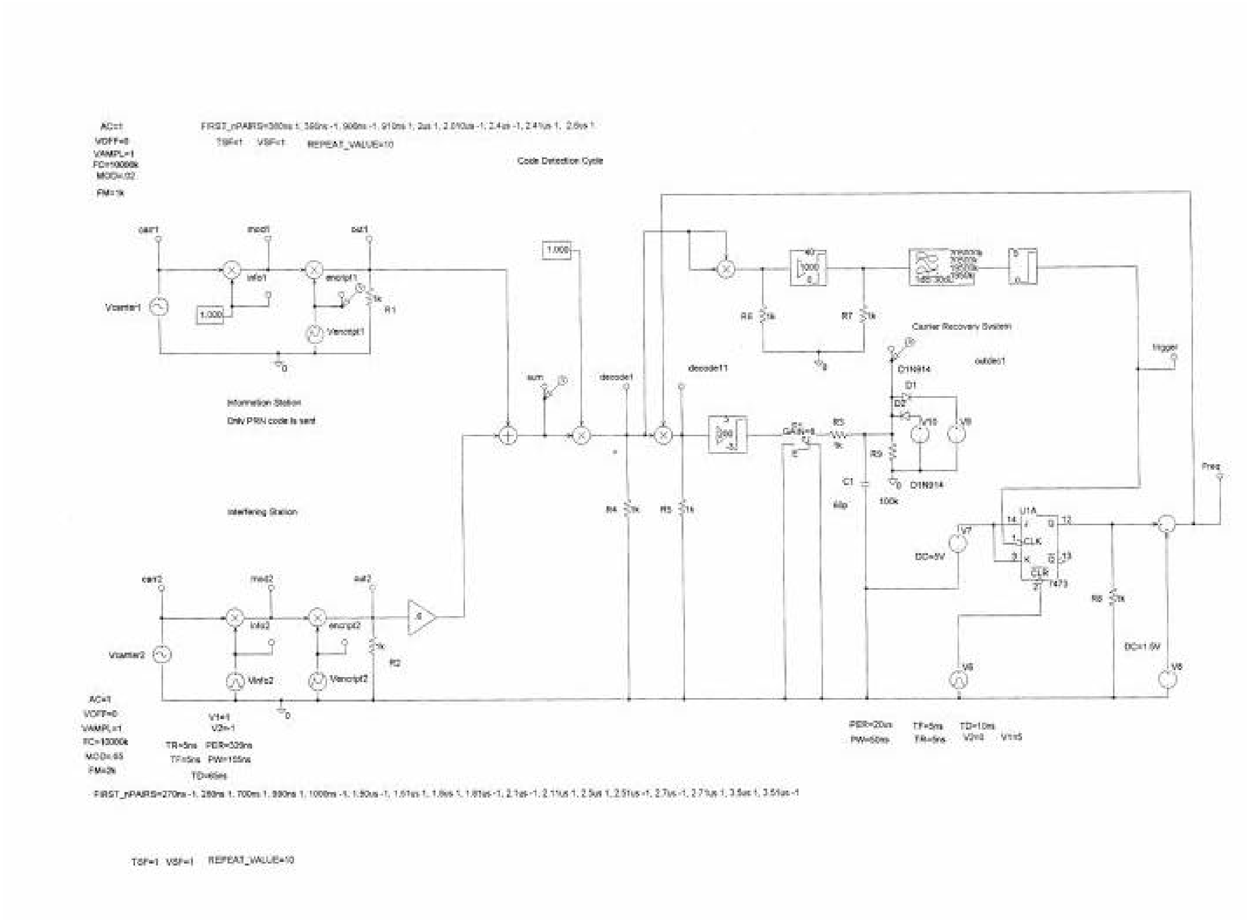

Figure 22: A simplified method to decipher the spreading code of the desired transmitter and reconstruct the carrier.

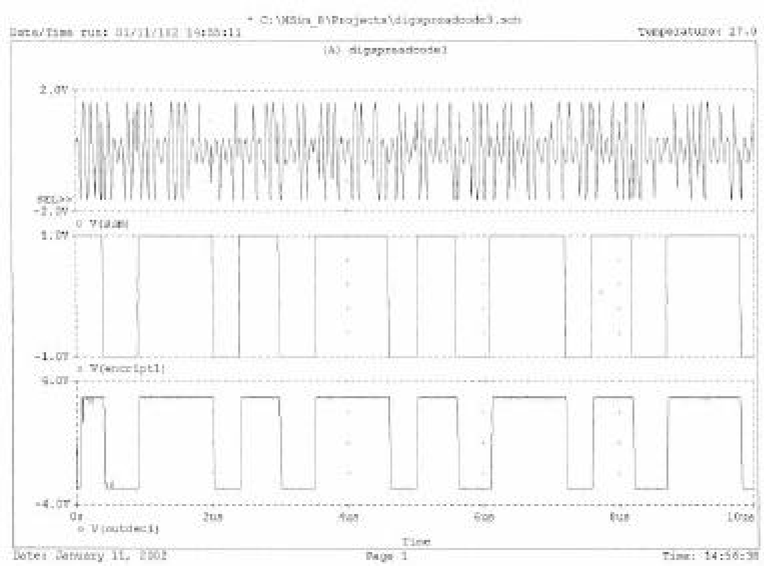

Figure 23: Waveforms related to the previous circuit.

Bibliography

[1] Andrew Rusek and Barbara Oakley, "PSpice Applications in the Teaching of Communications Electronics," Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition, (CDROM), Albuquerque, NM.

[2] Andrew Rusek and Barbara Oakley, "PSpice Applications in the Teaching of Wireless and High Frequency Electronics," Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition, (CDROM), Albuquerque, NM. (Nominated for best paper.)

ANDREW RUSEK
Andrew Rusek is a Professor of Engineering at Oakland University in Rochester, Michigan. He received an M.S. in Electrical Engineering from Warsaw Technical University in 1962, and a PhD. in Electrical Engineering from the same university in 1972. His post-doctoral research involved sampling oscillography, and was completed at Aston University in Birmingham, England, in 1973-74. Dr. Rusek is very actively involved in the automotive industry with research in communication systems, high frequency electronics, and electromagnetic compatibility. He is the recipient of the 1995-96 Oakland University Teaching Excellence Award.

BARBARA OAKLEY
Barbara Oakley is an Assistant Professor of Engineering at Oakland University in Rochester, Michigan. She received her B.A. in Slavic Languages and Literature, as well as a B.S. in Electrical Engineering, from the University of Washington in Seattle. Her M.S. in Electrical and Computer Engineering was received from Oakland University in 1995, and her Ph.D. in Systems Engineering, also from Oakland, was received in 1998. Her research involves biomedical applications and electromagnetic compatibility. She is a recipient of the NSF FIE New Faculty Fellow Award, was designated an NSF New Century Scholar, and has received the John D. and Dortha J. Withrow Teaching Award.