# A Direct Sequence Spread Spectrum (DSSS) system with a Transmitted Reference

**using the32-bit version of SystemView by ELANIX.**

**Introduction**

The purpose of this system is to show how SystemView along with the RF/Analog library may be used for the following 10 areas of design:

1. Present a simple example of a Direct Sequence Spread Spectrum (DSSS) system that has both a transmitter and a receiver that works with a path loss of 0 to 100 dB.
2. Although it is an inefficient use of the available spectrum, a transmitted reference system is used to simplify the receiver in this system.
3. The filters, amplifiers, limiting amplifiers, and mixers used in the system have their parameters set to values representative of Wireless Local Area Network (WLAN) chip sets that are presently available.
4. A Surface Acoustical Wave (SAW) filter is required in both the transmitter and the receiver. The response of the SAW filters is simulated by the custom design of two Finite Impulse Response (FIR) filters.
5. A system with typical frequency extremes of 1 MHz and 2.4 GHz is scaled to 1 MHz and 350 MHz. This will permit a faster simulation.

Although the use of a transmitted reference, the modulator, and the demodulator used in this example are not consistent with the IEEE 802.11 specification, some portions of the specification are pertinent:

6. A spreading code of 11 MHz is used. This results in a channel width of 22 MHz.
7. A data rate of 1 MHz is used. This gives a ratio of 11:1 (code:data).
8. Two channels are operated at the same time, at a spacing of 30 MHz. (The transmitted reference system requires the transmitter to use two transmitting channels at the same time. The 802.11 specification allows for two independent systems operating at the same time, without interference, at a channel spacing of 30 MHz.)
9. This example conforms to the IEEE 802.11 spectral mask requirements for transmission. The side lobe is at least 30 dB down from the main lobe.
10. The output power of each channel is +18 dBm.

**Detailed Description of the Simulation**

A hypothetical example of a Direct Sequence Spread Spectrum (DSSS) system, using a transmitted reference, and typical WLAN frequencies is shown in **Figure 1**. For more information about transmitted reference systems please refer to Robert C. Dixon's book (**Ref. 1**). In addition to a system description, the book refers to an IEEE paper – a study of these systems (**Ref. 2**), and (**Ref. 3**) a U.S. patent.

To simplify the diagram, many of the amplifiers and filters are not shown. A transmitted reference system does not require the use of a 0/90 degree modulator, but one may be used as long as there are separate I and Q inputs and outputs.

In **Figure 2** the frequencies of each stage have been set to be closer to each other, keeping the original 1 MHz and 11 MHz data and code input frequencies. This will allow the simulation to take less time. The 1st LO is set to a rather high 100 MHz. This allows the 2-pole filters to do a better job of rejecting the various LO feedthrough frequencies. Also, the wide band filters are narrower than in **Figure 1**. The new filter bandwidths are wide enough for the two channels of interest, and the reduced bandwidth helps reject the various LO feedthrough frequencies. The full spread spectrum system is represented in SystemView by the tokens in **Figure 3**.

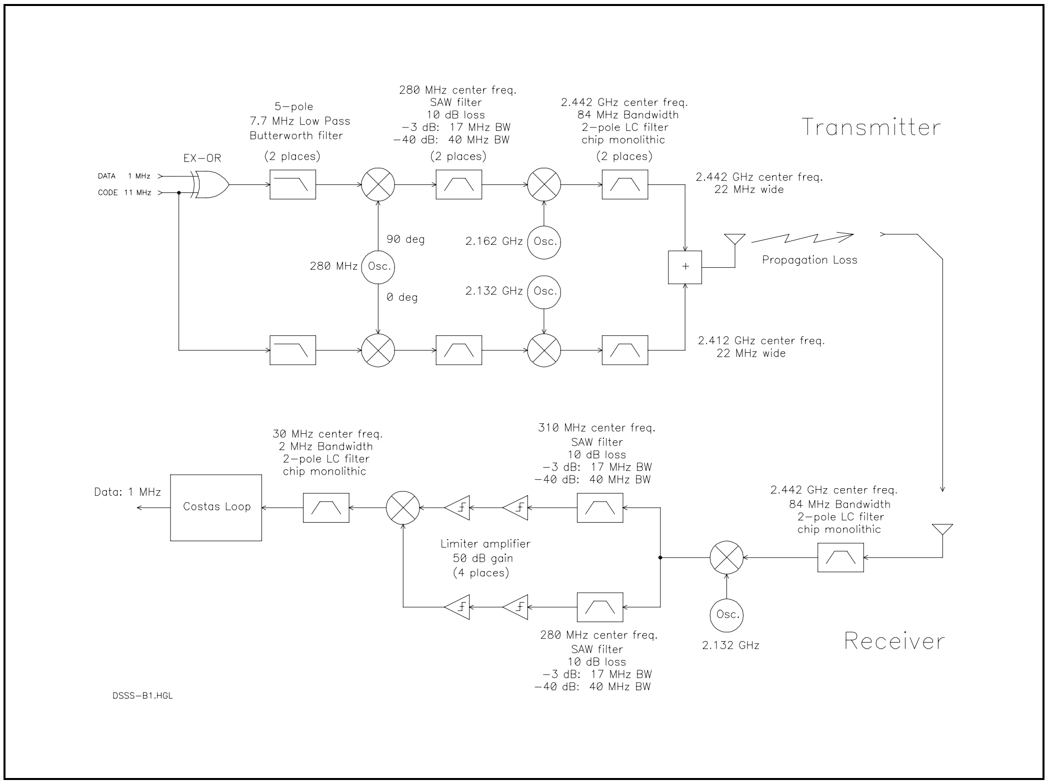


Figure 1. A hypothetical example of a Direct Sequence Spread Spectrum (DSSS) system, using a transmitted reference, and typical WLAN frequencies. To simplify the diagram, many of the amplifiers and filters are not shown.

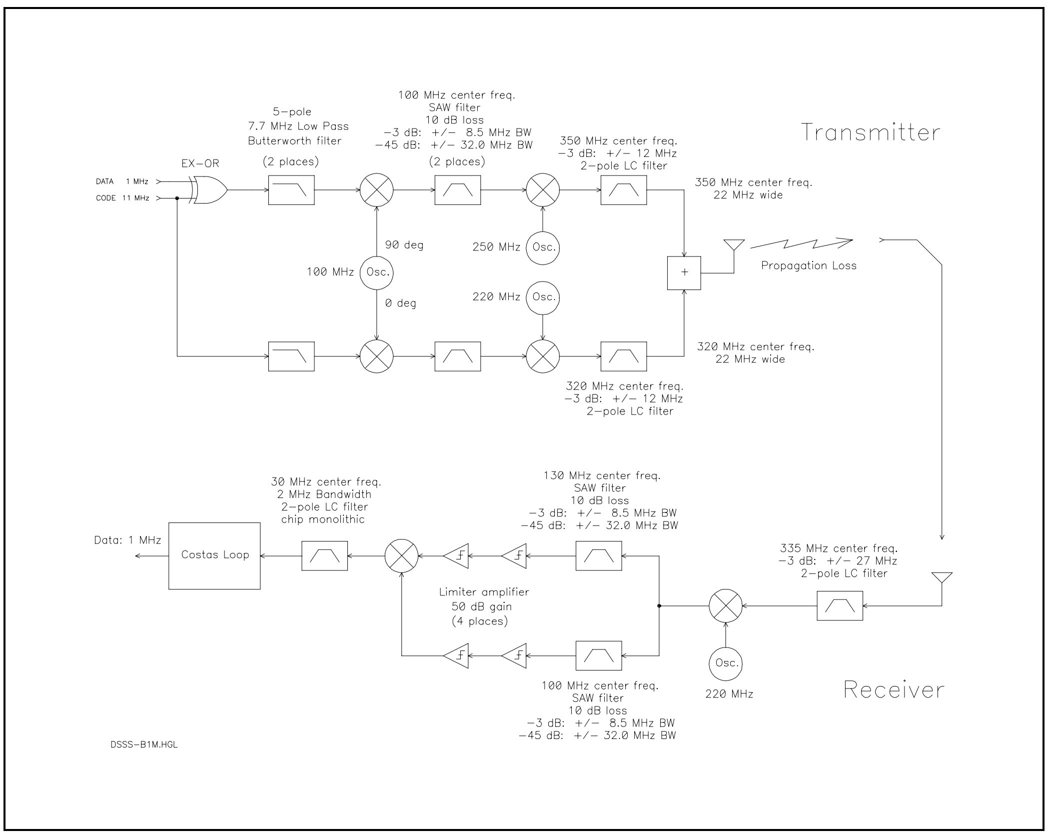


Figure 2. The example in **Figure 1** is shown with frequency scaling to permit a faster simulation time. The 2 and 3-pole filter bandwidths are not as wide as in **Figure 1**. Because the various frequencies are closer together, the filters are less effective in reducing out-of-band signals (the LO's).

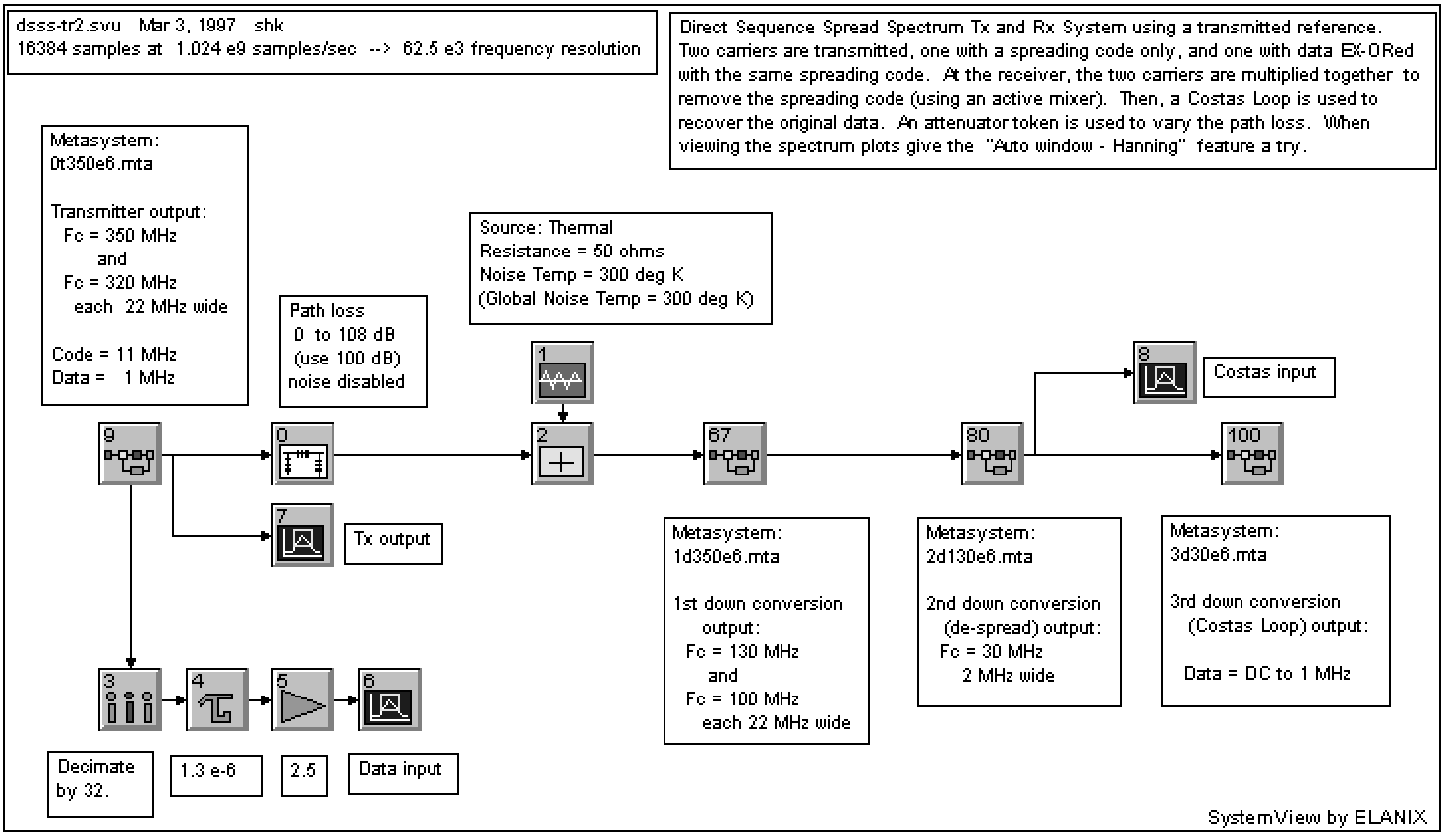


Figure 3. SystemView's opening window view of the Direct Sequence Spread Spectrum system, showing four metasystems: A transmitter, and three receiver down conversions.

## The TRANSMITTER -- Modulator

The transmitter portion of the system is contained in metasystem token (**Figure 4**). The input code and data are supplied by PN (pseudorandom) tokens. The spectrum of the code source (and the EX-OR gate) is the classic sin_x / x that has its side lobe down 13 dB from the peak of the main lobe. To meet the IEEE 802.11 spectral mask requirements of a -30 dB side lobe maximum, a 7.7 MHz 5-pole Butterworth filter is used to reduce the side lobes to be down to about 36 dB below the main peak. Non-linearity of the various mixers and amplifiers will cause this 36 dB value to grow towards the 30 dB value. To keep this spectral growth to a minimum in SystemView, an amplifier-multiplier metasystem is used instead of the usual active-mixer token. The harmonics of the square wave LO of the active mixer can alias with SystemView's sample rate. This can cause the side lobe to be only down about 25 dB from the peak (**Ref. 4**). The active-mixer will be used in the receiver portion of the system where the -25 dB side lobes can be tolerated. In **Appendix A**, **Figures 14**, **15**, and **16** show how the amplifier parameters are set to achieve the desired modulator output amplitude of both the main lobe and side lobe. The output of the transmitter is shown in **Figures 10** and **11**. Each filter is preceded by an attenuator to model the filter's loss. An additional attenuator in each path is used to set the final output amplitude. The FIR filters have a center frequency of 100 MHz. See **Appendix B** for the design details of the FIR filter.

**SAW Filter Simulation**

The surface acoustic wave (SAW) filter following the modulator is modeled by using a 100 MHz FIR filter that is set for a 2 dB ripple in its pass band. The 2 dB value causes the filter to have a smooth rounded top instead of the usual flat top. The parameters used in setting this filter (and the receiver's 130 MHz filter) can be found in **Appendix B**, **Figures 17**, **18**, and **Tables 1** and **2**. The sides of these FIR filters are not as steep as the intended SAW filters. To allow for a faster simulation 111 taps are used. More taps would produce a sharper cutoff filter and increase the simulation time. Since the FIR filter has a 10 dB loss, an attenuator is used before the filter to insert the desired noise figure into the system. This attenuator-before-a-filter plan is used for most of the filters in the system. The attenuator after the FIR filter is used to set the power output of the channel to +18 dBm. An article reprint from **Microwaves & RF** (**Ref. 5**) detailing a more accurate simulation of a SAW filter is available from ELANIX.

**IF to RF Converter**

An amplifier-multiplier metasystem is used again instead of the usual active-mixer token **(Figure 6**). This time the amplifier parameters have been set to the data book values for the desired mixer. Usually, not all the parameters required by SystemView are listed in a data sheet, and it may be necessary to convert a data sheet *input referenced* parameter to an *output referenced* parameter. For help on determining the value of a missing parameter, or input to output parameter conversion, please refer to **APPENDIX C** of the **SystemView -- A Guide to the RF / Analog Library**.

**Transmitter Power Pre-amp and Power Amplifier**

Following the IF to RF Converter is a chain of a pre-amp, and a power amplifier interspersed with three 2-pole filters. Both transmitting channels are summed to allow the use of only one attenuator in representing the path loss.

Continued on page 6.

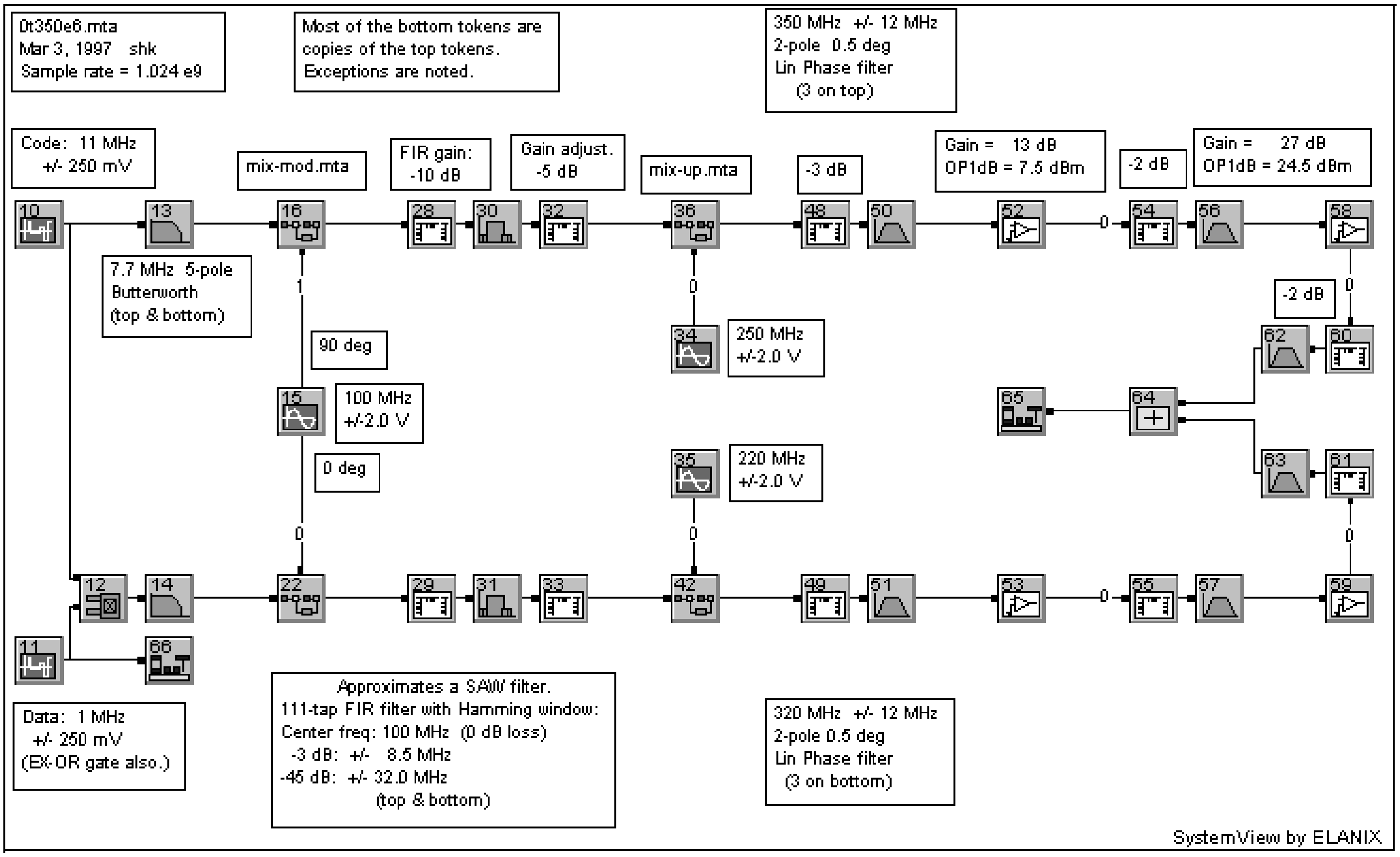


Figure 4. The transmitter section, including two mixer-modulator metasystems and two mixer-up-converter metasystems.

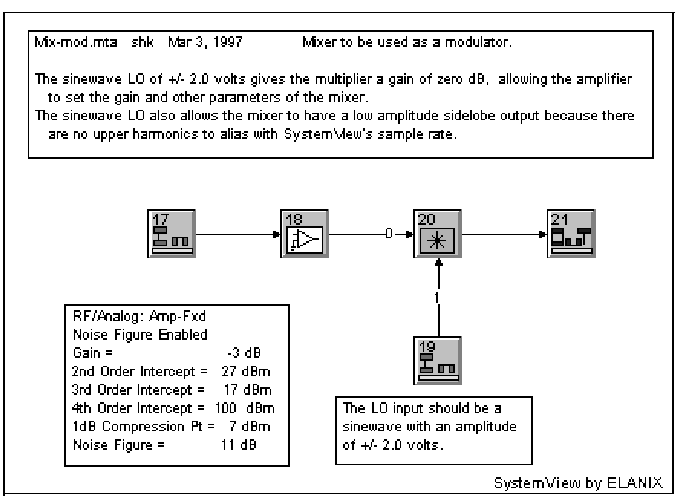


Figure 5. The parameters for the amplifier in the mixer-modulator metasystem have been determined experimentally by the system shown in **Appendix A**. With a given input, the output side lobes are down the desired amount.

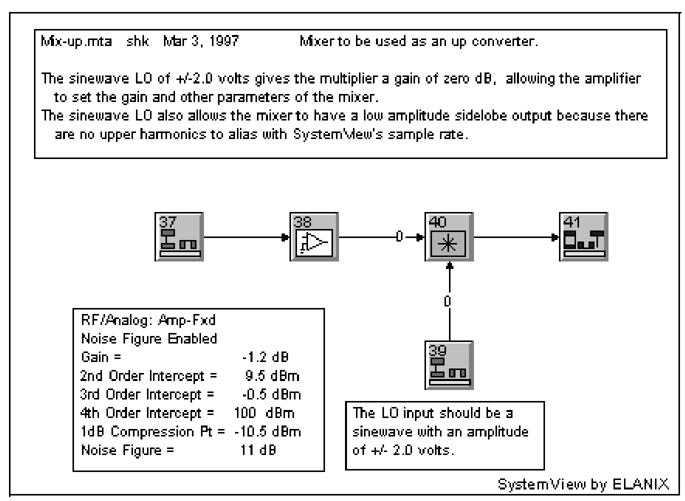


Figure 6. The parameters for the amplifier in the mixer-modulator metasystem have been set to the data book values for an up-converting mixer.

## The Receiver -- LNA, and RF to IF Converter

The receiver is comprised of three metasystems, one for each frequency conversion. The Low Noise Amplifier (LNA) and first down converter is shown in **Figure 7**. An active mixer is used with normal parameters except for the -80 dBm LO leakage. It necessary to reduce amount of the LO leakage because the frequencies of each stage have been set to be closer to each other making the stop bands of the various filters less effective.

## Limiting Amplifiers and de-Spreading Mixer

The input to the second down conversion stage (**Figure 8**) is separated into two channels using two FIR filters (100 MHz and 130 MHz, see **Appendix B**). Decimator tokens (decimate by 2) are used after the FIR filters to reduce the number of samples representing the data. This also reduces the system sample rate by 2. The result is a faster simulation and plotting time. There is a second decimation by at the output of the metasystem. Since the limiting amplifiers have a high gain (45 dB), the filters between the amplifiers are shown as having no loss in their pass band. The output of the de-spreading mixer is shown in **Figure 12**.

## The 3rd Down Conversion -- Costas Loop

The input signal (**Figure 12**) to the Costas Loop in **Figure 9** is a 30 MHz carrier modulated with the original 1 MHz data. The loops Voltage Controlled Oscillator (VCO) is the Frequency Modulator (FM) token. The VCO's gain parameter (2.4 MHz/volt) has been set to be consistent with a Mini-Circuits™ POS-50 linear tuning VCO. The output of the in-phase (I) and quadrature (Q) mixers is followed by a pair of pre-filters. These simple 2-pole filters remove most of the high side frequencies of the mixers, while the relatively high 10 MHz cutoff frequency allows the loop to lock-in rapidly. The pair of filters (500 kHz 5-pole Bessel) used for the sinks produce eye appealing plots. The classic RC loop filter (feeding the FM token) is followed by an inverting op-amp gain of -1/4. (When using an op-amp make sure that the feedback capacitor is an appropriate value.) **Figure 13** shows three overlaid plots. The Q output is a small amplitude wavy line, the I output is the filtered data that follows the original sharp-edged input data. The input data has been delayed to line up in this overlay. Also, with the Costas loop, the phase of the I output may be either 0 or 180 degrees relative to the input data. Normally, a data encoding scheme is used that is insensitive to the 0/180 degree output of the Costas loop.

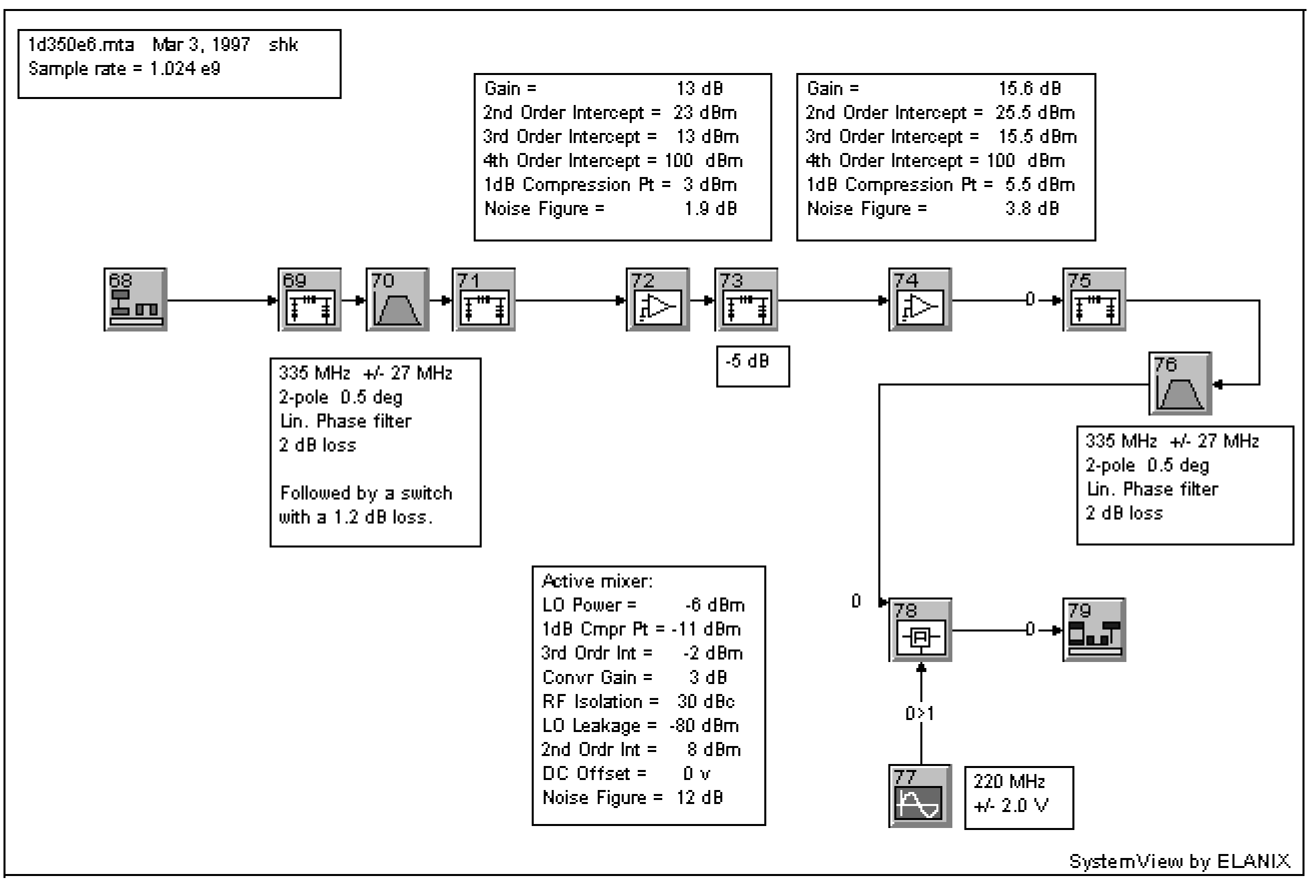


Figure 7. The first down-converter of the receiver includes the first active mixer used in the simulation.

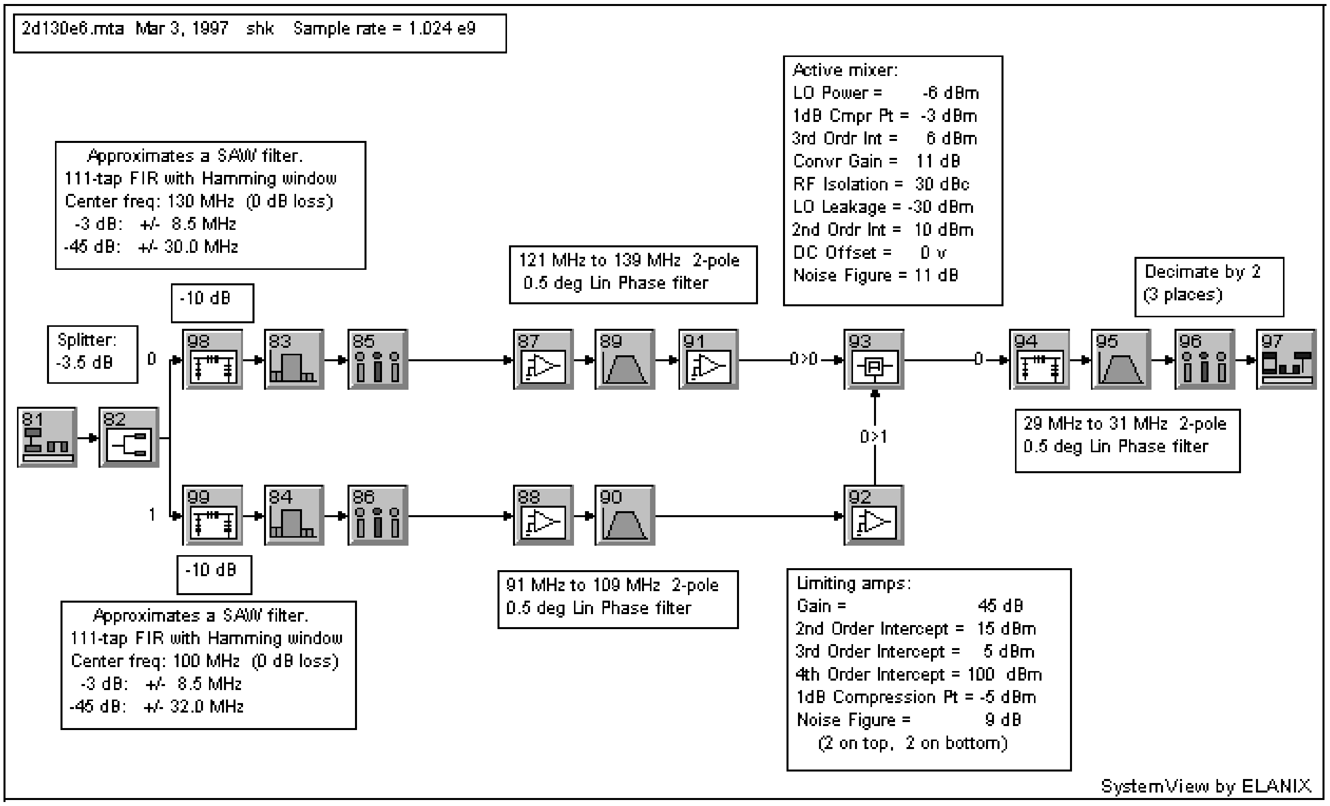


Figure 8. The second down-converter of the receiver features a pair of limiting amplifiers in each of the two channels. Because of the 3 decimator tokens in the system, the output rate of the system is ¼ (256 e6 samples/sec) of the input rate (1.024 e9 samples/sec).

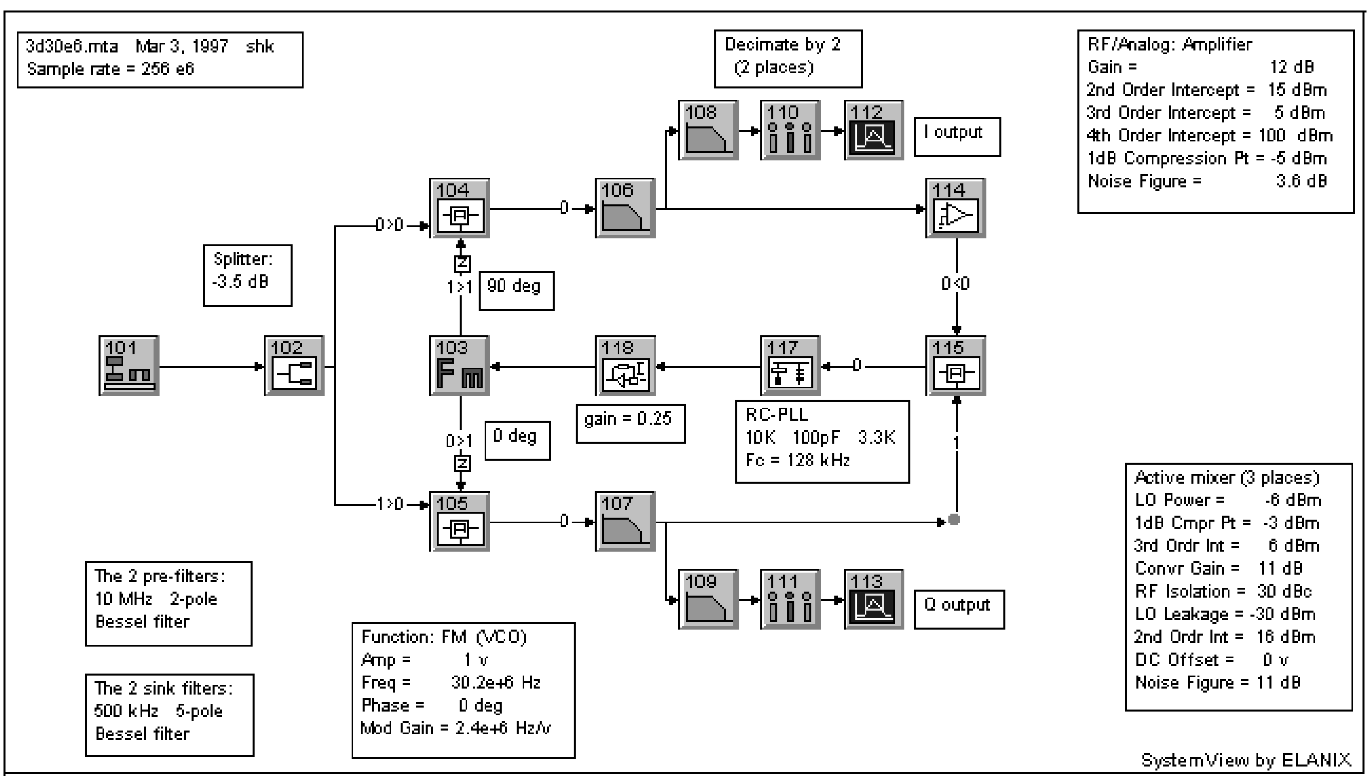


Figure 9. The third down-converter is a Costas-Loop Demodulator. The decimators in this system are used just to reduce the number of samples displayed in the output plot (saves some computer memory and speeds the plotting).

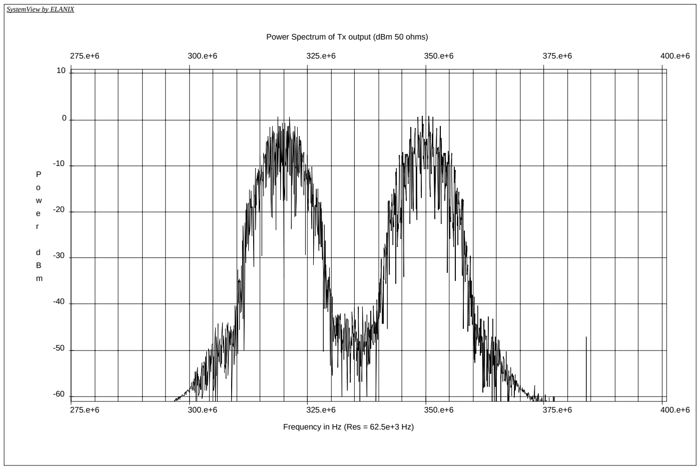


Figure 10. The output of the transmitter. A 22 MHz wide data-exor-code channel at 320 MHz, and a 22 MHz wide code-only channel at 350 MHz. The two attenuators in the transmitter have been set to give these output amplitudes.

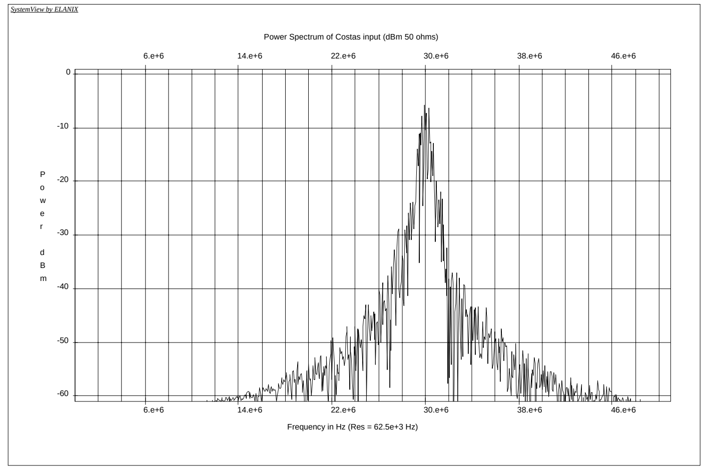


Figure 12. The de-spread output of the 2nd down conversion, 2 MHz wide centered at 30 MHz.

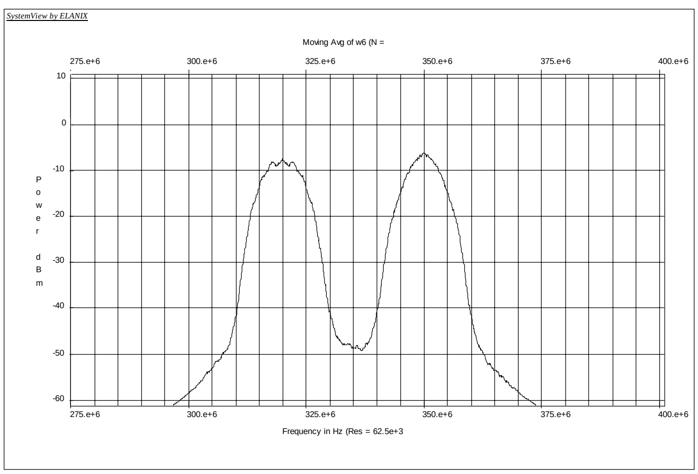


Figure 11. Performing a 50-point moving average on the spectrum in **Figure 10** clearly shows the peaks are at about -7 dBm. Please see **APPENDIX C** for details on this amplitude.

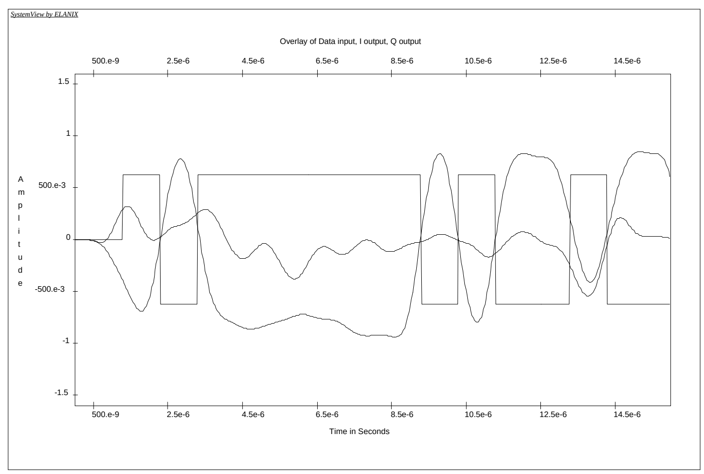


Figure 13. The perfect shaped input data along with the Costas loop I (data) and Q (near zero) output.

**Productivity**

The time to run the full Tx/Rx simulation on a 166 MHz Pentium Using the 32-bit version 1.9 of SystemView by ELANIX, Inc. and Windows 95 is summarized below.

| System samples | Data bits | Time (minutes) | Number of Loops |
|---:|---:|---:|---:|
| 16,384 | 16 | 1.9 | 1 |
| 131,072 | 512 | 15.4 | 1 |

**Conclusion**

The ease of simulating a direct sequence spread spectrum (DSSS) transmitting and receiving system has been shown. SystemView by ELANIX is equally at home with frequency hopping spread spectrum (FHSS) systems.

**More Information**

For more information on SystemView simulation software please contact: ELANIX, Inc. 5655 Lindero Canyon Road, Suite 721, Westlake Village CA 91362. Tel: (818) 597-1414 Fax: (818) 597-1427 or visit our web home page ( http://www.elanix.com ) to down load an evaluation version of the software that can run a simplified version (dsss.ev.svu) of this simulation as well as other user entered designs.

**References**

1. R. C. Dixon, *Spread Spectrum Systems*, "Transmitted-Reference Methods," pages 230 - 231, published by Wiley-Interscience.

2. R. M. Gagliardi, "A Geometrical Study of Transmitted Reference Communications Systems," IEEE Trans. Comm. Tech., December 1964.

3. R.W. Mifflin, and J. P. Wheeler, "Transmitted Reference Synchronization System," U.S. Patent 3,641,433 February 8, 1972.

4. SystemView example files, mix-sin.svu and mix-pn.svu, located in the following directory:
c:\SysVu_32\Examples\RfLib

5. Larry Burns, Microwaves & RF (magazine) February 1997, "Accurately Model SAW Filter Behavior" pages 85, 86, 88, and 89.

## APPENDIX A

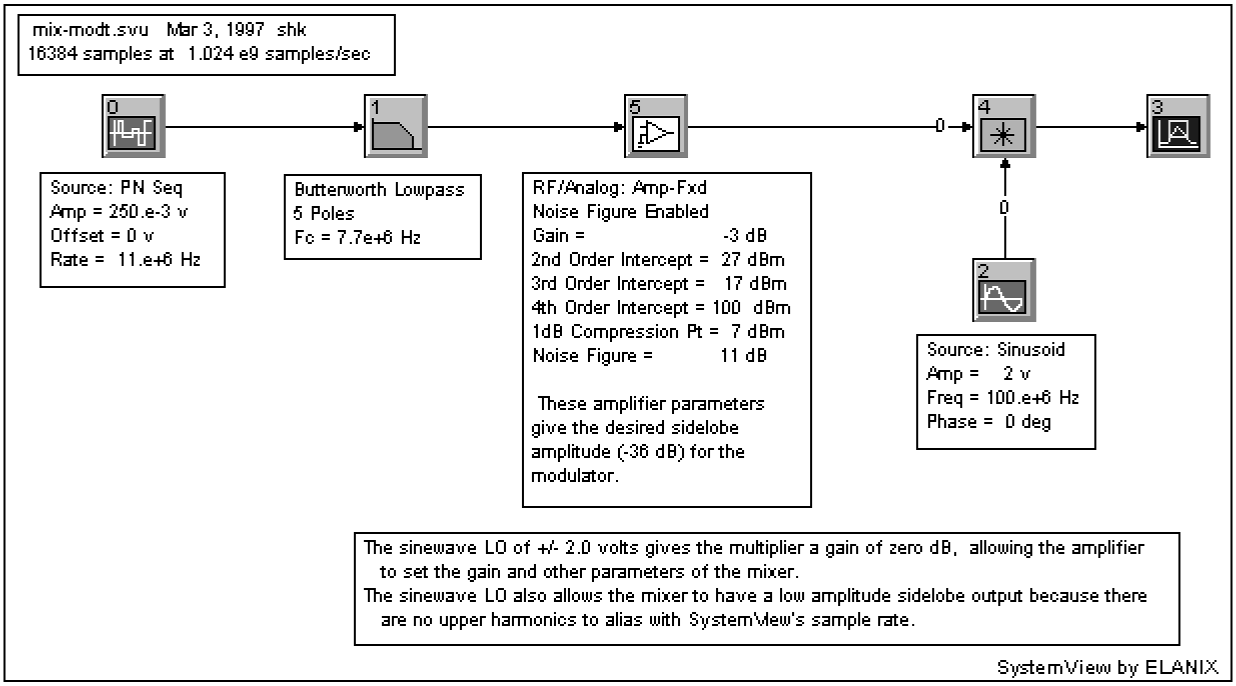


Figure 14. The test system used to set the amplifier parameters producing a main lobe peak of -24 dBm and a side lobe that is down 36 dB.

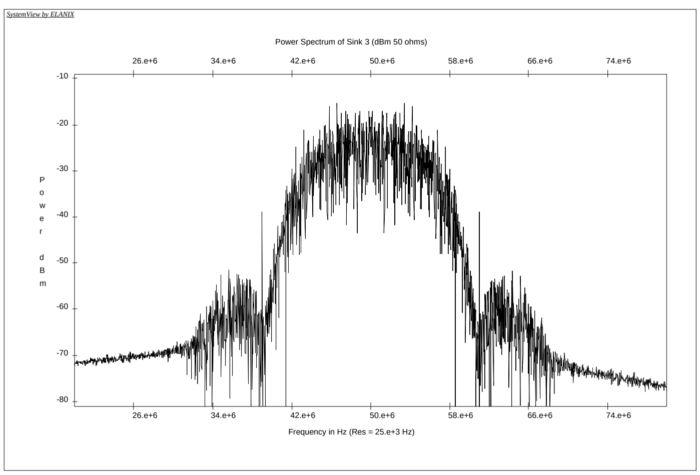


Figure 15. The output spectrum of the mixer showing a spectral line at each null due to the amplifier's Out IP2 term.

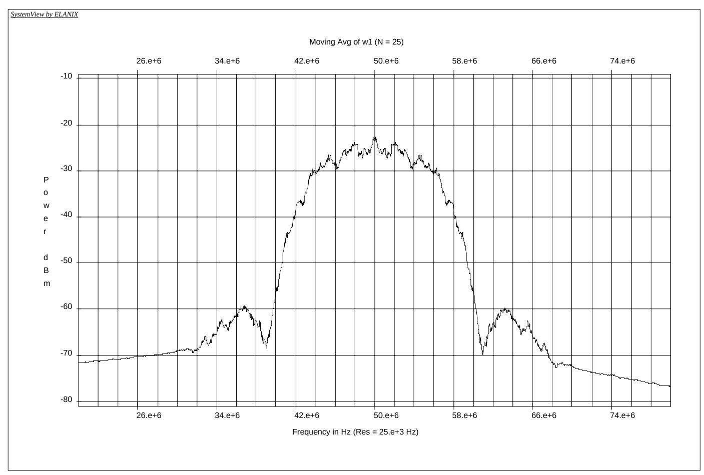


Figure 16. Performing a 25-point moving average on the spectrum in **Figure 17** clearly shows that the side lobe is down 36 dB.

## APPENDIX B

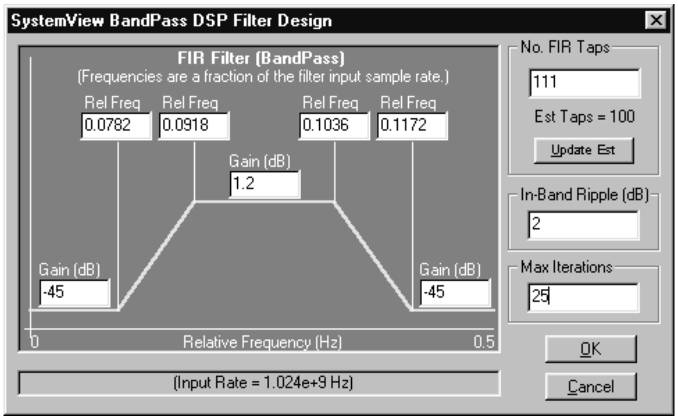


Figure 17. The SystemView FIR design window. In another design window, a Hamming window is applied to the design.

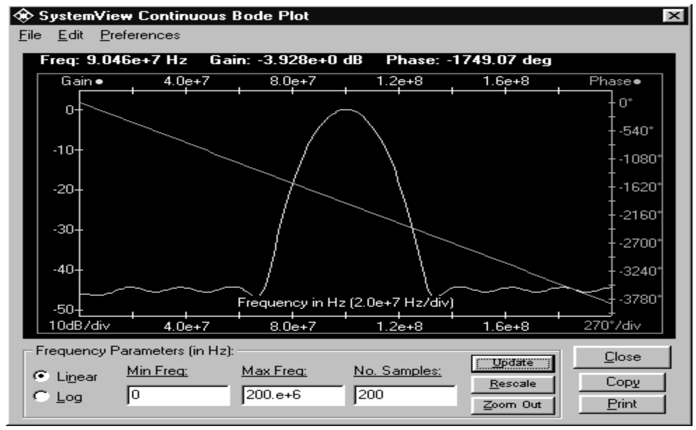


Figure 18. The resulting smooth rounding of the top due to using a 2 dB ripple factor in the design window.

# Parameters for the two different FIR Filters

| | | | | |
|---|---|---|---|---|
| 0.0782 | 0.0918 | 0.1036 | 0.1172 | Relative freq. (Fraction of sample rate) |
| 80 | 94 | 106 | 120 | Actual freq. (MHz) |
| | | | 1.2 | Gain in dB at center freq. |
| | | | -45 | Out of band loss in dB, low side |
| | | | -45 | Out of band loss in dB, high side |
| | | | 2 | Ripple in dB |
| | | | 100 | Recommended taps |
| | | | 111 | Taps used |
| | | | | Use Hamming window |
| | | | | Resulting bandwidths: |
| | | | -3 dB | +/- 8.5 MHz |
| | | | -45 dB | +/- 30 MHz |

Table 1. SystemView parameters for the 100 MHz FIR filter

| | | | | |
|---|---|---|---|---|
| 0.1075 | 0.1211 | 0.1329 | 0.1465 | Relative freq. (Fraction of sample rate) |
| 110 | 124 | 136 | 150 | Actual freq. (MHz) |
| | | | 1.2 | Gain in dB at center freq. |
| | | | -45 | Out of band loss in dB, low side |
| | | | -45 | Out of band loss in dB, high side |
| | | | 2 | Ripple in dB |
| | | | 100 | Recommended taps |
| | | | 111 | Taps used |
| | | | | Use Hamming window |
| | | | | Resulting bandwidths: |
| | | | -3 dB | +/- 8.5 MHz |
| | | | -45 dB | +/- 32 MHz |

Table 2. SystemView parameters for the 130 MHz FIR filter

**APPENDIX C**

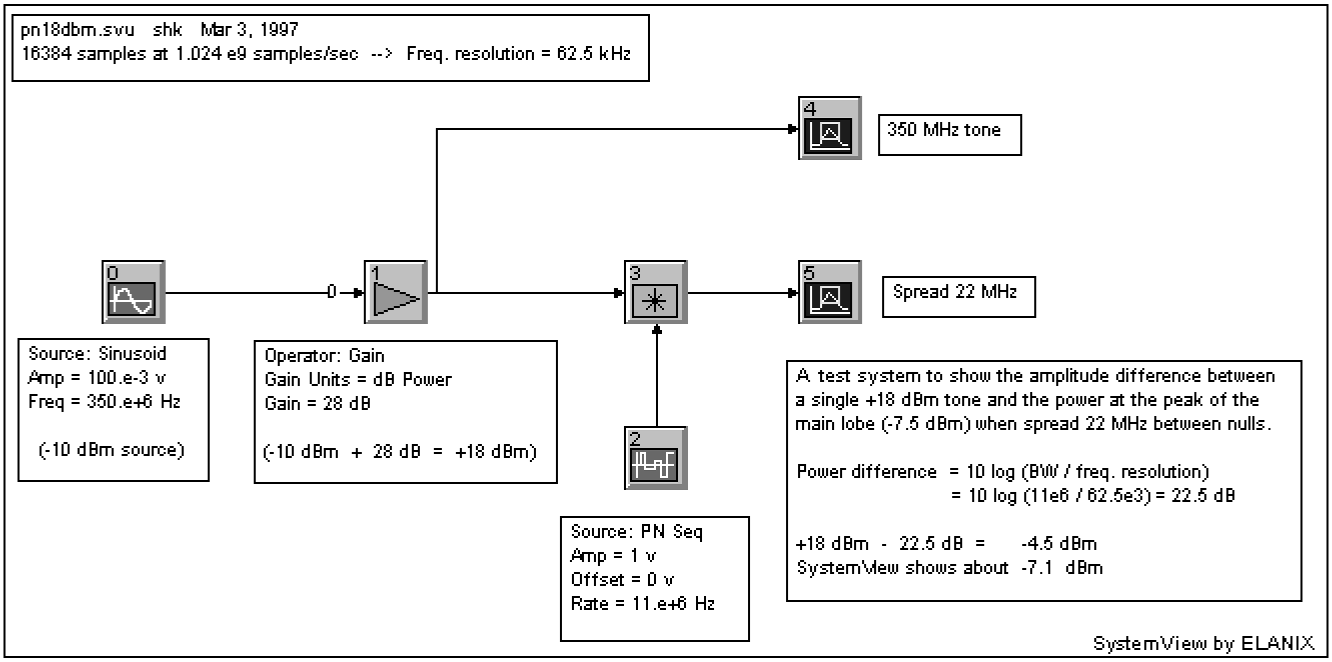


Figure 19. The test system used to help in setting the +18 dBm output amplitude of the transmitter.

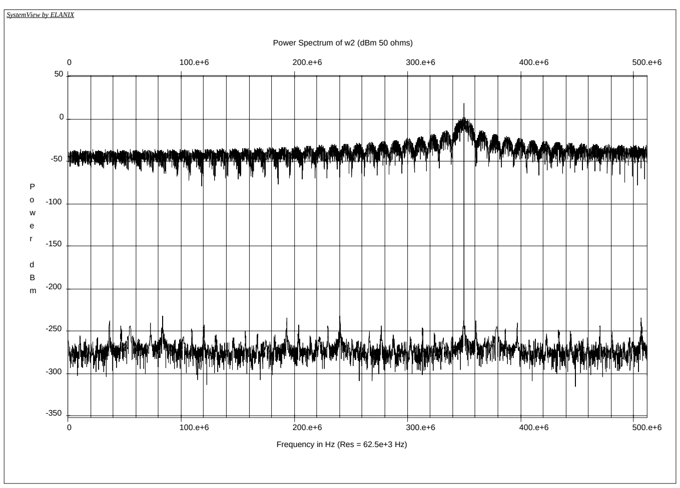


Figure 20. The +18 dBm tone is centered on the spread signal.

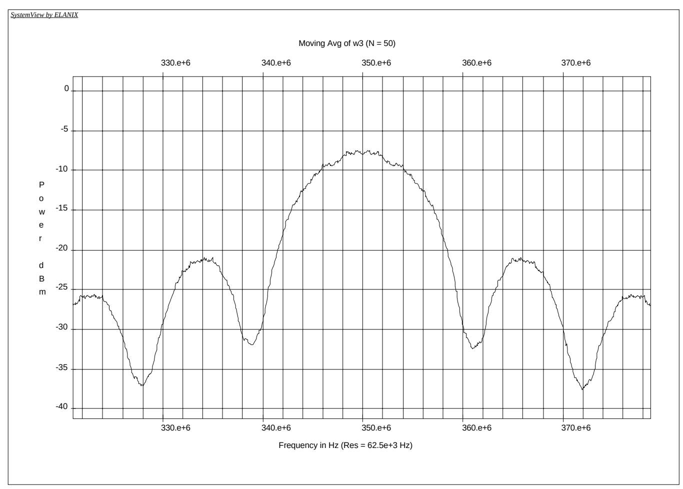


Figure 21. A zoomed-in view, after performing a 50-point moving average on the spectrum in **Figure 20**. The peak has an amplitude of about -7 dBm. (The 50-point moving average has removed the +18 dBm tone from the plot.)