SystemView Times

LEAD STORY

ELANIX Introduces Enhanced Filter Design Software for Satellite and Digital Comm Systems

ELANIX, Inc. introduced in March a powerful new version of its graphical filter design package available as part of the SystemView by ELANIX dynamic system simulator. This new filter design package gives designers the ability to design linear systems as Elliptic Filters and Sin t/t Filters and incorporate these filter types into their system simulation. These filters are essential for designers of modern digital and analog communication systems.

In addition to the new filter types available, ELANIX has added a new graphical interface that allows users to synthesize filters by dragging poles and zeros in a Root Locus plot representation of the system.

When designing modern digital communications systems designers require a complete range of linear systems. Elliptical filters, for example, are often used in the design of satellite communication systems. ELANIX's new Elliptical filter models provide full support for both analog and digital (DSP bit-true IIR) Elliptic filters. Designers may specify the number of poles, passband ripple, and stopband attenuation. They may also select lowpass, bandpass, or highpass filter types.

Sin t/t filters are of interest to engineers designing digital comm systems. ELANIX's new Sin t/t filter models are zero inter-symbol interference filters.

USER NEWS

New RF/Analog Library Simplifies IEEE 802.11 DSSS and BFSK System Simulation

ELANIX, Inc. proudly introduces a powerful new release of its RF/Analog Library. RF designers can now easily simulate a wide variety of systems, including applications such as Binary Frequency Shift Keying (BFSK), and spread spectrum systems with some features of the IEEE 802.11 specification. Noise figure can also be incorporated into the design. For analog systems, an expanded selection of Op-Amp circuits allows the design of Phase-Locked Loop (PLL) charge-pumps and circuits with hysteresis set by resistor parameters, just to name a few.

Also, the SystemView RF/Analog Library User's Guide has been updated with detailed technical explanations and notes that speed simulation model development.

Direct Sequence Spread-Spectrum (DSSS) Simulation

The IEEE 802.11 specification describes the implementation of a Direct-Sequence

SystemView Audio Enables Multi-Rate DSP Audio Processing

With the introduction of the new SystemView Audio Sources and Audio Sinks, ELANIX has opened the door to advanced audio signal processing for communications and DSP design engineers.

The new audio features include:

- Full support for monaural (1 channel) and stereo (2 channel) audio.

- Data may be 8- or 16-bits per audio sample.

- Playback and editing using SystemView's built-in tools and/or any Windows compatible multimedia devices/software.

- Complete visual (time and frequency) and aural (listen to the signal) access to the audio signal at any point within the system design.

- True multi-rate DSP audio processing, including up-sampling (interpolation) and down sampling (decimation).

Inside This Issue:

Spectral Analysis
Using Digital FFT Techniques

By Maurice L. Schiff, Ph.D., Chief Scientist, ELANIX, Inc.

Frequency domain or spectral analysis is a fundamental tool for engineering development. Despite such new analysis concepts as neural nets, wavelets, and higher order spectra, basic frequency domain analysis will remain the work horse analysis tool in the foreseeable future.

One change to spectral analysis that's becoming more prevalent is to use software tools such as SystemView by ELANIX, to perform the analysis as opposed to the standard test equipment approach using e.g. the HP 8568 spectrum analyzer. The difference brought about by the software analysis techniques is that the mathematical computations are digital in nature rather than analog. This fundamental change leads to several concepts which do not exist in the analog world.

The purpose of this article is to describe the concepts behind digital spectral analysis. The concept of the digital Fourier transform (DFT) will be derived, and some consequences of using this algorithm for spectral analysis will be discussed in detail.

The Fourier Integral and Its Digital Equivalent

The starting point is the basic definition of the Fourier transform pair,

$$H(f) = \int_{-\infty}^{\infty} h(t)e^{2\pi jft}dt$$

$$h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} H(f)e^{-2\pi jft}df$$

We recall that $P(f) = |H(f)|^2 \Delta f$ is the power in the signal h(t) in a narrow band of width Δf at the particular frequency f. The width Δf is the resolution bandwidth of the spectrum analyzer. The spectrum analyzer produces P(f) by filtering the signal s(t) with a bandpass filter centered at f, with a bandwidth Δf and then obtains the power by squaring the output. The output of the square law device is further smoothed by the video filter (B_{video}) of the spectrum analyzer.

The first thing to observe in the definitions above is that the limits of the integration are $\pm\infty$. In the real world you can only observe a signal over a finite time T. The first step then is to rewrite the expression for H(f) as,

$$H_T(f) = \int_0^T h(t)e^{2\pi jft}dt$$

The next step is to convert the above expression into a form that a computer can use. The basic technique is to evaluate the above integral numerically with the result expressed as,

$$H_T(f) = \Delta t \sum_{k=0}^{N-1} h_k e^{2\pi jfk\Delta t}$$

$$h_k = h(k\Delta t)$$

where Δt is the time spacing or sample time that is used to evaluate the integral. The sample rate is $f_s = 1/\Delta t$. For any frequency f, it is possible to calculate H(f). However, we desire H(f) over a range of frequencies in order to obtain the spectrum of the signal. Just like the time variable, the continuous frequency variable must be reduced to evaluation over a finite number of frequencies separated by a value Δf,

$$H(m\Delta f) = H_m = \Delta t \sum_{k=0}^{N-1} h_k e^{2\pi jmk\Delta t\Delta f}$$

The primary governing equation of DFT analysis is the relation,

$$\Delta t\, \Delta f = 1/N$$

from which the following important relations are derived,

Maximum frequency $\quad$ Fmax $= N\Delta f = 1/\Delta t = f_s$

Frequency resolution $\quad \Delta f = 1/N\Delta t = 1/T$

With this proviso, the DFT transform pair analogous to the continuous version given above is,

$$H_m = \sum_{k=0}^{N-1} h_k e^{2\pi jkm/N}$$

$$h_k = \frac{1}{N}\sum_{m=0}^{N-1} H_m e^{-2\pi jkm/N}$$

If h_k is a real function (as it will normally be), the relation

$$H_m = H_{N-m}^{*}$$

holds, where the * indicates complex conjugate. This relation implies that only the first N/2 values of H are unique. Thus, the maximum frequency, Fmax, can be modified to Fmax(useful) $= f_s/2$. This is, of course, Nyquist's sampling theorem.

DFT of a Sine Wave

Now let's apply the basic formula to the case where h(t) is a sine wave;

$$h(t) = \cos(2\pi f_0 t)$$

$$h_k = \cos(2\pi f_0 k\Delta t)$$

$$h_k = \cos(2\pi nk\Delta f\Delta t)$$

$$= [e^{2\pi jnk\Delta f\Delta t} + e^{-2\pi jnk\Delta f\Delta t}]/2$$

where we have chosen to represent the frequency in the form $f_0 = n\Delta f$, where n is not necessarily an integer.

Spectral Analysis
(continued from page 2)

For the discussion here, we need to only consider one of the complex exponential terms that describes the cosine function. Substituting h_k into the basic expression we have after some simplification,

$$H_m = \sum_{k=0}^{N-1} e^{2\pi j k(m-n)/N}$$

The above expression is a geometric series and can be evaluated in closed form as,

$$H_m = \left[e^{2\pi j(m-n)} - 1\right] \Big/ \left[e^{2\pi j(m-n)/N} - 1\right]$$

Finally, the power spectra $P_m = H_m H_m^*$ reduces to the simple form;

$$P_m = \sin^2[\pi(m-n)] \Big/ \sin^2[\pi(m-n)/N]$$

And now the fun begins!. Consider the case where n is an integer, and $m \neq n$. Then $P_m = 0$ since m is an integer also. When m = n, both the numerator and denominator are 0, and the limiting result is $P_1 = N^2$. Thus, when n is an integer, the digital spectra produces the intuitive result that P = 0 everywhere except at the desired frequency $f_n = n\Delta f$. In this case, we say that the input frequency is on an FFT bin. In short, it is exactly equal to one of the discrete frequencies computed by algorithm.

Bin Splatter

What happens if n is not an integer? This is the case where the DFT and the signal on a spectrum analyzer differ the most. The DFT result can be very confusing to someone seeing it for the first time. Analytic analysis is not useful here so we illustrate the point by showing the result in Figure 1 when n is an integer plus 0.5. In other words, the signal 'splits' the FFT bins.
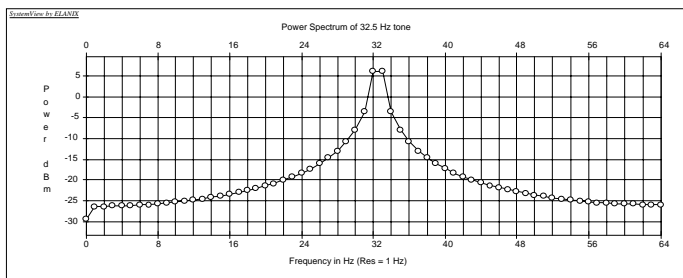

Figure 1 DFT of a 32.5 Hz tone with a DFT spacing of 1 Hz.

This is not at all what we expect. It looks like the tone has some modulation on it; it does not. The answer, however, is correct, and can be verified by directly calculating the ana-

lytical expression. Figure 1 shows what is called 'bin splatter'. Note how slowly the skirts decrease as a function of frequency (actually as $1/f^2$).

To obtain a more physical picture of what is happening return to the basic analog Fourier transform definition and evaluate it for the same sine wave. The resulting spectra is,

$$P(f) = \{\sin[\pi(f - f_0)T] / \pi(f - f_0)T\}^2$$

This expression has its maximum at $f = f_0$, and the nulls are separated at integer multiples of 1/T from this maxima. Let's see what happens if we evaluate P(f) for discrete frequencies which are multiples of 1/T which is the digital FFT resolution. In Figure 2, we evaluated P(f) for the case where $f_0 = 4$ Hz. Overlaid on Figure 2 is a sampling function corresponding to a 1 Hz FFT resolution. Note that at f = 4 Hz, we sample the maxima of the peak, while for any other sample the value is zero. The resulting sampled spectra is identical to the result discussed above. Now take the case where f = 4.5 Hz, as shown in Figure 3. The 1 Hz samples now intersect the spectrum as shown. The sampled spectra can be seen by the connected dots on Figure 3. This result is identical to the results of Figure 1.

In this article we have discussed some of the features of performing spectral analysis using a DFT especially as applied to power measurements of CW tones. The DFT results can be significantly different than what might be viewed on an analog spectrum analyzer. This is true whether using SystemView or any commercially available digital spectrum analyzer.

All is not lost however. In the next issue of the *SystemView Times*, the concept of "windowing" the time data before taking the DFT will be introduced. By applying the appropriate window to the data, the severe spectrum splatter described above can be virtually eliminated.
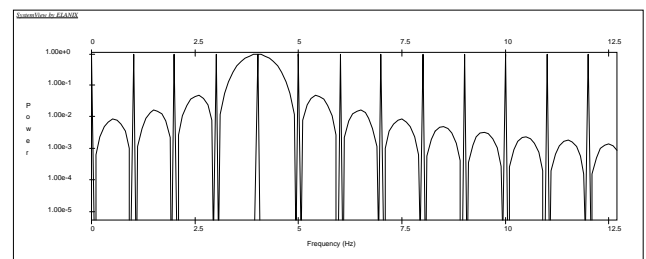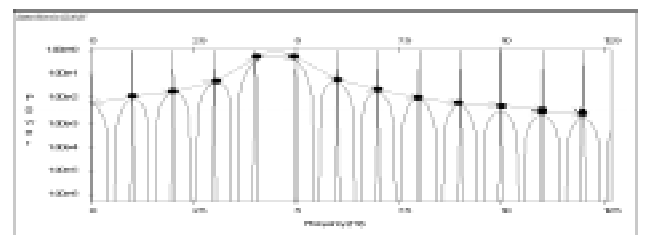

Figure 2 Sampled continuous spectra signal on FFT bin

Figure 3 Sampled continuous spectra with signal splitting FFT bin

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Simulating a Binary Frequency Shift Keying (BFSK) System Using SystemView 32

by Stephen H. Kratzet, ELANIX, Inc.

Two new application notes (AN113* and AN114*) are now available from ELANIX, describing the simulation of a Binary Frequency Shift Keying (BFSK) Transmitter/Receiver system, including a Bit Error Rate (BER) measurement. This article provides a summary of the system simulations described in AN113 and AN114. To receive your copies of these application notes, download from www.elanix.com, or call us at 818-597-1414.

The design begins with a block diagram typical of one that is produced at the beginning of a project. Some parts and frequencies are specified, and others are to be defined later.

First, the block diagram's frequency plan is modified to optimize the simulation time. Then the missing pieces of the block diagram are filled in. In application note AN113, a Butterworth filter is used in place of the specified raised cosine filter. In AN114*, the raised cosine filter is described, and compared with the simpler Butterworth filter. Also in AN114, a multiple-pass BER measurement is described.

The application notes described in this article have a total of 32 figures. Shown on this page are five of the 32 figures (Figures 1, 3, 8, 10, and 12).
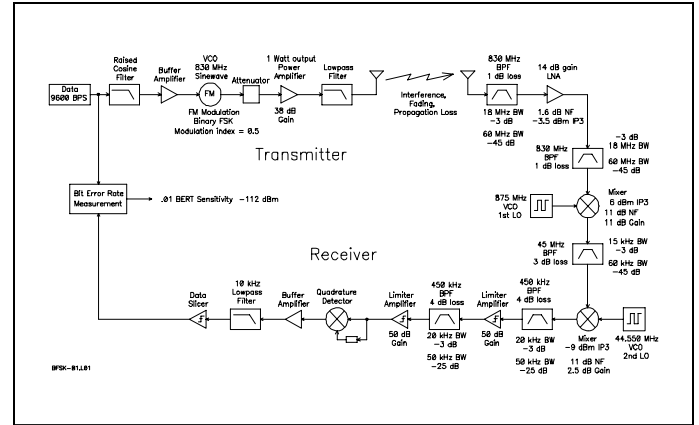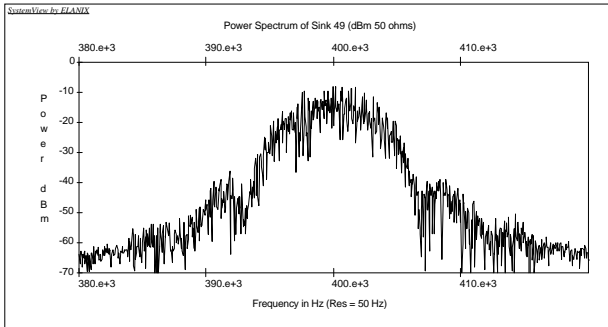

Figure 1: A typical BFSK Transmitter/Receiver system.

Figure 3: VCO output when driven with a 2-pole, 4800 Hz Butterworth filter. (65,536 samples at 3.2764 Msamples/sec).
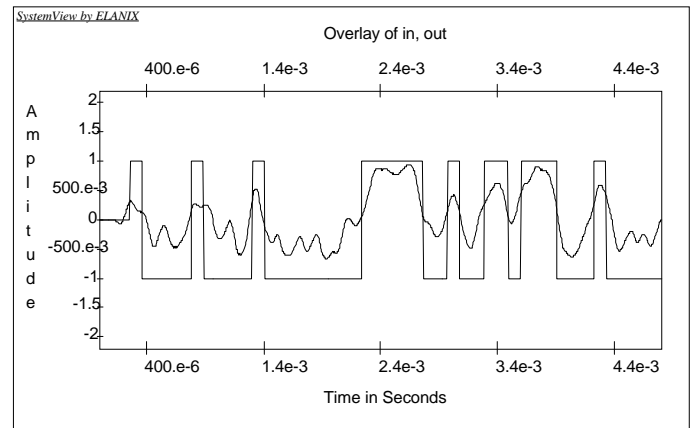

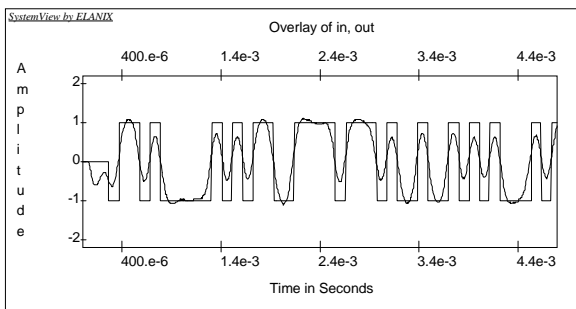*Figure 8: The perfect data input verses the output with a 50 dB path loss.*

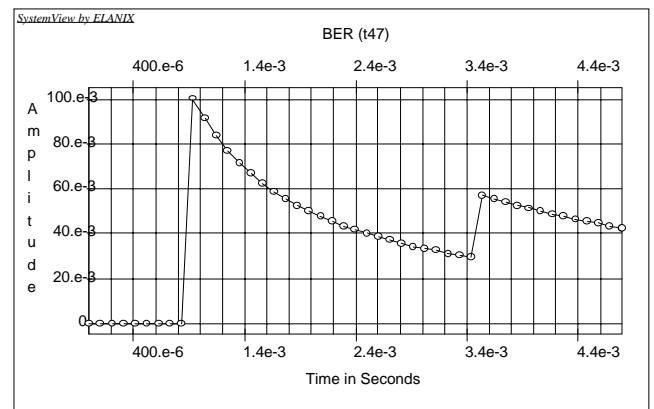*Figure 10: The perfect data input versus the output with a 148 dB path loss.*

Figure 12: The BER with a 148 dB path loss. ◆

*ELANIX Application Notes AN113 and AN114 describe this BFSK system in further detail.
Contact us at 818-597-1414 to receive your copy today.

Simulating the Cascaded Noise Figure of a Receiver Using SystemView 32

By Stephen Kratzet, ELANIX, Inc.

A new application note (AN110*) is now available from ELANIX describing a SystemView simulation that allows design engineers to quickly compare the noise factors of differing RF receiver topologies. This article provides a summary of the simulation described in AN110. To receive your copy of this application note, download from www.elanix.com, or call us at 818-597-1414 today.

An RF system is a collection of various filter, amplifier, and mixer processing blocks. These blocks either have gain or loss, but in either case they contribute noise to the output of a system. Although the overall function of a given system must remain unchanged, there are some design trade-offs that can be made to lower the noise present at the output of the system..

Noise Figure Simulation of an RF Receiver System

Only four types of tokens are required to simulate the noise figure of an RF processing system. Two tokens are from the main library: the *Thermal Noise* source token, and a sink token. The other tokens are from the SystemView RF/Analog Library: the *Amplifier* token, and the *Attenuator* token. The Source token represents thermal noise at the input to the system.

In the test system in **Figure 1,** two identical RF systems are run in parallel and their outputs are compared with each other. Because each token introduces its own noise, each simulation run will have slightly different output values as shown in **Figure 2**.

In **Figure 2,** the input filter has been split into two sections, each with half the attenuation of the original filter. The same losses and gains are present in the upper and lower systems, but they are distributed differently. After many simulations the noise outputs were always within 0.5 dB of each other. **Figure 4** shows the result of splitting the input filter, the output has about 2.6 dB less noise.
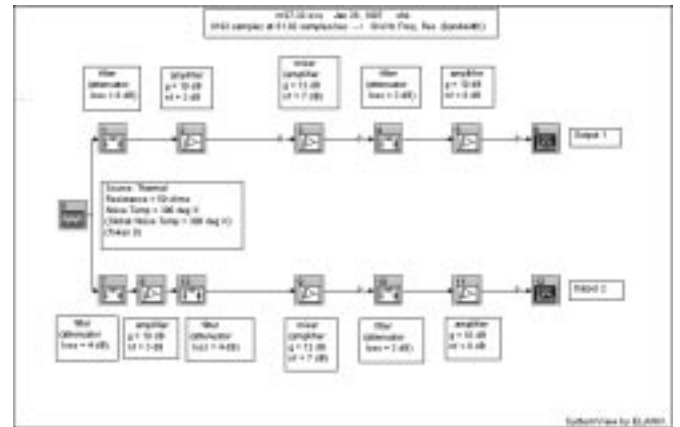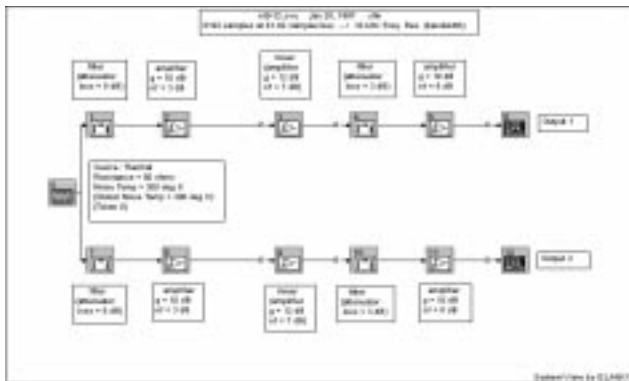

Figure 1: The two identical RF processing chains used to compare component generated noise.

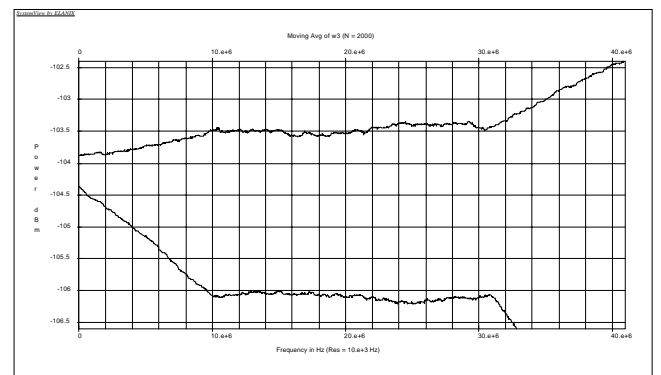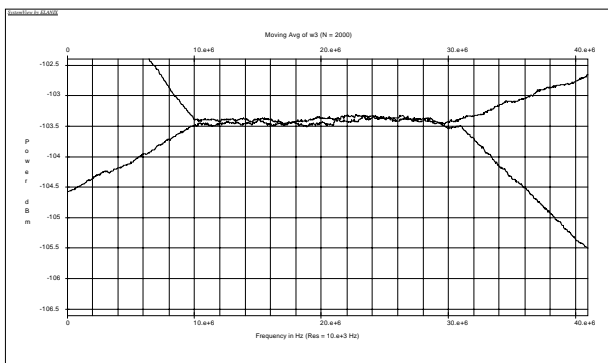*Figure 3: The lower input filter has been split into two sections.*

Figure 2: The noise outputs of two identical RF processing chains are within 0.5 dB of each other. Output 1 vs. output 2 after a 2000 point moving average on their spectrums. (dBm in 50 ohms).

Figure 4: Splitting the input filter into 2 sections lowers the noise in its path by about 2.8 dB. Output 1 vs. output 2 after a 2000 point moving average on their spectrums. (dBm in 50 ohms). ◆

*ELANIX Application Note AN110 describes this system in further detail.
Contact us at 818-597-1414 to receive your copy today.

Chaos Simulation

By Stephen Kratzet, ELANIX, Inc.

One of the new RF tokens in SystemView 1.9 is the Op-Hyst (OpAmp Hysteresis) token. It is the only non-linear token in the op amp library group. Any of the 3 resistors may be set to a zero or infinity (1e+18 ohms) value to simplify the circuit into an ordinary comparator circuit. However, as shown below, using all 3 resistors allows an op-amp circuit with positive feedback to be designed. This opens the door for some very interesting circuits.

One such circuit can be found in the SystemView example file \rflib\chaos.svu. This hysteresis circuit and several other op-amp circuits are connected together to produce a chaotic circuit. The resistor/capacitor values used in this example are from an article in **Scientific American**, August 1993, *The Amateur Scientist* conducted by Joseph Neff and Thomas L. Carroll, *Circuits That Get Chaos in Sync.* Also, in the same magazine issue, there is a related article, *Mastering Chaos,* by William L. Ditto and Louis M. Pecora.
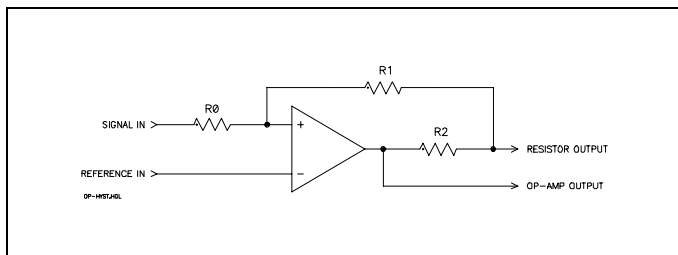

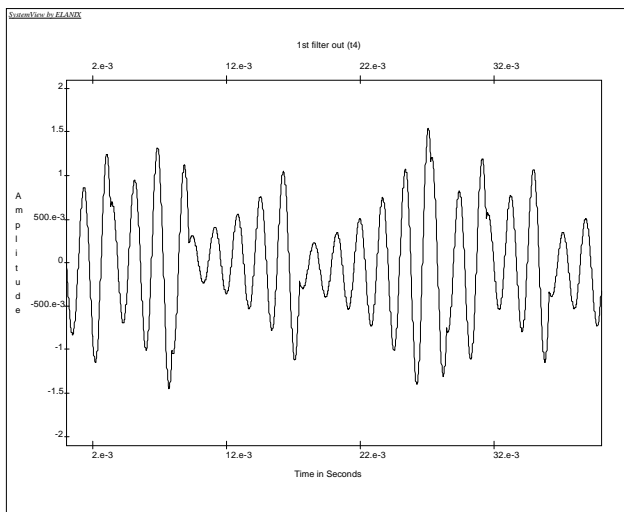*Figure 1. The circuit model of the Op-Hyst token.*

Figure 2. Chaos example, 1st filter output.

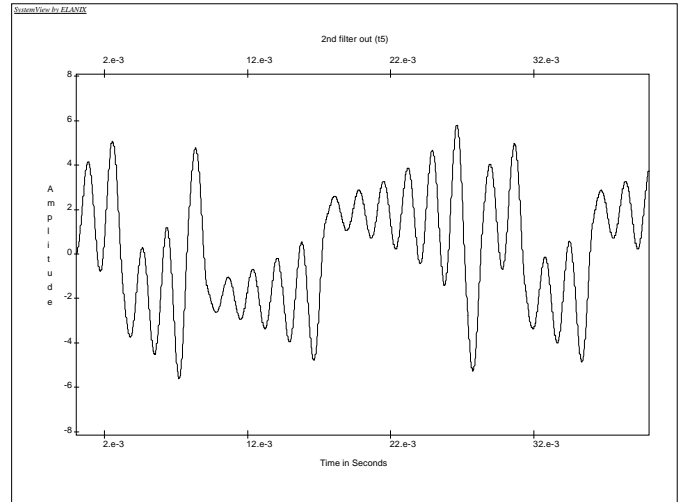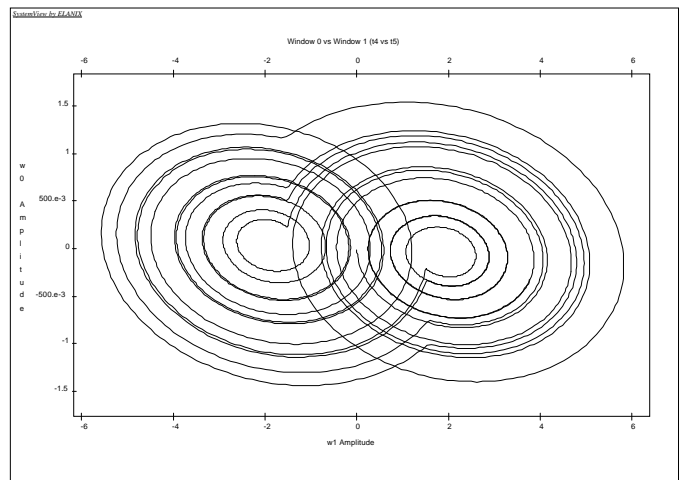*Figure 3. Chaos example, 2nd filter output.*

Figure 4. 1st filter output plotted against that of the 2nd filter output yields this chaotic attractor. ◆

SAW Filter Design

The February 1997 issue of Penton's *Microwaves & RF* Magazine (p. 85) features a technical article on SAW filter design using SystemView by 3Com Engineer Larry Burns. To receive a copy, contact ELANIX marketing at 818.597.1414. ◆

New RF/Analog Library
(continued from page 1)

Spread Spectrum (DSSS) system. Using the new SystemView RF/Analog Library, designers can now model such portions of the specification as IEEE 802.11 compliant: spreading codes, data rates, channel widths, channel spacing, spectral mask requirements, and output power. Application Note AN116 from ELANIX details the simulation of a DSSS system. In addition to the IEEE 802.11 portions, this system incorporates a transmitter and receiver with a path loss of 0 to 100 dB; a transmitted reference; filters, amplifiers, limiting amplifiers and mixers set to Wireless Local Area Network (WLAN) standard values; and Surface Acoustical Wave (SAW) filters. AN116 has an example SystemView file modeling the system described.

BFSK System Simulation
BFSK systems are commonly used in wireless applications. Application Note AN110 from ELANIX describes the implementation of a full Tx/Rx Binary Frequency Shift Keying (BFSK) system.

Highlights of this system include a transmitter/receiver (Tx/Rx) subsystem with BER measurement, a 2-pole Butterworth filter, and a raised-cosine filter. A procedure for multiple path testing is also described. AN110 also has an example SystemView file modeling the system described

New RF/Analog User's Guide
In SystemView, the designer will typically look up an RF or Analog circuit in a product data book, then enter the parameters. The new manual also includes an Appendix describing the noise figure calculation in SystemView. Finally, the manual includes detailed discussions of the use of each model in the library.

RF/Analog Library Enhancements.
A number of new circuits have been added to the SystemView RF/Analog Library for this release. These models include:

❏ <u>RC Charge Pump</u>. Complete charge pump circuit including four resistors around the two switches which model output leakage. This circuit can be used with the digital phase/frequency detector (Logic library) in your PLL designs.

❏ <u>Mixer-Active</u>. Distortion-true semiconductor active mixer model.

❏ <u>Op-Invert</u>. Inverting op-amp, gain set by the ratio of two resistors. The feedback resistor has a capacitor in parallel.

❏ <u>Op-Sum3</u>. Three-input inverting op-amp, gain set by the ratio of resistors. The feedback resistor has a capacitor in parallel.

❏ <u>Op-I-Dump (Integrate and Dump)</u>. Inverting op-amp, integrator with a switch across the feedback ca-

pacitor. Resistor in series with the switch and with the capacitor.

❏ <u>Op-PLL2</u>. A differential input PLL filter intended for use with the phase/frequency detector as outlined in ELANIX Application Note AN102.

❏ <u>Op-Schmit</u>. A non-inverting op-amp circuit with positive feedback using three resistors. Models a comparator with hysteresis, switch points set with resistor values. Also provides a nonlinear element useful in applications such as Chaos circuits.

❏ <u>Atten-Fixed</u>. Passive attenuator useful for introducing loss and noise (noise figure) into filter systems, etc.

❏ <u>PLL-RC1</u>. This model has been modified with an additional capacitor useful for setting a third break point for the PLL filter. ◆

Brain Teaser

Each issue of the *SystemView Times* contains a "brain teaser". This one caused a storm of debate when it first appeared in the magazine section of a Sunday newspaper:

You are a contestant on a quiz show. The host shows you three doors and informs you that behind one door is a prize; behind the other two doors are goats. He asks you to pick a door (e.g., #1); then he opens one of the other two doors (e.g. #2) which has a goat. You are given the chance to switch to the remaining door (#3). **Question: Should you switch?**

Last issue's solution:

A student writes home with the following message. How much does he want?

$$
\begin{array}{r}
\text{SEND} \\
+\text{MORE} \\
\hline
\text{MONEY}
\end{array}
$$

The key to the answer is to realize that M=1. When adding two four-digit numbers (SEND + MORE) to get a five-digit number (MONEY), the only possible value for the first digit (M) is 1, even if the numbers are both maximized to 9999. If M=1, S must be equal to 8 or 9. If it was less than 8, SEND + MORE would not equal a five digit number. Through trial and error, you can determine the remaining values.

$$
\begin{array}{rr}
\text{SEND} & 9567 \\
\text{MORE} & 1085 \\
\hline
\text{MONEY} & 10652
\end{array} \quad \blacklozenge
$$

Audio Processing
(continued from page 1)

• Bit-true and distortion true audio processing using SystemView's audio-compatible DSP and RF/Analog tools.

• End-to-end (audio input, audio output) comm system design and test.   ◆

Enhanced Filter Design

(continued from page 1)

Designers can use these filters to improve BER performance in their systems.

Analog filter design within SystemView has been greatly improved with the introduction of a new "Convert To Laplace" function. When this option is selected, the Laplace window opens with the number of sections and s-domain co-efficients for the exact filter the user has defined (lowpass, highpass, bandpass, Bessel, etc.). The coefficients can be used in a hardware design, the designer can modify the coef-ficients, and even move the poles and zeros with the mouse.

The new graphical interface allows users to design linear systems by using the mouse to physically move the poles and zeros in the SystemView Root Locus window. Simply click and drag the pole or zero to the desired location. You can then observe the results in either the Linear System plot win-dow or the Bode Plot window. ◆

Current SystemView Version Numbers

32-bit Professional:	version 1.9
32-bit Evaluation:	version 1.9
16-bit Professional:	version 1.8-7
16-bit Evaluation:	version 1.8-7

Mark Your
✔
Calendar

- **June 11 - 13**
 Blacksburg, VA; Virginia Tech Symposium on Wireless Communications; Bob Bublitz & Joel Kirshman, ELANIX, Inc.

- **September 15-17**
San Diego, CA; DSP World Expo; Dr. Maurice Schiff, Bob Bublitz, & Joel Kirshman, ELANIX, Inc.

- **October 7 - 9**
San Jose, CA; High Level Electronic System Design Conference; Dr. Maurice Schiff presents classes on Digital Communications system design and Spread Spectrum system design. ◆

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❑ SystemView Communications Library

❑ SystemView DSP Library

❑ SystemView Logic Library

❑ SystemView RF/Analog Library

❑ SystemView User Code Option (Create your own custom tokens!)