Intusoft Newsletter

Personal Computer Circuit Design Tools

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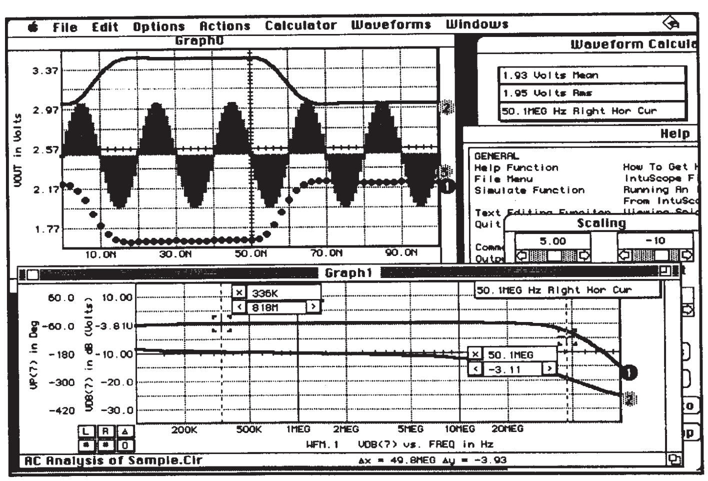
THE ULTIMATE SPICE POST PROCESSOR

Intusoft introduces INTUSCOPE for the Macintosh, a giant step forward in SPICE data post processing. IntuScope 3.0M uses the Macintosh interface to its fullest extent. A complete on-line help system, advanced waveform scaling window, and powerful waveform calculator make data display and analysis simple. The key word for INTUSCOPE 3.0M is easy. All the powerful features are at your fingertips. There's no complex commands, no hidden tricks, just one easy to use powerful data post processor.

In This Issue

INTUSCOPE generates report quality output supporting laser and dot matix printers, and output to popular desktop publishing programs. INTUSCOPE is an excellent alternative to other graphics data processors as it not only works with ISSPICE, but also any Berkeley SPICE 2G.6 compatible program and user generated data files. INTUSCOPE for the Macintosh is compatible with the new PC version of IntuScope (3.0), allowing data to be exchanged between platforms. For those PC users who have been patiently awaiting INTUSCOPE 3.0 for the PC, the release is just around the corner. We appreciate your patience. The May newsletter will contain ordering and technical information on the PC update.



Switched Capacitor Network Filters

Integrated circuit filters using reconfigurable switched capacitor biquadratic elements are widely available. In this application note, we shall develop the SPICE models for some of the more popular devices and explore IsSpice simulation techniques applicable to these components. Three sample circuits, including a low-pass filter, a band-pass filter, and a speech formant synthesizer will be developed and simulated using AC and Transient analyses.

We will begin the modeling discussion with the actual switched capacitor topology, realized with ideal switches, to establish a baseline. From this baseline we will show how to make a Z transform model and a Laplace transform based model. Any of these three models can be used to represent a switched capacitor filter, each having some advantages and limitations. The applicability of the different models will be explored in connection with several applications.

Switched Capacitor Integrators

Switched capacitor networks, SCN's, are based on the use of switches and capacitors to transfer charge. The network shown below is a commonly used 2 phase clock parasitic insensitive network described by Temes and Gregorian [1]. Using different clock phase and terminal connections, the network can be made into an integrator or summer with positive or negative gain.

The problem with the switch based integrator model is the

$$Vo(n+1) = Vo(n) + \frac{Ci}{Co}(Va(na) - Vb(nb))$$

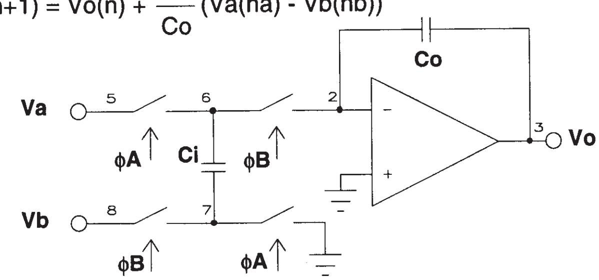


Figure 1, A two phase switched network; can be used to create an integrator or summer. The transfer function is shown above.

inability to use the AC analysis features of IsSpice to examine the frequency response, since in the AC analysis, the circuit is linearized about its nonlinear operating points. For two phase networks, this results in an opening of the path between the input and output, resulting in no signal transmission and no gain at all. Frequency response can be found by running a transient analysis and performing a Fourier transform. However, the transient simulation must run for many cycles with a large number of computations per cycle making most simulations impractical. The AC analysis is much more efficient and can save 2 to 3 orders of magnitude in simulation time if the proper continuous time models can be developed.

Making Continuous Time SCN Models

There are two approaches to making continuous time models, first, one can replace the SCN integrators with Laplace domain integrators; second, a Z transform equivalent circuit can be substituted.

Laker [2] and Meares [3] have developed Z transform techniques for making SPICE models. A thorough explanation of the Z transform SCN models can be found in the new "Spice Applications Handbook" and the "Simulating With Spice" book. These models are based on a charge model in which current is modeled as the analog of charge. Even and odd interval switch states (voltage and charge) in the system of equations are modeled separately in the circuit topology. Figure 2 shows the actual switched capacitor

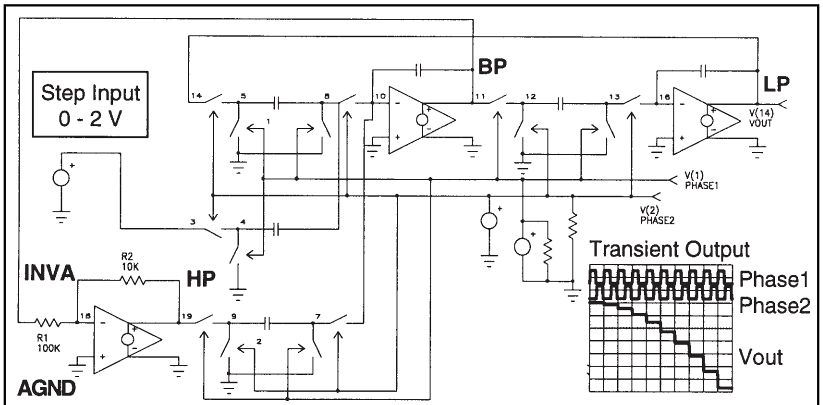


Figure 2, Low-pass switched capacitor filter using actual switches; standard IsSpice AC analysis will not work using this topology.

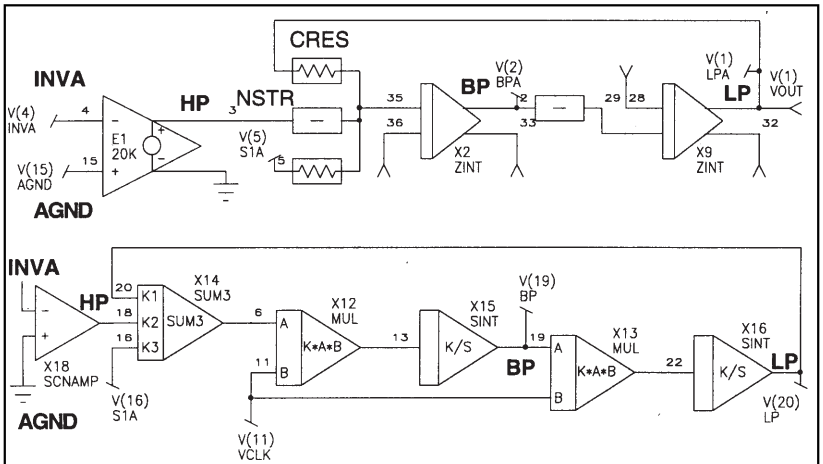


Figure 3, Low-pass filter using Z transform (top) models and Laplace (bottom) domain models. The signal names in bold correspond to the connections on the LTC1060 and equivalent components.

topology for a biquadratic low-pass filter along with the corresponding connections as they relate to the LTC1060 SCN filter. Figure 3 shows the same low-pass filter implemented using Z transform and Laplace equivalent circuits. The positive and negative "storistor" (PSTR and NSTR) and "capacitive resistor" (CRES) blocks used in the Z transform circuit are described in [3].

The Laplace transform models are simple building blocks taken from the analog computer library included with the PreSpice package. The blocks are built out of basic IsSpice elements and can be hooked together to represent complex functions. The generic nature of the elements allows them to be reconfigurable. In addition to SCN models, the analog computer functions can be used to perform system analysis, solve differential equations, and much more. The models can be used in both AC and transient analyses.

The test configuration for most of our discussions on SCN models will use the external components shown in Figure 4. The SCN model being developed is for the Linear Tech. LTC1060, a universal filter block. The LTC1060 has other commercial equivalents, for example, the MF10 from National Semiconductor. A number of similar SCN filters can

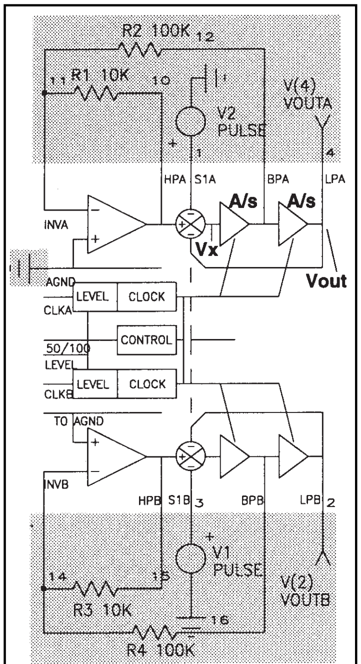


Figure 4, Schematic of a low-pass filter using the new SpiceNet symbol for the LTC1060. Shaded areas are external components.

easily be built out of the elements developed for the LTC1060.

The configuration shown to the left makes a low-pass filter with 20 dB overshoot (Q = 10). The equations governing operation are:

$Vout = A / s * A / s * Vx$, where
$Vx = - A_2 * Vout * s / A - Vout - Vin$
and $A_2 = R1/R2$

The transfer function; G = Vout / Vin is;

$$G = - A^2 / (s^2 + A * A_2 s + A^2)$$

The natural frequency, Fn, is defined for $(2\pi Fn)^2 = A^2$

and $Q = G(f = Fn) / G(f = 0)$
$= A^2 / (A_2 * 2\pi * Fn * A)$
$= 1 / A_2$
$= R2/R1$

For a switched capacitor integrator, the gain A is given by:

$A = Ci / Co * Fclk$, which is the constant of integration

Then, $Ci / Co * Fclk = 2\pi * Fn$, and $Fclk / Fn = 2\pi * Co / Ci$,

For the SCN "gain" specification of 100, Co / Ci is then 16.

Actual values used by Linear Technology for the LTC1060 are 32 pF for Co and 2 pF for Ci; the 50 gain setting is accomplished by changing Ci from 2 pF to 4 pF. The constant of integration , A, then evaluates as 31.25K for the Laplace model. The "Constant" of integration in the Laplace model was made a simulation variable in order to make Fclk a control system variable. This allowed the Fclk signal to control the filter's center frequency. Unfortunately, this degree of freedom is unavailable for the Laker model since the transmission line delay time used to make Z transforms cannot be varied during the simulation.

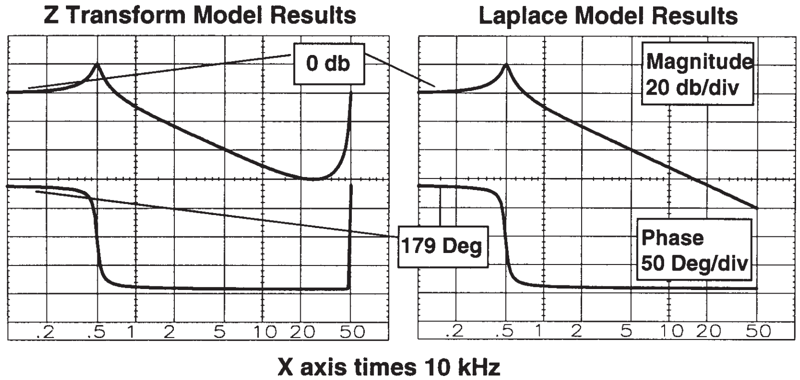


Figure 5, AC analysis of an SC low-pass filter. Z transform results reveal an accurate response near the Nyquist frequency. Both models give virtually the same response at frequencies in and around the passband.

Figure 5 compares the AC analysis results of the low-pass filter using Z transform and Laplace models. Figure 6 compares the transient results for all three models which gives reasonable results; with the main difference being simulation time. Use of the Laplace model is preferable to both the Z transform and switch models because of the faster (1 to 2 orders of magnitude) transient analysis. However, the Z transform model is more accurate near the Nyquist or folding frequency. The Z transform frequencies in the neighborhood of the Nyquist frequency are equivalent to the Laplace transform model in the neighborhood of infinite frequency. All zero's at infinity map to the Nyquist frequency, causing the DC response to be replicated. Depending on the circuit topology, this may cause magnitude and phase errors near the Nyquist frequency for the

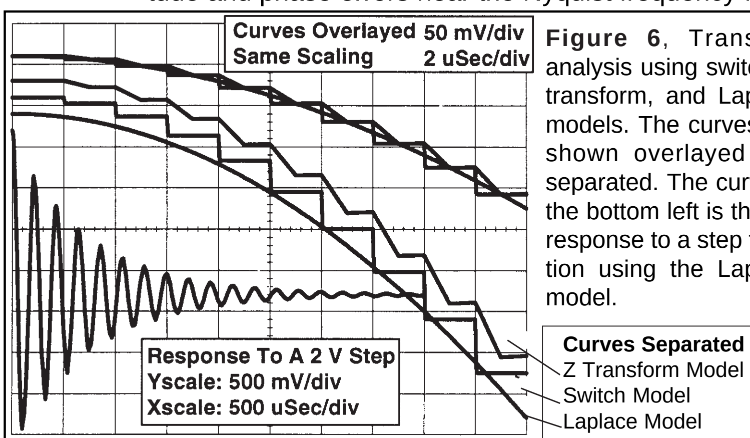
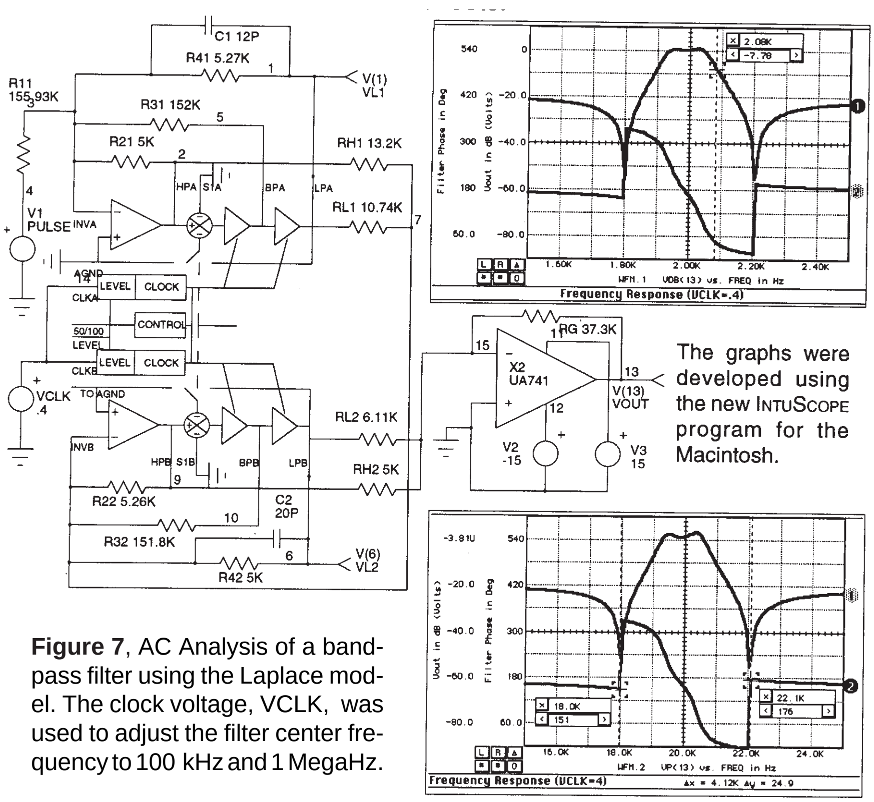


Figure 6, Transient analysis using switch, Z transform, and Laplace models. The curves are shown overlayed and separated. The curve at the bottom left is the full response to a step function using the Laplace model.

Laplace model. However, errors in the Laplace model are not a problem for most filters using SCN's because the region of interest is 2 decades below the Nyquist frequency. However, some interesting applications let a filter pass-band approach the Nyquist frequency in order to get a steeper transition region. Other applications operate filters above their Nyquist frequency in order to get higher frequency bandpass operation or hetrodyne signal detection. For these applications, the Z transform model is necessary.

A SCN Bandpass Filter

The Laplace model gives acceptable results in the majority of cases for both AC and time domain analyses. Figure 7 shows a standard bandpass circuit in which the clock frequency is used to sweep the filter's center frequency. The 2 AC analysis curves are taken for the same operating point as is shown in the Linear technology data sheet for the LTC1060. The transfer function prediction is in good agreement with the data sheets.



The graphs were developed using the new IntuScope program for the Macintosh.

Figure 7, AC Analysis of a bandpass filter using the Laplace model. The clock voltage, VCLK, was used to adjust the filter center frequency to 100 kHz and 1 MegaHz.

A Speech Synthesis Problem

Applying this filter to a speech synthesis problem gives some insight into the complexity of analysis that is possible using IsSpice. First, the voicing signal source was made using 2 over modulated FM signal generators. The first generator used a 100 Hz carrier with a modulation frequency of 300 Hz and a modulation index of 5. The second generator tripled the frequencies of the first. Figure 8 shows the resulting time domain waveform along with an arbitrary sinusoidal formant control function and the resulting output. Simulation time using a 33 MegHz 386 and IsSpice/386 was 17 minutes and 54 seconds for 50 msec of real time data. The simulation time estimate for a time domain model using switches and based on the data from Figure 6, would be over 200 Hours; needless to say we didn't even try to run that configuration.

Getting More SCN Filter Models

The listings for the LTC1060 model (Laplace and Z transform versions) are shown. There are a number of options associated with the LTC1060 that affect the model topology. They include the variable gain setting (50/100) and the Sa/b summer select switch. The various models, test circuits, and SpiceNet symbols for these variations are available by contacting ***intusoft***. Z transform and Laplace

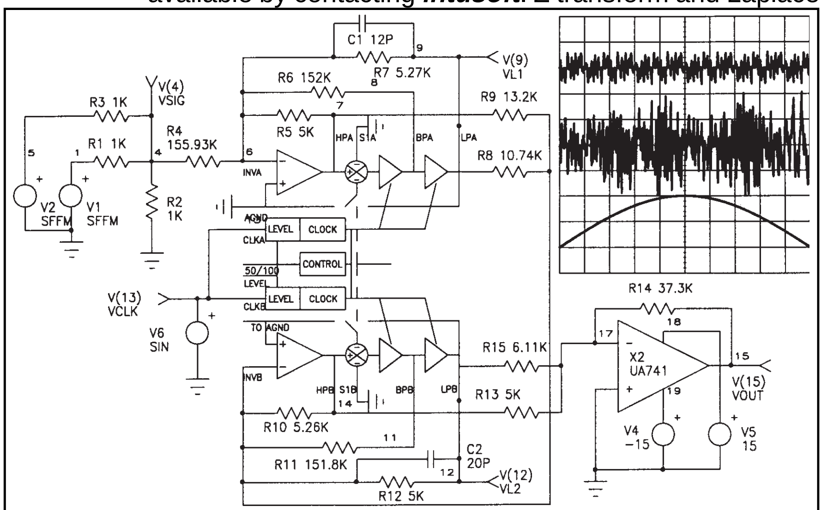


Figure 8, Speech Formant Synthesizer using SCN bandpass filter. Transient results of the input, output, and control signals are shown above.

models, and SPICENET symbols for other similar commercial components including the Linear Technology LTC1059, LTC1064, and the National Semiconductor MF5 and MF10 are also available. PRESPICE owners and other interested parties may obtain the material on floppy disk for $20 by writing, calling, or faxing Intusoft.

Conclusions

In conclusion, popular reconfigurable SCN filters can be modeled for use with the ISSPICE program using several methods. The most efficient of which uses models with Laplace transform elements. For simulations where the frequency of interest is near the Nyquist frequency, a Z transform model can be used to provide accurate results.

References

[1] Analog MOS Integrated Circuits For Signal Processing, Temes, G. Gregorian, R. John Wiley & Sons, Inc. 1986 ISBN 0-471-09797-7

[2] Equivalent Circuits For The Analysis and Synthesis of Switched Capacitor Networks, Laker, K.R. Bell System Technical Journal, Vol. 58 No.3 March 1979 pp. 729-769

[3] SIMULATING WITH SPICE, Meares, L.G.; Hymowitz, C.E. Intusoft, 1988 ISBN 0-923-34500-0

[4] SPICE APPLICATIONS HANDBOOK Vol. #1, Meares, L.G.; Hymowtiz, C.E. Intusoft, 1990 ISBN 0-923-34501-9

Model Listings

```
*Z Transform Model, SA/B switch connected to LP
*Connections are AGND, INVA, HPA, BPA, S1A,
*LPB, BPB, S1B, LPA, HPB, INVB
*Power Connections are not required
.SUBCKT LTC1060Z 15 4 3 2 5 20 19 16 1 18 17
*FOR GAIN OF 100 DEFINE /SCNCAP=2P,
*FOR GAIN OF 50 DEFINE /SCNCAP=4P
X19 31 30 19 34 ZINT  {TD=1U C=32P }
X2 35 36 2 33 ZINT  {TD=1U C=32P }
X4 1 35 CRES  {C= /SCNCAP }
X5 5 35 CRES  {C= /SCNCAP }
X8 2 29 NSTR  {TD=1U C= /SCNCAP }
X9 28 29 1 32 ZINT  {TD=1U C=32P }
XE1 4 15 3 SCNAMP
X11 3 35 NSTR  {TD=1U C= /SCNCAP }
X20 20 31 CRES  {C= /SCNCAP }
X21 16 31 CRES  {C= /SCNCAP }
X22 19 38 NSTR  {TD=1U C= /SCNCAP }
X23 37 38 20 40 ZINT  {TD=1U C=32P }
X24 18 31 NSTR  {TD=1U C= /SCNCAP }
XE2 17 15 18 SCNAMP
.ENDS
**************
.SUBCKT SCNAMP  2    3  6
*             - IN   +  OUT
RIP 3 0 10MEG
CIP 3 0 1.4PF
IBN 2 0 1.0000P
RIN 2 0 10MEG
CIN 2 0 1.4PF
VOFST 2 10
RID 10 3 200K
EA 11 0 10 3 1
R1 11 12 5K
R2 12 13 50K
C1 12 0 5.2000P
GA 0 14 0 13 378.00
C2 13 14 1.0800P
RO 14 0 75
L 14 6 12.000U
RL 14 6 1000
CL 6 0 3PF
.ENDS
**********
*Laplace Model, SA/B switch connected to AGND
*Connections are INVA, AGND, HPA, S1A, BPA, LPA,
*INVB, BPB, LPB, CLKA, CLKB, HPB, S1B
*Power Connections are not required
.SUBCKT LTC1060S 4 15 3 5 2 1 17 19 20 10 11 18 16
X3 2 10 7 MUL  {K=1 }
X1 14 10 9 MUL  {K=1 }
X8 15 3 5 14 SUM3  {K1=-1 K2=1 K3=-1 }
XE2 4 15 3 SCNAMP
X9 9 2 SINT  {K=31.25K }
X10 7 1 SINT  {K=31.25K }
X12 6 11 13 MUL  {K=1 }
X13 19 11 22 MUL  {K=1 }
XE3 17 15 18 SCNAMP
X15 13 19 SINT  {K=31.25K }
X16 22 20 SINT  {K=31.25K }
X14 15 18 16 6 SUM3  {K1=-1 K2=1 K3=-1 }
.ENDS
*INCLUDE SYS.LIB
*****************
```

Cyrix Coprocessors

There have been a number of inquiries as to the effectiveness of the new Cyrix numeric coprocessor. The Cyrix 83D87 is a CMOS coprocessor, pin for pin, and software compatible with the 80387. It boasts up to 10X the performance on some transcendental operations and about a 2x to 6x increase on floating point multiplies and adds, depending on the software run.

Unfortunately, the 83D87 is no panacea for SPICE's speed appetite. In our tests, the Cyrix coprocessor only produced about a 15% overall increase in the execution speed of IsSpice. (Call Intusoft for the actual benchmark times) It seems that although SPICE is probably one of the most coprocessor intensive programs in widespread use today, most of the floating point calculations are multiplies and adds, with a few divides thrown in. In addition, IsSpice uses the coprocessor in two main areas; the first is in evaluating device models so that coefficients can be found for the matrix, and the second is in solving the matrix. Since this is only a portion of the actual data manipulation that IsSpice is performing, the overall speed increase is marginal.

Our recommendation is that if you have to get the most processing power out of your current system, and are still required to maintain compatibility with other software that uses the coprocessor, the Cyrix 83D87 is a good purchase. There are other specialized coprocessors such as the Weitek which the IsSpice/386 program supports. The Weitek 3167 provides a slightly better speed increase (30%), albeit at the expense of software compatibility and price. However, a little reminder. IsSpice/386 runs on a 25 MegHz 486 platform about 3 times faster than on a 25 MegHz 386.