# Agilent EEsof EDA

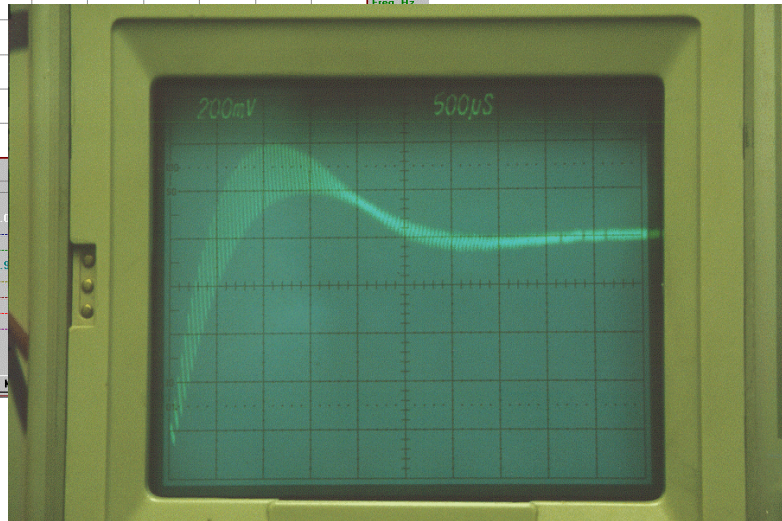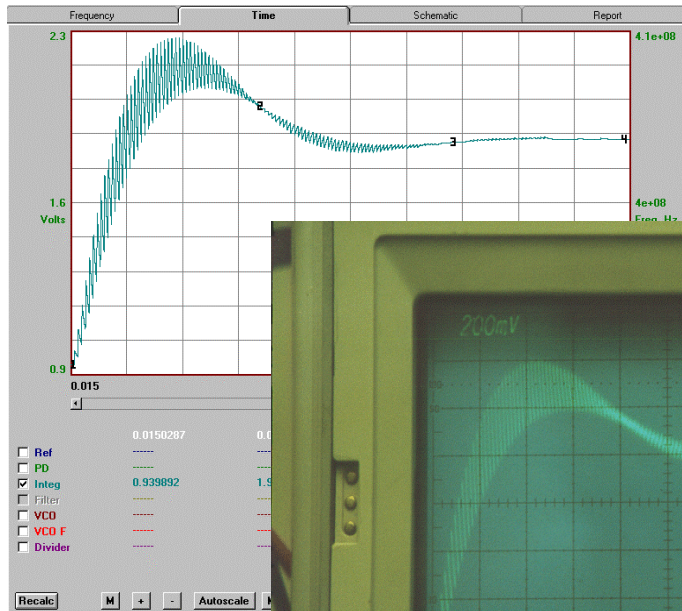## Design and Measurement of a 400 MHz Frequency Synthesizer: Accuracy Proof

**Agilent Technologies**

# Eagleware  PN 12

# Design and Measurement of a 400 MHz Frequency Synthesizer: Accuracy Proof

## Product Note



*Design, simulation and measurement of a frequency synthesizer using a National Semiconductor LMX1501 IC.*

## Design and Measurement of a 400 MHz Frequency Synthesizer

Synthesizer design is often a tradeoff between channel switching time, phase noise performance, and reference sideband suppression. For this reason, deciding on the best loop bandwidth and phase margin for a particular design is not always a simple matter. Eagleware's PLL program integrates traditional frequency domain analysis with true time domain transient simulation for quick evaluation of a variety of designs. Phase noise plots show each component's contribution to the total noise spectrum for easy identification of which blocks need improvement.

In this product note, a frequency synthesizer tunable from 395 to 405 MHz is designed. The National Semiconductor LMX1501 synthesizer IC is used with the following specifications:

- A channel spacing of 25 kHz is required;
- An 8 MHz crystal oscillator is used for the reference;
- A discrete bipolar LC VCO is used;
- The phase margin should be at least 50° for guaranteed loop stability.

Using the PLL program, it was decided that a loop bandwidth of 378 Hz gives the best noise performance for the experimental synthesizer, while maintaining an acceptable lock time of 5 ms or less.

Eagleware's PLL program calculates integrator component values for the desired loop characteristics. First, data for the pre-selected components must be input to the program. All PLL input prompts are shown in Figure 1.
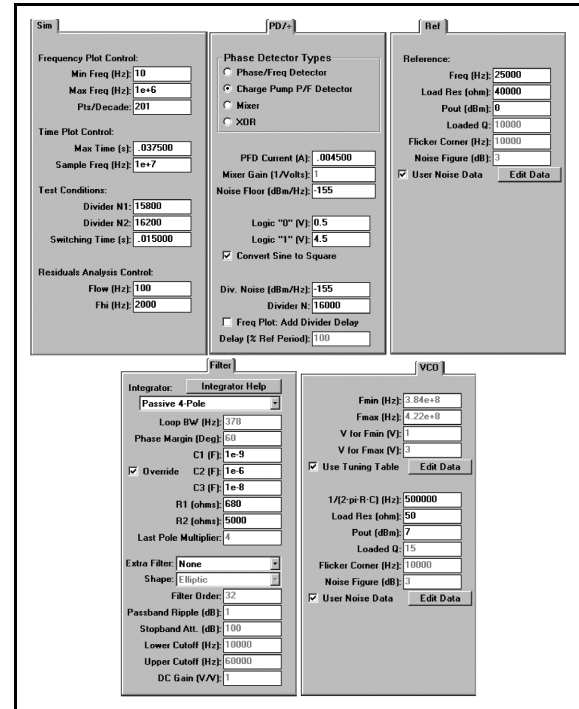


**Figure 1: PLL Input Tabs**

### Reference Oscillator

A crystal oscillator was chosen for its ability to provide a stable, low noise reference signal. In most synthesizers, the reference frequency is equal to the desired channel spacing. Therefore, the internal reference divider in the LMX1501 was set to N=320, giving a final reference frequency of 25 kHz (8 MHz÷320=25 kHz).

The reference oscillator data is entered on the **Ref** tab (see Figure 1). Since PLL does not include a reference divider, the frequency specified in the program is actually the divided frequency (25 kHz).

Since the reference oscillator is divided inside the LMX1501 synthesizer IC, the final reference phase noise is not

measurable. It was assumed that at low offsets, the divider noise floor is reached. Therefore, a low frequency offset noise floor estimate of −155 dBc was made.

## Phase Detector

The LMX1501 data is entered into the **PD/÷** tab (see Figure 1). The phase detector in this synthesizer is a charge pump phase/frequency detector, providing a current output. In the experimental setup, the detector has a maximum sink/source current of 4.5 mA. The noise floor of the phase detector and feedback divider is estimated to be −155 dBc, the same value used for the reference divider.

The logic "0" and "1" voltages in PLL are specified just inside the 0 and 5 volt LMX1501 supply rails used in the experimental synthesizer.

The loop should be designed for mid-band operation 400 MHz for this synthesizer. This places the feedback divider N at 16000.

## Integrator

The integrator information in PLL is contained in the **Filter** tab (see Figure 1). A passive 4-pole integrator is chosen here for increased reference sideband suppression. The component values calculated by PLL have been placed on standard values, and the final integrator schematic is shown in Figure 2. The 5.1 kΩ resistor and 10 nF capacitor form a pole at 3.1 kHz. This is far enough outside the loop bandwidth (about 8 times) that it doesn't degrade the phase margin excessively, but low enough to provide better close-in selectivity than a third order loop.
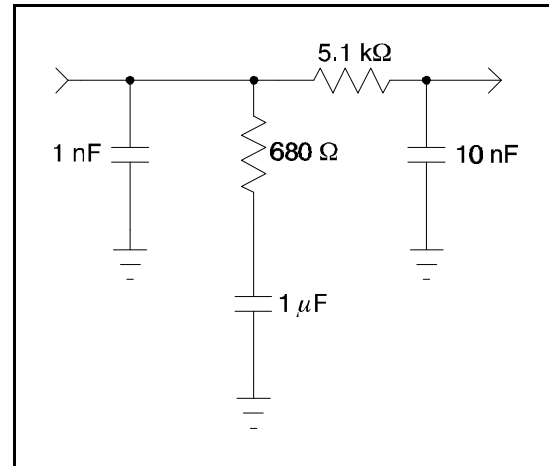


**Figure 2: Integrator Schematic**

Also on the **Filter** tab are the Loop Bandwidth and Phase Margin prompts. Notice that although the desired phase margin is 50°, it has been specified as 60°. The 5.1 kΩ resistor and 10 nF capacitor in Figure 2 are not included in the design of the integrator values. The pole formed by these components is specified by the user as a multiple of the loop bandwidth. If this pole is too close to the loop bandwidth, the phase margin can be degraded. This can often be corrected by designing the loop for a higher phase margin. For the experimental synthesizer, the number specified in the phase margin prompt was increased until an actual phase margin of 50° was achieved <u>with</u> the extra pole in place. Since a design value of 60° was needed, we can conclude that the extra pole degrades the phase margin by 10°.

## VCO

The VCO schematic is shown in Figure 3. The measured tuning range for this circuit is 384-422 MHz. Measured tuning data and phase noise plots are shown in Figures 2 and 3, respectively. VCO data is entered in the **VCO** tab

(see Figure 4).  Tuning and noise data tables have been used to specify the measured VCO data shown in Figures 2 and 3.
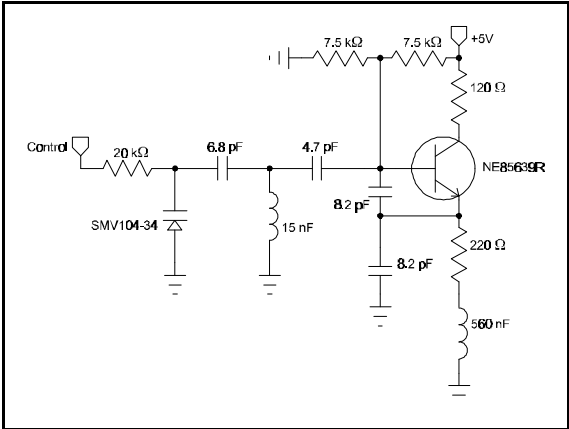


**Figure 3:  VCO Schematic**

Isolation resistors are often used to inject a voltage into a varactor tuned VCO.  When combined with the varactor capacitance and any isolation capacitance, this added resistance forms a lowpass RC pole.  The effect of this pole is to slow the VCO response to a changing control voltage.  This pole frequency (labeled "1/(2*pi*R*C)" in the VCO tab) is estimated to be 500 kHz for the circuit shown in Figure 3.
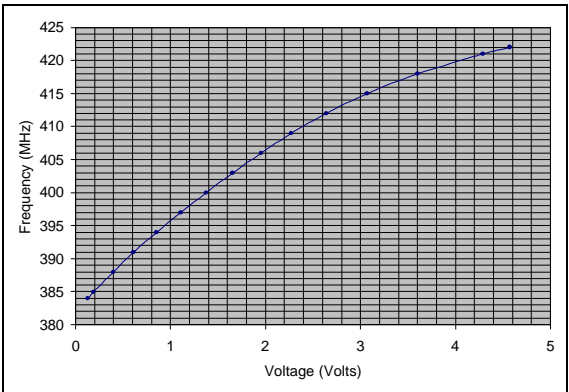


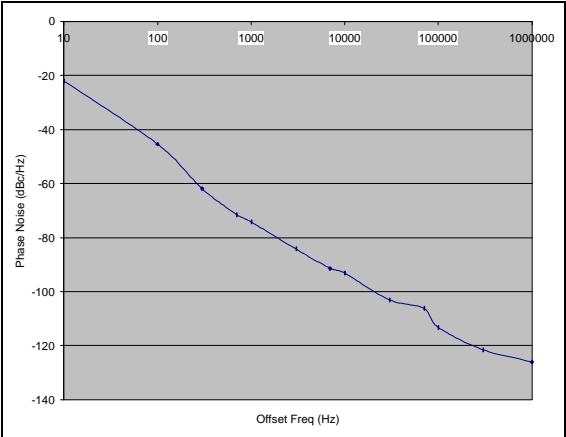**Figure 4:  Measured VCO Control Voltage vs. Output Frequency**



**Figure 5:  Measured VCO Phase Noise**

## Simulation vs. Measured Data

Simulation parameters are specified in the **Sim** tab (see Figure 1).  The simulated open loop gain and phase responses are shown in Figure 6.  According to the figure, the actual loop bandwidth is about 375 Hz, and the phase margin is about 49.6°.  These numbers differ slightly from the design values, and can be attributed to changing the integrator components to standard values.
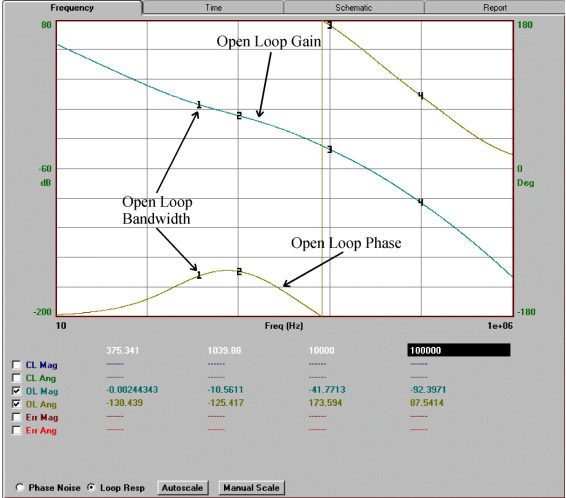


**Figure 6:  Simulated Open Loop Gain and Phase Responses**

For transient analysis, the loop is switched between 395 and 405 MHz (N=15800 and N=16200) every 15 ms. Figure 7 shows the simulated VCO control voltage for initial lock, and 2 switching cycles. The simulation always starts at t=0, with each node set to 0 volts. This shows loop turn-on characteristics, and predicts behavior for initially acquiring lock.
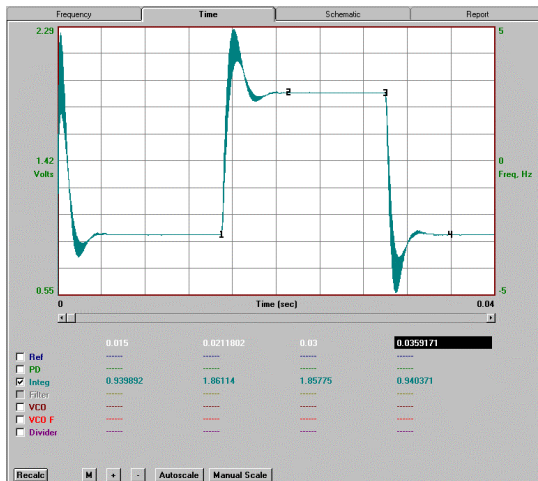


**Figure 7: Transient Plot of VCO Control Voltage Showing Switching Behavior**

In Figure 7, the loop starts with N=15800 (output freq=395 MHz), and acquires initial lock in about 3.3 ms. At t=15 ms, N switches to 16200 (output freq=405 MHz), and the loop again aquires lock in about 5 ms. At t=30 ms, N switches to 15800 and the loop acquires lock again in about 3.4 ms.

Figure 8 shows a zoomed view of the VCO control voltage when switching the loop from 395 to 405 MHz. Figure 9 shows the measured control voltage for the same frequency switch. The oscilloscope photo has a horizontal scale of 500 µs/division.
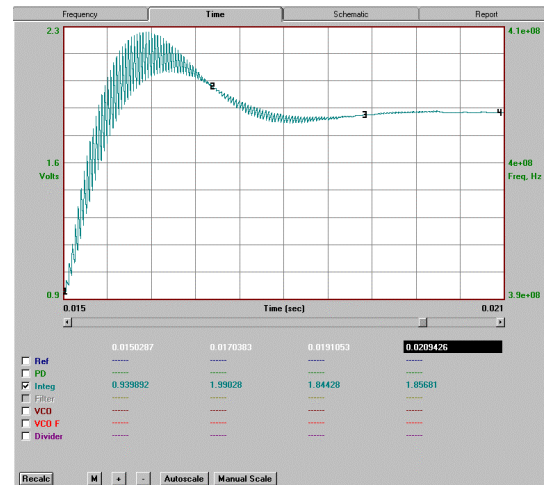


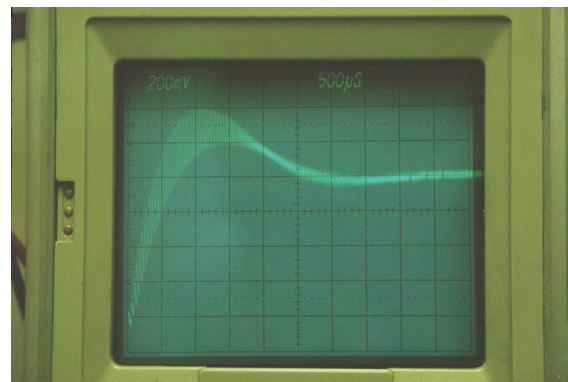**Figure 8: Simulated VCO Control Voltage (zoomed) for Switch From 395-405 MHz**



**Figure 9: Measured VCO Control Voltage For Switch From 395-405 MHz**

Figure 10 shows a zoomed view of the VCO control voltage when switching the loop from 405 to 395 MHz. Figure 11 shows the measured control voltage for the same frequency switch. The difference in these waveforms is primarily in the undershoot area, and is due to negative current limiting in the synthesizer IC, which is not modeled in PLL. This was later verified on the bench by switching from 405 to 400 MHz. The undershoot in this case was not severe enough to cause current limiting, and the lock waveform exhibited behavior closer to that predicted by the PLL program.
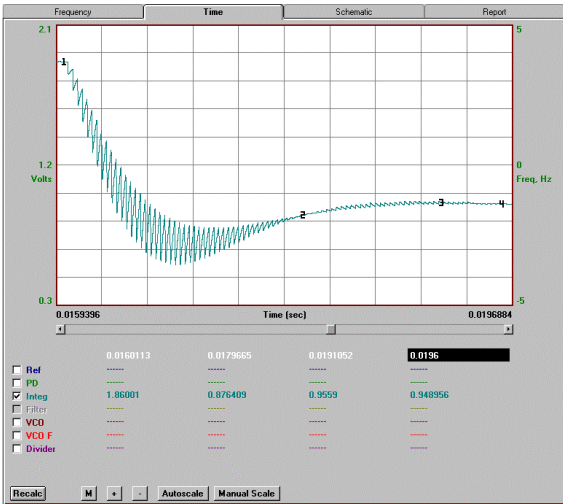
**Figure 10: Simulated VCO Control Voltage (zoomed) for Switch From 405-395 MHz**
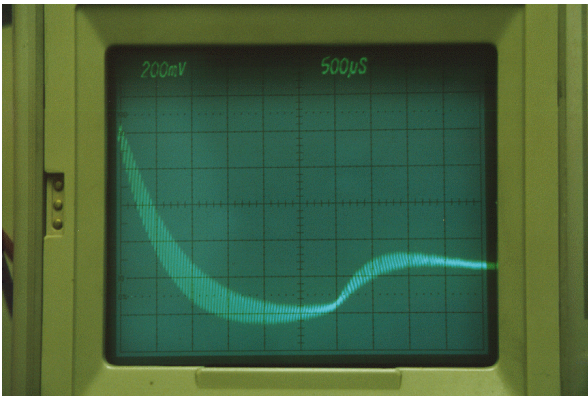


**Figure 11: Measured VCO Control Voltage For Switch From 405-395 MHz**

Figure 12 shows the simulated phase noise contribution due to each loop component, and the total sum of the noise sources. The plot colors correspond to the colored descriptions at the bottom of the figure. The red trace shows the total noise obtained by summing the other curves. This curve corresponds to actual loop noise observable on a spectrum analyzer.

Figure 13 shows the measured total loop phase noise vs. the simulated total. The curves shown in Figure 13 differ mostly for frequencies below the

378 Hz loop bandwidth. As can be seen in Figure 12, the low frequency phase noise contribution is primarily from the reference oscillator. The author believes that the performance variation seen in Figure 13 is due to an inaccurate estimate of the reference phase noise contribution. The original –155 dBc reference noise floor assumption was not sufficiently noisy at low offsets.
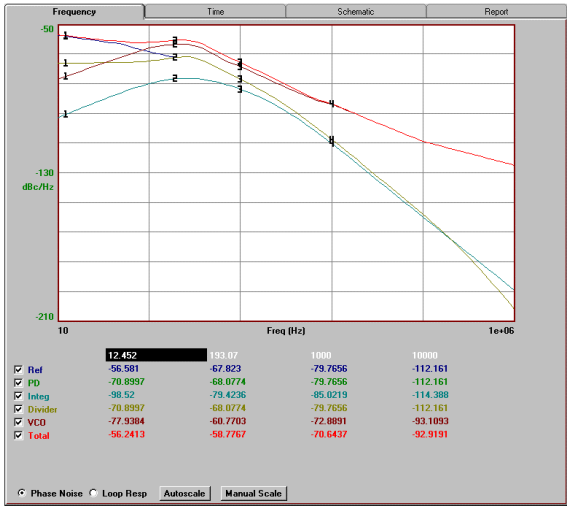


**Figure 12: Simulated Phase Noise Contribution For Each Loop Component.**
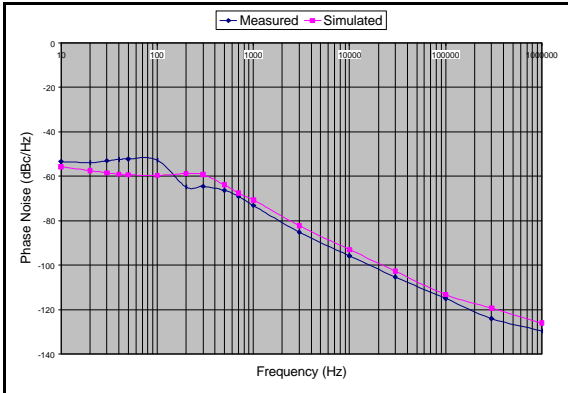


**Figure 13: Measured (Blue) vs. Simulated (Pink) Total Loop Phase Noise**

## Conclusion

The PLL program is a powerful tool for design <u>and</u> analysis of a variety of single loop applications, such as:

- Frequency Synthesizer
- Phase Modulator
- Frequency Modulator
- Phase Demodulator
- Frequency Demodulator

The built-in simulation engine allows quick and easy determination of stability and noise performance, and provides a realistic prediction of lock-time and switching transients. By entering measured phase noise of an existing PLL as the reference, cascaded synthesizer phase noise can be calculated. This gives the engineer a powerfully effective tool for designing real PLLs.

## Acknowledgment

Eagleware would like to thank Terry Hock at the National Center For Atmospheric Research (NCAR) for providing a board for evaluating the synthesizer design described in this article.

# Worldwide Sales and Support

**Australia / New Zealand**
Electronic Development Sales
16 Smith Street, PO Box D3013
Chatswood NSW 2067
Australia
Tel:  +61 2 9496 0500
Fax:  +61 2 9496 0599
web: http://www.edsales.com.au
E-mail: info@edsales.com.au

**Brazil**
Anacom Software e Hardware Ltda.
Rua Conceicao, 627
Sao Caetano do Sul,
SP, Brazil 09530-060
Tel:  (0xx) 11 4229.5588
Fax:  (0xx) 11 4221.5177
web: http://www.anacom.com.br
E-mail: vendas@anacom.com.br

**China, North**
Hongshi Electronic
Rm 705, Yujing Building No 19 Xinxi
Midroad
Shangdi, Haidian District
Beijing Huabei 100085 China
Tel:  +86-10-62988137
Fax:  +86-10-62974793
E-mail: mah@hongshi.com

**China, South**
Everjet
6B, Weiyuan Building, 7th Industrial
Rd
Shekou, Shenzhen
Guan Dong China 518067
Tel:  +86.775.6684050
Fax:  +86.755.6673708
E-mail: everjet@public.szptt.net.cn

**France, Belgium**
Tech Inter
Immeuble Sezac B
I. Rond-Point Pariwest
78310 Maurepas/France
Tel:  +33 (0) 1 30 51 66 99
Fax:  +33 (0) 1 30 62 20 19
E-mail: sales@tech-inter-net.com

**Germany, Austria, Switzerland**
TSS (Technical Software Service)
Postfach 1261
89264 Weissenhorn, Germany
Tel:  +49 7309 9675-0
Fax:  +49 7309 3275
E-mail: hendrik@tssd.com

**India**
Step Electronics PVT. LTD.
#326, 3rd Stage, 4th Block
Basaveshwaranagar,
Bangalore - 560 079
Tel: +91-80-323 7427
Fax: +91-80-323 7487
E-mail: srinu@vsnl.com

**Israel**
Summit Electronics
P.O. Box 1121
44110 Kfar-Saba, Israel
Tel: +972 3-6490329
Fax: +972 3-6478334
E-mail: summit@summit-il.com

**Italy**
Sematron Italia (Headquarters and
South Italy)
Viale Marx 153/2
00137 Roma
Tel: (396) 8689.5015
Fax: (396) 8680.2253
E-mail: sematronitalia@flashnet.it

Sematron Italia (North Italy)
Via Mazzini 46
20056 Trezzo sull'Adda MI Italy
Tel: +390290929158
Fax: +390290929166
Web: http://www.sematronitalia.it
E-mail: sematronitalia@flashnet.it

**Japan**
AET JAPAN
Ursis Bldg 9th Floor 1-2-3 Manpukuji
Asaoku
Kawasaki City 215 0004 Japan
Tel: +81-44-966-9981
Web: http://www.aetjapan.co.jp/
E-mail: info@aetjapan.co.jp

**South Korea**
MOAsoft Corporation
Suite 700, Back-Am Bldg.
123 Karak-Dong
Songpa-Ku, 138-160, Seoul, Korea
Tel: +82-2-420-3203
Fax: +82-2-407-3511

**Singapore**
SPS-DA PVT.LTD
3 International Business Park
#03-18/19 Nordic European Center
Singapore 609927
Tel: +65-890-6938
Fax: +65-896-0928
Web: http://www.spsda.com.sg/
E-mail: hhgoh@spsda.com.sg

**Sweden**
Pronesto AB
Finlandsgatan 18
Box 6014,
SE-164 06 Kista SWEDEN
Tel:  +46-8-444 10 68
Mobile: +46-70-5888 51 88
Fax:  +46-8-751 41 11
Web: http://www.pronesto.se
E-mail: fredrik.knutsen@pronesto.se

**Taiwan**
Evergo Electronics Corporation
10-1 Floor #287, NanKing E Rd
Section 3
Taipei, Taiwan 105
Tel:  +886-02-2716-6676
Fax:  +886-02-2716-6676
E-mail: evergo@ms4.hinet.net

**United Kingdom, Eire**
Melcom Electronics Limited
Elliott House, Gogmore Lane
Chertsey
Surrey, KT16 9AF
Tel:  +44 1932 565544
Fax:  +44 1932 569988
Web: www.melcom.co.uk
E-mail: melcomsales@melcom.co.uk

**United States**
Eagleware Corporation
635 Pinnacle Court
Norcross, GA 30071
Tel:  +1 678-291-0995
Fax:  +1 678-291-0971
Web:  http://www.eagleware.com
E-mail:  sales@eagleware.com

**635 Pinnacle Court**
**Norcross, Georgia 30071 USA**
**Telephone:  +1 678-291-0995**
**Facsimile:  +1 678-291-0971**
**www.eagleware.com**

For more information about
Agilent EEsof EDA, visit:

**www.agilent.com/find/eesof**

**Agilent Email Updates**

**www.agilent.com/find/emailupdates**
Get the latest information on the
products and applications you select.

**Agilent Direct**

**www.agilent.com/find/agilentdirect**
Quickly choose and use your test
equipment solutions with confidence.

**www.agilent.com**

For more information on Agilent Technologies'
products, applications or services, please
contact your local Agilent office. The
complete list is available at:

**www.agilent.com/find/contactus**

**Americas**
| | |
|---|---|
| Canada | (877) 894-4414 |
| Latin America | 305 269 7500 |
| United States | (800) 829-4444 |

**Asia Pacific**
| | |
|---|---|
| Australia | 1 800 629 485 |
| China | 800 810 0189 |
| Hong Kong | 800 938 693 |
| India | 1 800 112 929 |
| Japan | 0120 (421) 345 |
| Korea | 080 769 0800 |
| Malaysia | 1 800 888 848 |
| Singapore | 1 800 375 8100 |
| Taiwan | 0800 047 866 |
| Thailand | 1 800 226 008 |

**Europe & Middle East**
| | |
|---|---|
| Austria | 0820 87 44 11 |
| Belgium | 32 (0) 2 404 93 40 |
| Denmark | 45 70 13 15 15 |
| Finland | 358 (0) 10 855 2100 |
| France | 0825 010 700* |
| | *0.125 €/minute |
| Germany | 01805 24 6333** |
| | **0.14 €/minute |
| Ireland | 1890 924 204 |
| Israel | 972-3-9288-504/544 |
| Italy | 39 02 92 60 8484 |
| Netherlands | 31 (0) 20 547 2111 |
| Spain | 34 (91) 631 3300 |
| Sweden | 0200-88 22 55 |
| Switzerland | 0800 80 53 53 |
| United Kingdom | 44 (0) 118 9276201 |

Other European Countries:
www.agilent.com/find/contactus
Revised: March 27, 2008

Product specifications and descriptions
in this document subject to change
without notice.

**Agilent Technologies**