Development of a spice op-amp macro-model for current-feedback amplifiers (Part 2 of 2)

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(***Part 1*** of this article discussed the overall approach, the input stage, gain stage, frequency-shaping stages, noise module, and output stage)

Simulation Results

The simulation results of the macromodel should be compared with the real world device to verify its functionality. The example op amp used in this article is the EL5165, a high-speed current-feedback amplifier. Some SPICE simulation results are compared with the real test curve. (Note: you can find the **EL5165 Macromodel Netlist** below the **About the Authors** box.)

The gain plots in **Figure 9** show a remarkable similarity between our model on the left at a gain of two and measurements from the EL5165 on the right. The measurements from the device are taken at both unity gain and a gain of two. There is less than 1% error between the -3-dB frequency of the two gain-of-two measurements.

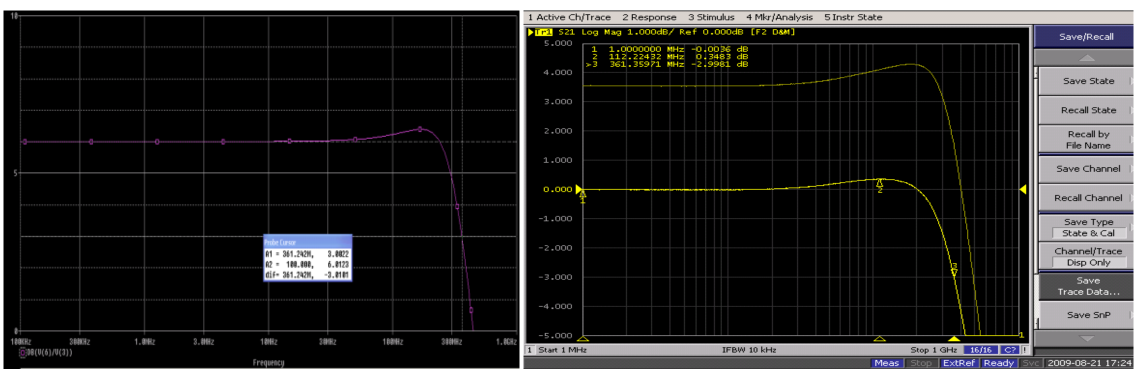

Figure 9: AC response for Gain=+2 of the macromodel (left) and EL5165 device (right).

At a gain of three, the discrepancy increases a bit as shown in **Figure 10**. Now the error in cut-off frequency is within 5%.

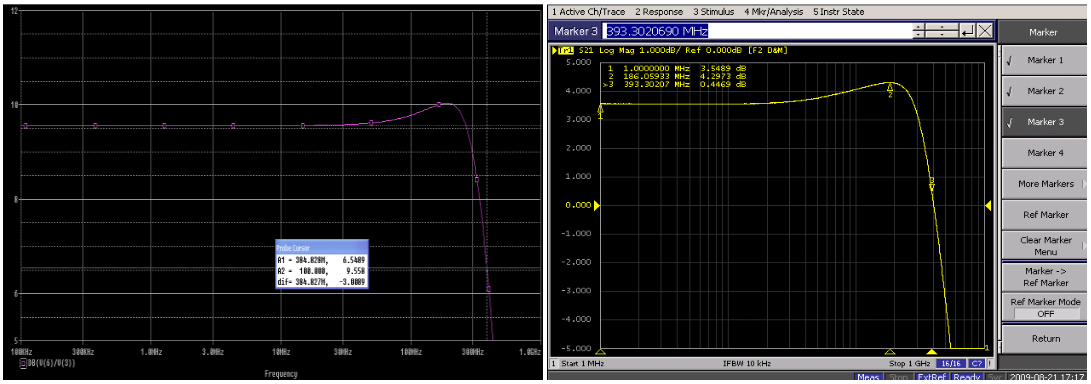

Figure 10: AC response for Gain=+3 of the macromodel (left) and EL5165 device (right).

Since the feedback resistor has an effect on bandwidth, we offer a comparison of frequency response for a range of resistors in **Figure 11**. The values of resistance are listed on the plot on the right that comes from the data sheet. The left plot is from our macromodel. Again, the matching of -3 dB frequency is within 5%.

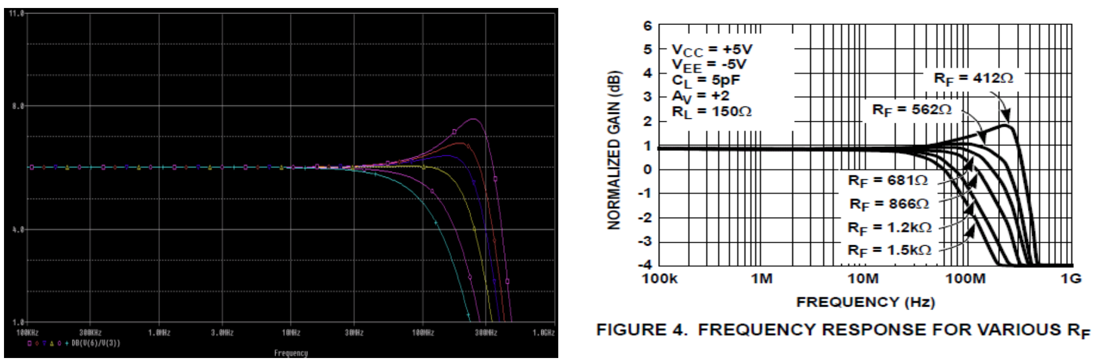

Figure11: Frequency response with different Rf for the model (left) and the device (right).

After examining the small-signal response versus frequency, the next logical step is to inspect the large-signal response as shown in **Figure 12**. Here we look at the slew rate of the step response with a gain of two driving a load of 150 ohms from a dual 5-volt supply. While the time base (x-axis) is at different resolutions in the two plots, the slew rate of the macromodel shown on the left is 5000 V/us. This is approximately 5% from the slew rate on the output signal of the EL5165 on the right.

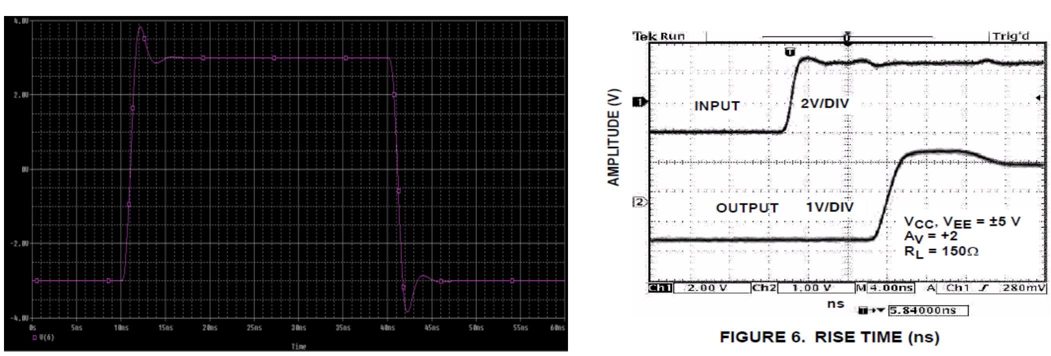

Figure 12: Large-signal step response for the macromodel (left)
and from the device data sheet (right).

After frequency response and slew rate, our next goal is to match the noise performance, **Figure 13**. We have chosen to demonstrate the voltage noise, so the model in Figure 6 is included, but not the current noise model from Figure 7. The voltage noise model exhibits the spectrum shown in the plot on the left and has a value of $2.15\, nV/\sqrt{Hz}$ at 1 MHz. The datasheet curve for voltage noise is on the right and has a value of $2.1\, nV/\sqrt{Hz}$ at 1 MHz.

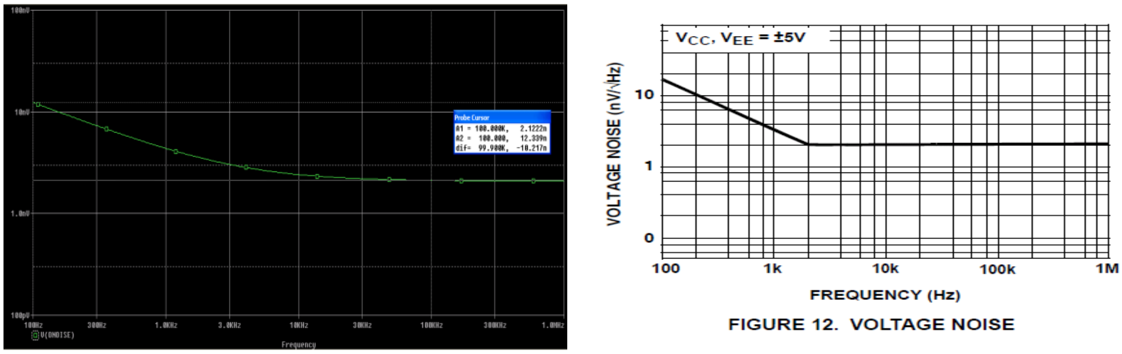

Figure 13: Input noise voltage versus frequency for macromodel (left) and device (right).

Conclusion

A truly comprehensive SPICE macromodel for a current-feedback amplifier is developed. This macromodel includes effects such as transfer response, accurate AC response, DC offset and voltage noise. It is convenient to use such a model and change the parameters to fit other current-feedback amplifiers. Several of Intersil's current-feedback amplifiers use the same model topology.

References

1. Derek Bowers, Mark Alexander, Joe Buxton, "A Comprehensive Simulation Macromodels for 'Current Feedback' Operational Amplifiers," IEEE Proceedings, Vol. 137, April 1990 pp.137-145.
2. Mark Alexander, Derek Bowers, "AN-138 SPICE-Compatible Op Amp Macro-Models", Analog Devices Inc., Application Note 138.
3. "AN-840 Development of an Extensive SPICE Macromodel for 'Current-Feedback' Amplifiers", National Semiconductor Corp., Application Note 840.
4. "Current-feedback amplifier Theory and Applications", Intersil Corp., Application Note 9420.

About the authors

Jian Wang was born in China in 1975 and has served as an applications engineer with Intersil since 2005, focusing on high speed amplifiers and drivers. He received a Ph.D. from the University of California at Davis in 2006.

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EL5165 Macromodel Netlist

```
.subckt  EL5165        3    2    7    4    6
*
*Input Stage
C_Cin1        0 3  1.8p
V_Vos         1 N4150175 1.5mVdc
I_I1        8 4 DC 85uAdc
I_I2        7 5 DC 85uAdc
I_Ib1        7 1 DC 2uAdc
I_Ib2        7 2 DC 2uAdc
G_Gi1        8 10 8 10 0.001
G_Gi2        5 9 5 9 0.001
G_Gi3        12 4 12 4 0.01
G_Gi4        7 11 7 11 0.01
G_Gb1        7 2 1 16 0.0000001
Q_Q1        7 1 8 Inpn
Q_Q2        11 9 2 Inpn
Q_Q3        4 1 5 Ipnp
Q_Q4        12 10 2 Ipnp
D_D9        19 11 DX
D_D10        12 18 DX
V_V7        7 19 1.5dc
V_V8        18 4 1.5Vdc
C_C1        9 7  0.03p
C_C2        4 10  0.03p
C_Cs1        2 7  0.25p
C_Cs2        4 2  0.25p
I_I3        7 4 DC 3mAdc
*Gain stage
C_C3        VV2 7  0.405p
C_C4        4 VV2  0.405p
D_D3        13 7 DX
D_D4        4 14 DX
G_G1        7 VV2 7 11 0.01
G_G2        VV2 4 12 4 0.01
R_R7        VV2 7  10meg
R_R8        4 VV2  10meg
R_R17        13 0 1G
R_R18        14 0 1G
V_V5        13 VV2 1.6Vdc
V_V6        VV2 14 1.6Vdc
*High-order poles
E_E3        16 4 7 4 0.5
C_C5        VV3 7  0.0032p
C_C6        4 VV3  0.0032p
C_C7        4 VV4  0.0009p
```

```
C_C8         VV4 7  0.0009p
C_C9         4 VV5  0.0001p
C_C10         VV5 7  0.0001p
R_R9         VV3 7  100k
R_R10         4 VV3  100k
R_R11         VV4 7  100k
R_R12         4 VV4  100k
R_R15         VV5 7  100k
R_R16         4 VV5  100k
G_G3         4 VV3 VV2 16 0.00001
G_G4         7 VV3 VV2 16 0.00001
G_G9         7 VV4 VV3 16 0.00001
G_G10         4 VV4 VV3 16 0.00001
G_G11         7 VV5 VV4 16 0.00001
G_G12         4 VV5 VV4 16 0.00001
*Output stage
G_G5         15 4 6 VV5 0.0001
G_G6         17 4 VV5 6 0.0001
G_G7         7 6 7 VV5 -0.04
G_G8         6 4 VV5 4 -0.04
R_R13         6 7  25
R_R14         4 6  25
D_D5         7 15 DX
D_D6         7 17 DX
D_D7         4 15 DY
D_D8         4 17 DY
*Voltage noise
E_EN         N4150175 3 101 103 1
V_V15         102 0 0.5Vdc
V_V16         104 0 0.5Vdc
D_DN1         102 101 Iden
D_DN2         104 103 Iden
R_R21         0 101  55
R_R22         0 103  55
*Current noise
R_R23         0 NI2  0.022
R_R24         0 NI2  0.022
R_R25         0 NI1  0.022
R_R26         0 NI1  0.022
G_Gn1         3 0 NI1 0 1
G_Gn2         2 0 NI2 0 1
*
* Models
*
.model Ipnp pnp(is=1e-15 bf=1E9 VAF=65)
.model Inpn npn(is=1e-15 bf=1E9 VAF=65)
```

```
.model Iden d(kf=100e-14 af=1)
.MODEL DY D(IS=1E-20 BV=50 Rs=1)
.MODEL DX D(IS=1E-15 Rs=1)
.ends EL5165
```