

DIGITAL HYBRID WITH THE Si305x DAAs

1. Introduction

This application note is a guide to understanding and implementing the digital hybrid feature found in Si305x DAA products. The Si305x contains an on-chip analog hybrid that performs the 2- to 4-wire conversion and near-end echo cancellation. This hybrid circuit is adjusted for each ac termination setting selected to achieve a minimum transhybrid balance of 20 dB. The Si305x also offers a digital filter for additional near-end echo cancellation to compensate for any line impedance mismatch. For each ac termination setting, the eight programmable hybrid registers (Registers 45-52) can be programmed with coefficients to increase the cancellation under real-world line conditions. This digital filter can produce 10 dB or greater of near-end echo cancellation in addition to the 20 dB from the analog hybrid circuitry.

1.1. Digital Hybrid Overview

Figure 1 describes the basic architecture of the digital hybrid. It is composed of an 8-tap FIR filter. “b0” through “b7” represent the filter coefficients in 2s complement form. The initial 4-sample bulk delay is used to compensate for the round trip delay through the line-side device. This architecture is designed to delay and filter the transmit signal to match the portion not cancelled by the analog hybrid.

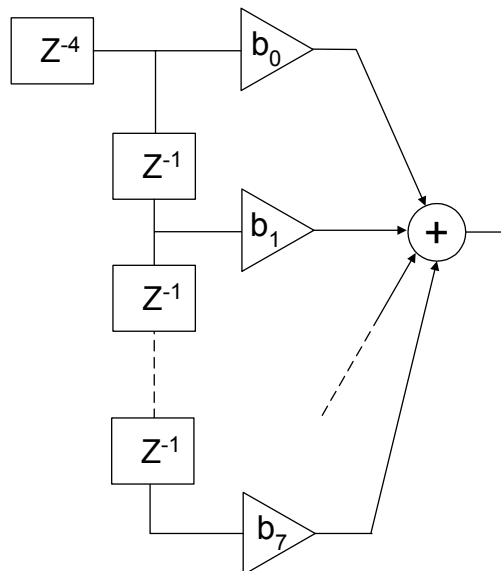


Figure 1. Digital Hybrid Structure

Figure 2 illustrates the basic signal flow of the DAA. The digital signal has been upsampled to 16 kHz at the digital hybrid stage. The transmit signal goes through a digital filter, digital-to-analog converter, and analog filter before going out on the line or being used in the analog hybrid circuitry. After the analog hybrid, the receive signal passes through an analog filter, analog-to-digital converter, and digital filter before going back into the digital hybrid. The analog hybrid path adds approximately four samples of delay to the signal. The digital hybrid structure matches this filter delay by delaying the digital samples by the same amount.

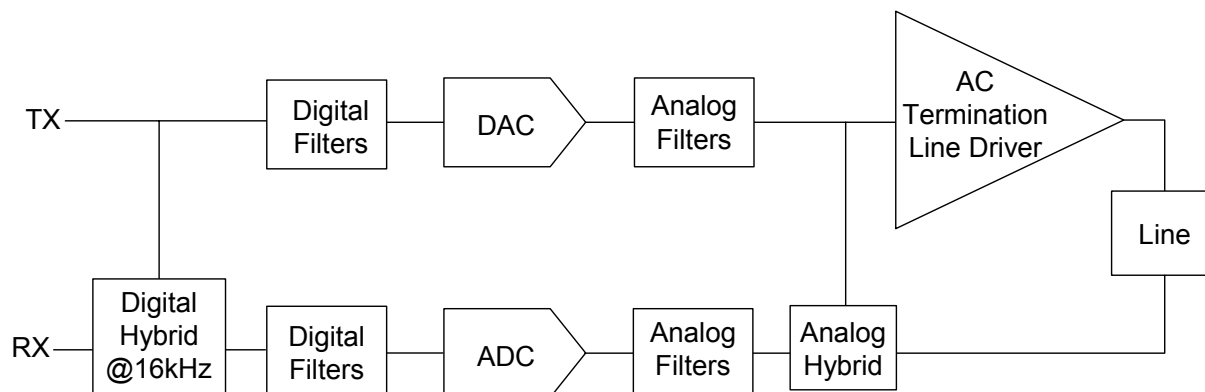


Figure 2. Signal Flow Diagram

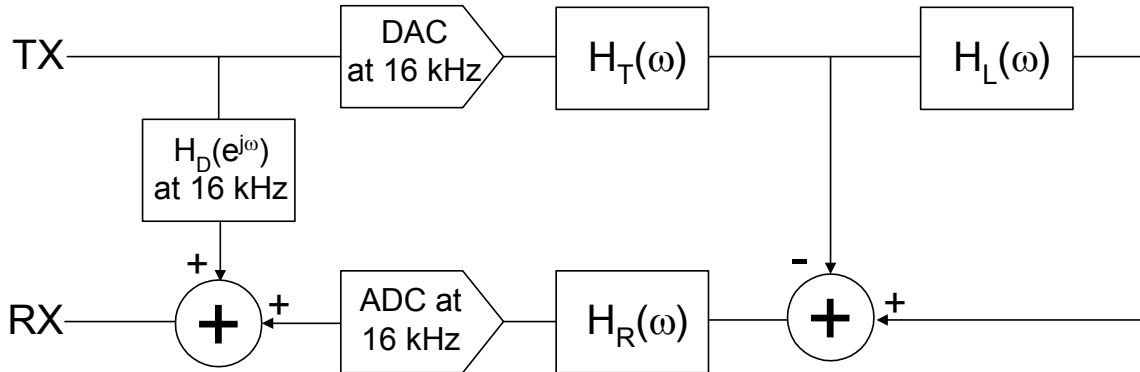


Figure 3. Model

A model of the DAA and the phone line is shown in Figure 3. In an ideal system, the analog hybrid yields perfect cancellation of the near-end echo from the transmit path. A mismatch between the ac termination and the load produces an echo that is not removed by the analog hybrid. To increase the near-end echo cancellation, the digital hybrid must equalize the disparity between the impedance mismatch of the ac termination and the line.

From the above model, the echo is equal to:

$$\begin{aligned} \text{echo} &= H_T(\omega) \times H_L(\omega) \times H_R(\omega) - H_T(\omega) \times H_R(\omega) \\ &= H_T(\omega) \times H_R(\omega) [H_L(\omega) - 1] \end{aligned}$$

$H_L(\omega)$ consists of the DAA's ac termination in combination with the impedance of the twisted pair transmission line terminated at the central office (CO) by a reference impedance. Figure 4 shows the analog hybrid circuitry and the $H_L(\omega)$ model expanded to include the ac termination and line.

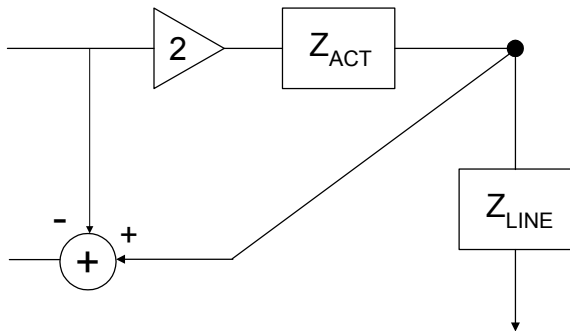


Figure 4. $H_L(\omega)-1$ Model

Substituting for $H_L(\omega)$ in the equation results in:

$$H_L - 1 = 2 \times \frac{Z_{\text{Line}}}{Z_{\text{Line}} + Z_{\text{ACT}}} - 1 = \frac{Z_{\text{Line}} - Z_{\text{ACT}}}{Z_{\text{Line}} + Z_{\text{ACT}}}$$

If Z_{LINE} and Z_{ACT} are matched, the analog hybrid perfectly cancels the transmit signal.

Substituting this result into the echo equation yields:

$$\text{echo} = H_T(\omega) \times H_R(\omega) \left[\frac{Z_{\text{Line}} - Z_{\text{ACT}}}{Z_{\text{Line}} + Z_{\text{ACT}}} \right]$$

The model for the $H_T(\omega)$ and $H_R(\omega)$ plays a critical role in this calculation. The models are quite complex, and sampled data of the models are necessary to calculate the hybrid coefficients. Contact Silicon Labs to acquire the sampled data of the $H_T(\omega)$ and $H_R(\omega)$ models.

A group delay, which was not illustrated in the model, must also be taken into consideration. Internal DSP and filters cause this delay. Taking the group delay into account, the echo is equal to:

$$\text{echo} = H_T(\omega) \times H_R(\omega) \times [H_L(\omega) - 1] e^{\left(\frac{j2\pi}{16000} \times \text{gd}\right)}$$

where gd is the group delay.

The digital hybrid must cancel the echo by intentionally adding the negative of the echo. The $H_D(\omega)$ should be:

$$H_D(\omega) = -H_T(\omega) \times H_R(\omega) \times [H_L(\omega) - 1] e^{\left(\frac{j2\pi}{16000} \times \text{gd}\right)}$$

1.2. Digital Hybrid Calculation Tool

Silicon Labs has developed a useful graphical user interface tool (shown in Figure 5) that will assist in calculating the coefficients to use with the digital hybrid in the Si305x DAA product family. The tool allows the user to enter the reference termination of the central office (in an $R + R||C$ format) and the model for the phone line between the DAA and the central office. The line can be represented by one of the EIA models, shown in "Appendix C—EIA Line Models" on page 24, or as a specified length of wire. The software then executes the Matlab code found in "Appendix A—Sample MATLAB Code" on page 7, which graphically shows the expected trans-hybrid response of the digital hybrid and lists the best hybrid coefficients to use given the line characteristics.

Three graphs are shown in Figure 6. An echo graph is created by intentionally mismatching the $600\ \Omega$ ac termination with the TBR21 mode CO termination. The digital hybrid response is the 8-tap FIR filter response calculated using the sample code found in Appendix A. The cancelled graph is obtained by adding the echo and the digital hybrid response. The digital hybrid response looks very similar to an echo. Figure 7 shows the phase of the echo and the digital hybrid response. The phase of an echo and the digital hybrid have the opposite polarity. Figure 8 compares the rejection in dB with and without the digital hybrid. By properly using the digital hybrid, near-end echo cancellation has increased by approximately 20 dB.

To use the Digital Hybrid Calculation Tool, simply enter the ACIM value recommended in Table 13 of the Si3050 datasheet into the ACIM control. This value determines the impedance presented by the DAA to the line. It is governed by the region in which the application will be deployed. Next, enter values for R1 and R2 in ohms and C in farads into the appropriate controls. These values will represent the impedance presented by the central office to the line. This value is also governed by the region in which the application will be deployed. Also, select the line-side device used in the application in the pull-down box. Finally, select the line model to be used that will most closely model the line connecting the DAA to the central office. This is done by either picking a specific EIA line model or by specifying a wire gauge and length. Once this is complete, hitting the "CALCULATE" button will generate the coefficients that provide the best performance.

For example, if we assume that an application will be deployed within the U.S., we enter a 0 for the ACIM value. Also, the central office impedance in the US is $900\ \Omega$ in series with $2.16\ \mu\text{F}$. To enter this information in the GUI, we enter 900 for R1 and a fairly large value for R2, since it is not present. For this example, the value of $100,000\ \Omega$ was used. For the C value, we enter $2.16\text{e-}6$ since the expected units are farads. Also, for this example, we use an EIA model of 0. This means essentially no loop length, and the central office impedance is connected directly to the application. Now, the "CALCULATE" button is pressed, and the resulting coefficients, 0xF8, 0xF9, 0x03, 0xFE, 0xFE, 0x00, 0xFE, and 0x00, are generated.

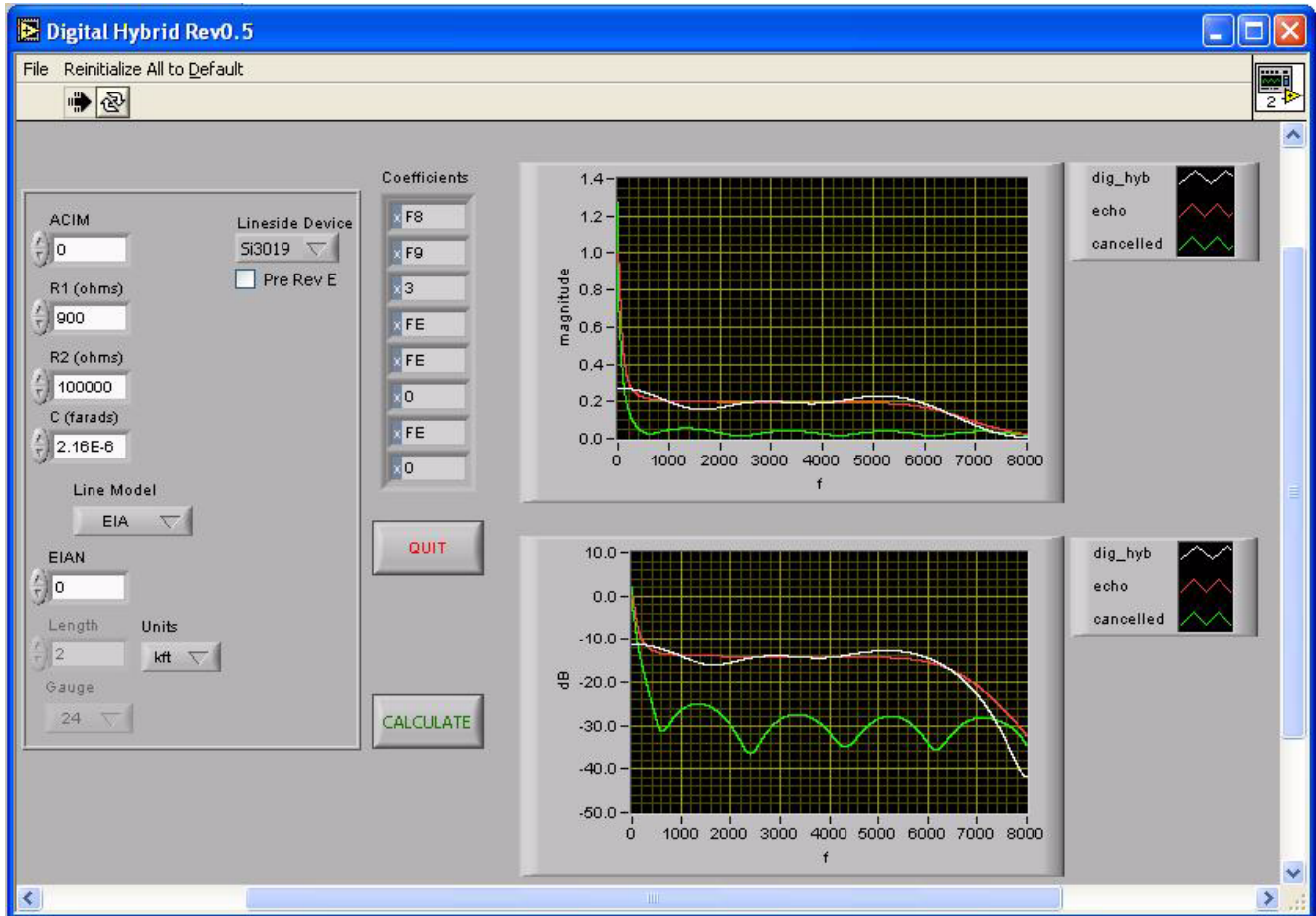


Figure 5. Digital Hybrid

1.3. Conclusion

The Si305x DAA product family is designed to increase the near-echo cancellation with an additional hybrid in the digital path operating at 16 kHz. Near-end echo is primarily caused by the mismatch between the ac termination and the CO termination. The transmit and receive signal path also affects the echo to a lesser extent. By introducing a filter that models the near-end echo 180 degrees out-of-phase to the receive path echo, the hybrid response can be improved. This improvement in the hybrid response results in greater cancellation of the transmit signal when the near-end echo and digital hybrid response are added together at the digital hybrid stage.

To generate the coefficients, the 8-tap FIR filter structure used in the digital hybrid must be taken into account. This digital filter structure requires the hybrid response to be represented in the z-domain.

“Appendix A—Sample MATLAB Code” contains sample MATLAB code to calculate the hybrid coefficients. This code should help in understanding the process of calculating the hybrid coefficients.

A hybrid coefficient lookup table can be found in “Appendix B—Hybrid Coefficient Lookup Tables” on page 10. These tables provide a set of coefficients to use for different line conditions.

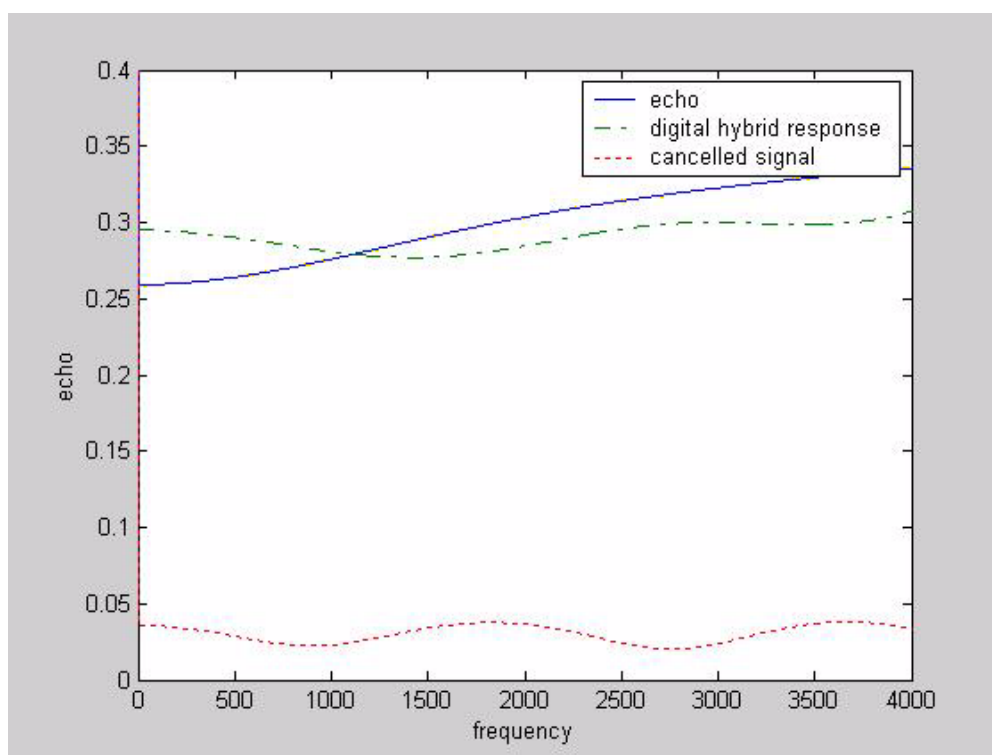


Figure 6. Echo

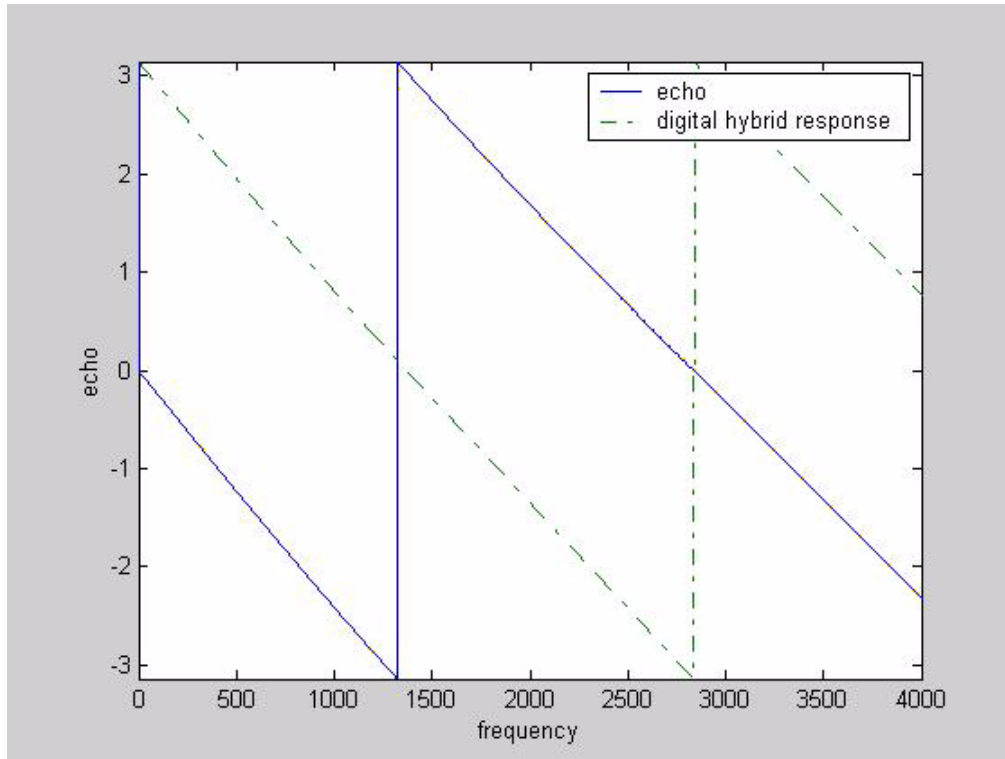


Figure 7. Echo Phase

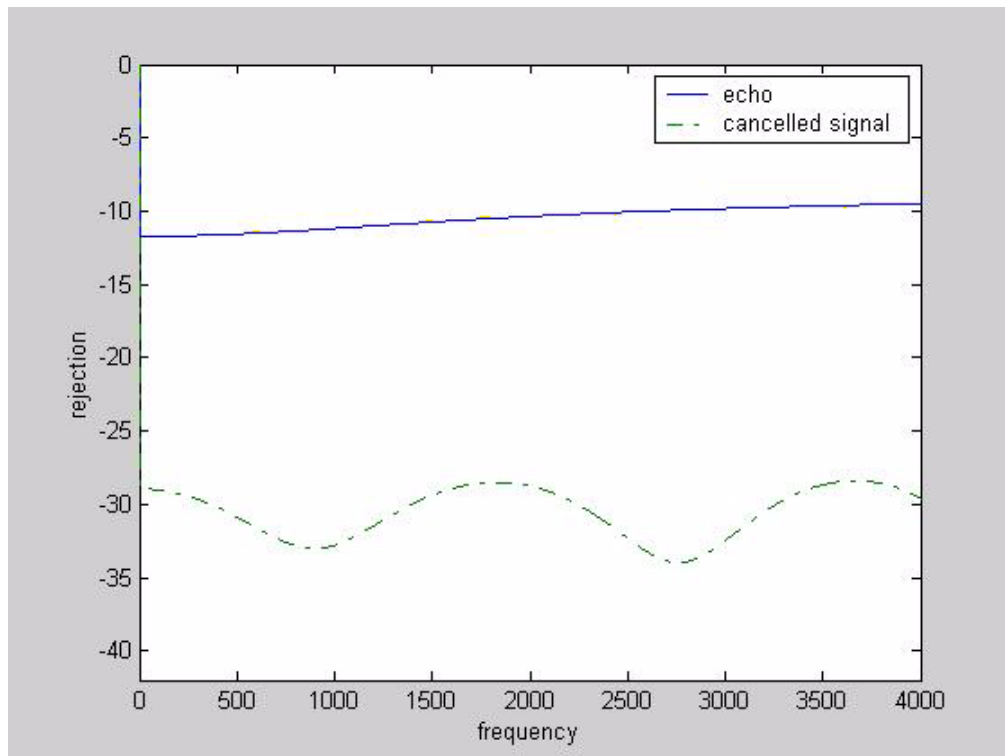


Figure 8. Rejection

APPENDIX A—SAMPLE MATLAB CODE

A sample MATLAB program for use in setting the hybrid coefficients is shown below. The code takes the ACIM (Register 30) setting and line model as an input and outputs the best coefficient for the digital hybrid to match the line.

```
function hdh = dig_hybrid(ACIM, R1line, R2line, Cline, HtMag, HtPhase, HrMag,
HrPhase);

% hdh = dig_hybrid(ACIM, R1line, R2line, Cline, HtMag, HtPhase, HrMag, HrPhase);
%
% This function calculates the coefficient values for the digital
% hybrid given a R1+R2||C model for the line.
%
% ACIM : register setting of the AC termination
% R1line : line R1
% R2line : line R2
% Cline : line C
% HtMag : Transmit path response
% HtPhase : Transmit path response
% HrMag : Receive path response
% HrPhase : Receive path response
%
% hdh : digital hybrid coefficients

Nact=ACIM+1;
if(R1line==0), R1line=eps; end
if(R2line==0), R2line=eps; end
if(Cline==0), Cline=eps; end
%eps is the smallest value after 0

% Set sample rate and frequency grid
fs=16000;
f=[eps:1:7999];
w=2*pi*f/fs;

%%%%%%%% Transmit path (Ht)

Ht = HtMag .* exp(j*HtPhase)

%%%%%%%% Receive path (Hr)

Hr = HrMag .* exp(j*HrPhase)
```

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```
%%%%%%%%%% Near end echo (H2)

% Calculate Zline
Zcline=1./(j*2*pi*f*Cline);
Zline=R1line + R2line.*Zcline./(R2line+Zcline);

% Calculate Zref, assume perfect ACT
R1ref=[eps eps 270 220 370 320 370 275 120 350 eps 600 900 900 600 270];
R2ref=[600 900 750 820 620 1050 820 780 820 1000 900 1e9 1e9 1e9 1e9 750];
Cref =[eps eps 150 117 310 230 110 132 110 210 30 2160 1000 2160 1000 150]*1e-9;

Zcact=1./(j*2*pi*f*Cref(Nact));
Zact=R1ref(Nact) + R2ref(Nact).*Zcact./(R2ref(Nact)+Zcact);
C9r=0*1e-9;
Ycact2=(j*2*pi*f*C9r);
Zact=1./(1./Zact + Ycact2);

%%%%%%%%
HL=2*Zline./(Zact+Zline);
HL(1)=0;

% Add extra group delay to match measurements
gde=-0.225;
Hd=-Ht.*Hr.*(HL-1).*exp(j*2*pi/16000*gde*[0:length(Ht)-1]);
Hd=[Hd conj(fliplr(Hd))];

% Estimate impulse response to match
hd=real(ifft(Hd));

% Truncate coefficients and express in [0 255]
hdh=round(hd(5:12)*64);
ind=find(hdh<0);
hdh(ind)=hdh(ind)+256;

echo = Ht.*Hr.*(HL-1).*exp(j*2*pi/16000*gde*[0:length(Ht)-1]);
hyb_coef = [0 0 0 0 hd(5:12)];
dig_hyb = freqz(hyb_coef,1,w);

figure
plot(f,abs(echo),'-',f,abs(dig_hyb),'-.',f,abs(echo+dig_hyb),':')
axis([0 4000 0 0.4])
legend('echo','digital hybrid response','cancelled signal')
```



```
xlabel('frequency')
ylabel('echo')
```

```
figure
plot(f, angle(echo), '-', f, angle(dig_hyb), '-. ')
axis([0 4000 -pi pi])
legend('echo', 'digital hybrid response')
xlabel('frequency')
ylabel('echo')
```

```
figure
plot(f, 20*log10(abs(echo)), '-', f, 20*log10(abs(echo+dig_hyb)), '-. ')
axis([0 4000 -42 0])
legend('echo', 'cancelled signal')
xlabel('frequency')
ylabel('rejection')
```

APPENDIX B—HYBRID COEFFICIENT LOOKUP TABLES

Tables 1–14 (for Rev C and prior versions of the Si3019) and Tables 15–28 (for Rev E and later versions of the Si3019) provide fixed digital hybrid coefficients to best match the line load with specific EIA line models. For this calculation, the EIA line model was incorporated into the HL(w) model. The first column shows which line type was used to calculate the hybrid coefficient. The remaining columns display the hybrid coefficients (Registers 45–52).

Table 1. ACIM = 0000 and CO Termination = 900 Ω + 2.16 μ F

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	248	249	3	254	254	0	254	0
EIA 1	251	240	255	5	250	2	254	255
EIA 2	2	240	238	7	253	254	2	254
EIA 3	5	239	235	7	252	254	2	254
EIA 4	1	242	240	1	252	255	0	255
EIA 5	7	244	233	1	250	253	0	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	253	242	254	5	250	2	255	255
2000 ft. 24 awg	252	240	254	5	250	2	254	255
2000 ft 26 awg	251	240	255	5	250	2	254	255

Table 2. ACIM = 0000 and CO Termination = 600 Ω

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	255	247	255	4	253	2	0	0
EIA 2	2	243	241	8	253	255	2	254
EIA 3	5	240	238	9	252	255	2	254
EIA 4	1	242	241	2	253	255	1	255
EIA 5	7	244	234	2	251	254	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	2	250	254	4	253	1	0	0
2000 ft. 24 awg	1	249	254	4	253	1	0	0
2000 ft 26 awg	255	247	255	4	253	2	0	0

Table 3. ACIM = 0000 and CO Termination = 1200 Ω + 376 Ω + 112 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	240	242	7	255	254	3	254	1
EIA 1	247	232	254	8	249	4	255	0
EIA 2	2	238	234	6	253	254	2	254
EIA 3	4	237	231	5	252	254	2	254
EIA 4	1	241	239	255	251	254	0	255
EIA 5	7	244	233	0	249	252	0	253
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	249	233	253	8	249	3	255	0
2000 ft. 24 awg	248	232	253	8	249	4	255	0
2000 ft 26 awg	247	232	254	8	249	4	255	0

Table 4. . ACIM = 0000 and CO Termination = 150 Ω + 510 Ω + 47 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	3	249	252	5	253	1	0	255
EIA 1	2	246	249	7	252	1	1	255
EIA 2	3	244	240	5	254	255	2	255
EIA 3	5	241	238	6	252	255	2	254
EIA 4	1	242	241	2	252	255	1	255
EIA 5	7	244	234	2	251	253	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	4	248	246	7	253	0	1	255
2000 ft. 24 awg	3	247	247	8	253	0	1	255
2000 ft 26 awg	2	246	249	7	252	1	1	255

Table 5. ACIM = 0000 and CO Termination = 220 Ω + 820 Ω + 150 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	6	246	239	5	253	255	2	255
EIA 1	3	246	241	2	254	255	1	255
EIA 2	3	245	240	1	252	254	1	255
EIA 3	5	242	238	4	250	255	0	254
EIA 4	1	242	241	2	251	254	0	254
EIA 5	7	244	234	2	250	252	0	253
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	6	249	237	2	255	253	2	254
2000 ft. 24 awg	5	247	239	3	254	254	2	255
2000 ft 26 awg	3	246	241	2	254	255	1	255

Table 6. ACIM = 0000 and CO Termination = 600 Ω + 1.5 μF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	255	254	254	254	254	254	254	254
EIA 1	255	246	253	3	251	0	254	254
EIA 2	2	242	241	7	252	254	1	253
EIA 3	5	240	237	8	252	254	1	253
EIA 4	1	242	241	2	252	255	0	254
EIA 5	7	244	234	1	251	253	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	1	249	251	2	251	255	254	254
2000 ft. 24 awg	0	247	252	3	251	0	254	254
2000 ft 26 awg	255	246	253	3	251	0	254	254

Table 7. ACIM = 0010 and CO Termination = 220 Ω + 120 Ω + 115 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	9	16	5	254	2	255	0	0
EIA 1	2	10	9	255	1	0	255	1
EIA 2	255	0	3	2	0	1	0	0
EIA 3	1	253	0	4	254	1	0	0
EIA 4	253	252	0	255	0	0	0	0
EIA 5	4	253	249	255	254	255	0	255
EIA 6	1	254	242	4	8	246	2	254
EIA 7	244	241	19	11	244	2	253	1
2000 ft. 22 awg	6	15	6	254	3	255	0	0
2000 ft. 24 awg	5	12	7	255	2	0	0	0
2000 ft 26 awg	2	10	9	255	1	0	255	1

Table 8. ACIM = 0011 and CO Termination = 220 Ω + 820 Ω + 115 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	255	0	255	254	1	255	0	0
EIA 2	255	0	253	252	255	254	255	0
EIA 3	1	254	252	253	253	255	255	255
EIA 4	253	255	255	251	254	254	254	255
EIA 5	4	0	249	252	253	253	254	254
EIA 6	1	1	242	2	9	245	3	253
EIA 7	245	243	18	10	245	0	253	1
2000 ft. 22 awg	1	2	252	255	1	254	1	255
2000 ft. 24 awg	0	1	253	255	1	255	0	0
2000 ft 26 awg	255	0	255	254	1	255	0	0

Table 9. ACIM = 0100 and CO Termination = 370 Ω + 620 Ω + 310 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	254	252	2	1	255	1	255	0
EIA 2	255	248	253	4	253	0	0	255
EIA 3	1	246	251	6	252	1	0	255
EIA 4	252	247	253	2	253	0	255	255
EIA 5	3	248	246	3	252	255	255	254
EIA 6	0	249	240	8	8	247	2	254
EIA 7	244	236	18	14	241	5	254	1
2000 ft. 22 awg	1	255	255	0	255	0	0	0
2000 ft. 24 awg	0	253	0	1	255	1	0	0
2000 ft 26 awg	254	252	2	1	255	1	255	0

Table 10. ACIM = 0100 and CO Termination = 220 Ω + 820 Ω + 120 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	248	254	6	255	2	1	0
EIA 1	254	249	253	4	255	1	1	0
EIA 2	255	249	251	2	254	0	0	0
EIA 3	1	246	250	4	252	1	0	255
EIA 4	252	247	253	1	253	0	255	255
EIA 5	3	248	246	2	252	254	255	254
EIA 6	0	249	240	8	8	247	2	254
EIA 7	244	236	18	14	241	5	254	1
2000 ft. 22 awg	1	251	249	5	0	0	2	255
2000 ft. 24 awg	0	249	251	5	255	0	1	0
2000 ft 26 awg	254	249	253	4	255	1	1	0

Table 11. ACIM = 0101 and CO Termination = 300 Ω + 1000 Ω + 220 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	1	0	255	1	0	0	0	0
EIA 1	254	255	2	0	255	1	0	0
EIA 2	255	252	0	2	254	0	255	255
EIA 3	1	249	255	4	252	1	255	255
EIA 4	252	250	1	1	254	0	255	255
EIA 5	3	251	251	2	253	255	255	254
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	1	254	255	1	255	0	0
2000 ft. 24 awg	0	0	0	0	0	0	0	0
2000 ft 26 awg	254	255	2	0	255	1	0	0

Table 12. ACIM = 0101 and CO Termination = 370 Ω + 620 Ω + 310 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	4	4	0	1	1	0	1
EIA 1	254	0	6	1	0	2	255	1
EIA 2	255	252	1	3	254	1	0	0
EIA 3	1	249	255	5	253	1	0	255
EIA 4	252	250	1	2	255	0	255	0
EIA 5	3	251	250	3	254	255	255	255
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	3	3	0	1	0	0	0
2000 ft. 24 awg	0	1	4	1	0	1	0	0
2000 ft 26 awg	254	0	6	1	0	2	255	1

Table 13. ACIM = 0101 and CO Termination = 270 Ω + 750 Ω + 150 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	254	2	4	1	2	1	0
EIA 1	254	253	2	3	1	2	1	1
EIA 2	255	252	0	2	255	1	0	0
EIA 3	1	249	254	4	253	1	0	0
EIA 4	252	250	1	1	254	0	255	0
EIA 5	3	251	250	2	253	255	255	255
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	0	255	3	2	0	1	0
2000 ft. 24 awg	0	254	0	3	1	1	1	0
2000 ft 26 awg	254	253	2	3	1	2	1	1

Table 14. ACIM = 1010 and CO Termination = 200 Ω + 560 Ω + 100 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	6	5	249	0	2	254	2	255
EIA 1	4	4	247	255	2	253	2	255
EIA 2	4	2	243	253	2	252	2	255
EIA 3	6	0	242	254	0	253	1	255
EIA 4	2	0	244	251	0	252	1	255
EIA 5	8	1	238	252	254	250	1	254
EIA 6	6	2	231	2	8	245	4	251
EIA 7	249	244	8	12	245	252	0	1
2000 ft. 22 awg	7	6	244	0	3	252	3	255
2000 ft. 24 awg	6	5	246	0	2	253	2	255
2000 ft 26 awg	4	4	247	255	2	253	2	255

Table 15. ACIM = 0000 and CO Termination = 900 Ω + 2.16 μ F

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	248	249	3	254	254	0	254	0
EIA 1	251	240	255	5	250	2	254	255
EIA 2	2	240	238	7	253	254	2	254
EIA 3	5	239	235	7	252	254	2	254
EIA 4	1	242	240	1	252	255	0	255
EIA 5	7	244	233	1	250	253	0	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	253	242	254	5	250	2	255	255
2000 ft. 24 awg	252	240	254	5	250	2	254	255
2000 ft 26 awg	251	240	255	5	250	2	254	255

Table 16. ACIM = 0000 and CO Termination = 600 Ω

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	255	247	255	4	253	2	0	0
EIA 2	2	243	241	8	253	255	2	254
EIA 3	5	240	238	9	252	255	2	254
EIA 4	1	242	241	2	253	255	1	255
EIA 5	7	244	234	2	251	254	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	2	250	254	4	253	1	0	0
2000 ft. 24 awg	1	249	254	4	253	1	0	0
2000 ft 26 awg	255	247	255	4	253	2	0	0

Table 17. ACIM = 0000 and CO Termination = 1200 Ω + 376 Ω + 112 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	240	242	7	255	254	3	254	1
EIA 1	247	232	254	8	249	4	255	0
EIA 2	2	238	234	6	253	254	2	254
EIA 3	4	237	231	5	252	254	2	254
EIA 4	1	241	239	255	251	254	0	255
EIA 5	7	244	233	0	249	252	0	253
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	249	233	253	8	249	3	255	0
2000 ft. 24 awg	248	232	253	8	249	4	255	0
2000 ft 26 awg	247	232	254	8	249	4	255	0

Table 18. ACIM = 0000 and CO Termination = 150 Ω + 510 Ω + 47 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	3	249	252	5	253	1	0	255
EIA 1	2	246	249	7	252	1	1	255
EIA 2	3	244	240	5	254	255	2	255
EIA 3	5	241	238	6	252	255	2	254
EIA 4	1	242	241	2	252	255	1	255
EIA 5	7	244	234	2	251	253	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	4	248	246	7	253	0	1	255
2000 ft. 24 awg	3	247	247	8	253	0	1	255
2000 ft 26 awg	2	246	249	7	252	1	1	255

Table 19. ACIM = 0000 and CO Termination = 220 Ω + 820 Ω + 150 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	6	246	239	5	253	255	2	255
EIA 1	3	246	241	2	254	255	1	255
EIA 2	3	245	240	1	252	254	1	255
EIA 3	5	242	238	4	250	255	0	254
EIA 4	1	242	241	2	251	254	0	254
EIA 5	7	244	234	2	250	252	0	253
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	6	249	237	2	255	253	2	254
2000 ft. 24 awg	5	247	239	3	254	254	2	255
2000 ft 26 awg	3	246	241	2	254	255	1	255

Table 20. ACIM = 0000 and CO Termination = 600 Ω + 1.5 μ F

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	255	254	254	254	254	254	254	254
EIA 1	255	246	253	3	251	0	254	254
EIA 2	2	242	241	7	252	254	1	253
EIA 3	5	240	237	8	252	254	1	253
EIA 4	1	242	241	2	252	255	0	254
EIA 5	7	244	234	1	251	253	1	254
EIA 6	4	244	228	6	7	247	1	253
EIA 7	248	230	8	18	234	2	1	255
2000 ft. 22 awg	1	249	251	2	251	255	254	254
2000 ft. 24 awg	0	247	252	3	251	0	254	254
2000 ft 26 awg	255	246	253	3	251	0	254	254

Table 21. ACIM = 0010 and CO Termination = 220 Ω + 120 Ω + 115 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	9	16	5	254	2	255	0	0
EIA 1	2	10	9	255	1	0	255	1
EIA 2	255	0	3	2	0	1	0	0
EIA 3	1	253	0	4	254	1	0	0
EIA 4	253	252	0	255	0	0	0	0
EIA 5	4	253	249	255	254	255	0	255
EIA 6	1	254	242	4	8	246	2	254
EIA 7	244	241	19	11	244	2	253	1
2000 ft. 22 awg	6	15	6	254	3	255	0	0
2000 ft. 24 awg	5	12	7	255	2	0	0	0
2000 ft 26 awg	2	10	9	255	1	0	255	1

Table 22. ACIM = 0011 and CO Termination = 220 Ω + 820 Ω + 115 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	255	0	255	254	1	255	0	0
EIA 2	255	0	253	252	255	254	255	0
EIA 3	1	254	252	253	253	255	255	255
EIA 4	253	255	255	251	254	254	254	255
EIA 5	4	0	249	252	253	253	254	254
EIA 6	1	1	242	2	9	245	3	253
EIA 7	245	243	18	10	245	0	253	1
2000 ft. 22 awg	1	2	252	255	1	254	1	255
2000 ft. 24 awg	0	1	253	255	1	255	0	0
2000 ft 26 awg	255	0	255	254	1	255	0	0

Table 23. ACIM = 0100 and CO Termination = 370 Ω + 620 Ω + 310 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	0	0	0	0	0	0	0
EIA 1	254	252	2	1	255	1	255	0
EIA 2	255	248	253	4	253	0	0	255
EIA 3	1	246	251	6	252	1	0	255
EIA 4	252	247	253	2	253	0	255	255
EIA 5	3	248	246	3	252	255	255	254
EIA 6	0	249	240	8	8	247	2	254
EIA 7	244	236	18	14	241	5	254	1
2000 ft. 22 awg	1	255	255	0	255	0	0	0
2000 ft. 24 awg	0	253	0	1	255	1	0	0
2000 ft 26 awg	254	252	2	1	255	1	255	0

Table 24. ACIM = 0100 and CO Termination = 220 Ω + 820 Ω + 120 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	248	254	6	255	2	1	0
EIA 1	254	249	253	4	255	1	1	0
EIA 2	255	249	251	2	254	0	0	0
EIA 3	1	246	250	4	252	1	0	255
EIA 4	252	247	253	1	253	0	255	255
EIA 5	3	248	246	2	252	254	255	254
EIA 6	0	249	240	8	8	247	2	254
EIA 7	244	236	18	14	241	5	254	1
2000 ft. 22 awg	1	251	249	5	0	0	2	255
2000 ft. 24 awg	0	249	251	5	255	0	1	0
2000 ft 26 awg	254	249	253	4	255	1	1	0

Table 25. ACIM = 0101 and CO Termination = 300 Ω + 1000 Ω + 220 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	1	0	255	1	0	0	0	0
EIA 1	254	255	2	0	255	1	0	0
EIA 2	255	252	0	2	254	0	255	255
EIA 3	1	249	255	4	252	1	255	255
EIA 4	252	250	1	1	254	0	255	255
EIA 5	3	251	251	2	253	255	255	254
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	1	254	255	1	255	0	0
2000 ft. 24 awg	0	0	0	0	0	0	0	0
2000 ft 26 awg	254	255	2	0	255	1	0	0

Table 26. ACIM = 0101 and CO Termination = 370 Ω + 620 Ω + 310 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	4	4	0	1	1	0	1
EIA 1	254	0	6	1	0	2	255	1
EIA 2	255	252	1	3	254	1	0	0
EIA 3	1	249	255	5	253	1	0	255
EIA 4	252	250	1	2	255	0	255	0
EIA 5	3	251	250	3	254	255	255	255
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	3	3	0	1	0	0	0
2000 ft. 24 awg	0	1	4	1	0	1	0	0
2000 ft 26 awg	254	0	6	1	0	2	255	1

Table 27. ACIM = 0101 and CO Termination = 270 Ω + 750 Ω + 150 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	0	254	2	4	1	2	1	0
EIA 1	254	253	2	3	1	2	1	1
EIA 2	255	252	0	2	255	1	0	0
EIA 3	1	249	254	4	253	1	0	0
EIA 4	252	250	1	1	254	0	255	0
EIA 5	3	251	250	2	253	255	255	255
EIA 6	0	252	244	8	9	247	3	254
EIA 7	244	239	21	14	244	5	254	1
2000 ft. 22 awg	1	0	255	3	2	0	1	0
2000 ft. 24 awg	0	254	0	3	1	1	1	0
2000 ft 26 awg	254	253	2	3	1	2	1	1

Table 28. ACIM = 1010 and CO Termination = 200 Ω + 560 Ω + 100 nF

Line Type	Hybrid Coefficient #							
	1	2	3	4	5	6	7	8
EIA 0	1	2	1	0	0	0	0	0
EIA 1	255	1	0	255	1	255	0	0
EIA 2	255	255	252	252	0	255	0	0
EIA 3	1	253	250	254	254	255	0	0
EIA 4	253	253	253	251	255	254	255	0
EIA 5	3	254	246	252	253	253	255	254
EIA 6	1	255	239	1	8	245	3	253
EIA 7	244	242	16	9	245	0	254	1
2000 ft. 22 awg	2	4	253	255	2	254	1	0
2000 ft. 24 awg	1	2	254	255	1	255	1	0
2000 ft 26 awg	255	1	0	255	1	255	0	0

APPENDIX C—EIA LINE MODELS

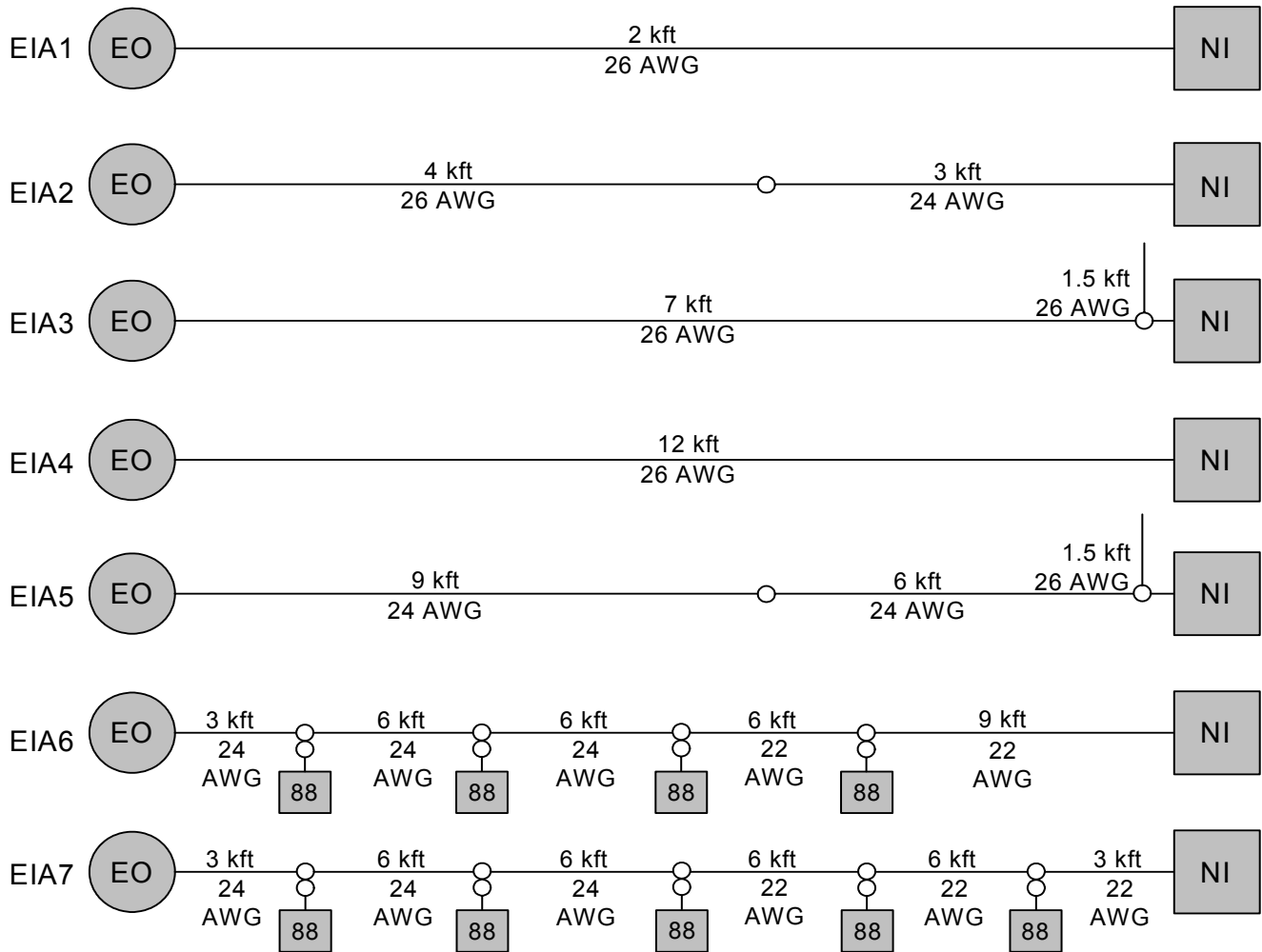


Figure 9. EIA Line Models

DOCUMENT CHANGE LIST

Revision 0.3 to Revision 0.4

- Added Figure 5 on page 4.
- Added " Appendix C—EIA Line Models" on page 24.

Revision 0.4 to Revision 0.5

- Updated Figure 5 on page 4.
- Added Tables 17–32 (information for Rev E and later versions of the Si3019).

Revision 0.5 to Revision 0.6

- Updated "1.2. Digital Hybrid Calculation Tool" on page 3.
- Updated Figure 5 on page 4.
- Updated " Appendix B—Hybrid Coefficient Lookup Tables" on page 10.

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