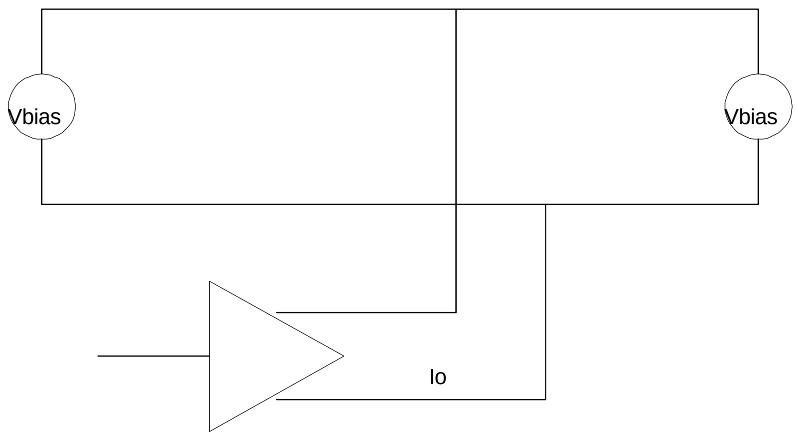
To: T10 Membership
Subject: DRIVER/RECEIVER ANALYSIS
Date: May 1, 1997

Shown below is an analysis of both the driver and receiver response using the biased asymmetrical design. This expands on the analysis that Kevin did on the driver and includes the effects of the receiver on the response of the system under worst case conditions using the limits of the specification values in SPI 2. This shows the system would be much better behaved without the bias and the potential errors can add to very significant distortion of high speed pulses. Also from the equations one can see that the receiver response to assertion and negation drive level mismatch in the absence of a bias. At the very least there may be a need to tighten values in the current specification to allow error free operation at SPI 2 rates.

DRIVER

At the April 18 meeting Kevin provided an equation for the driver and bias setup of the current Ultra 2 configuration. His diagram and equations are shown below.



The expressions for the assertion and negation currents are as follows:

Va = ia*Rt/2 +Vb

Vn = ib*Rt/2 -Vb

For Va = Vn

ia*Rt/2 + Vb = in*Rt/2 -Vb

ia - in = 4Vb/Rt

For example if Vb = 100 mv and Rt =100 ohms

ia - in = 4 ma

For Va = Vn = 500 mv with Rt = 100 ohms and Vb = 100 mv

500 = ia*50 + 100
ia = 8 ma

$500 = in*50 - 100$
$in = 12$ ma

But the difference current is a function of the match of the Rt and Vb to the ones used to calculate the current difference required. In the AC case after picking the currents the waveform will only be symmetric if Rt = Loaded Zo.

Assume we did the design as above for Rt = 100 ohms and Vb = 100 mv and then used the driver on a loaded cable with a loaded Zo of 70 ohms.

$Va = ia*Zo/2 + Vb$

$Va = 8*35 + 100 = 380$ mv

$Vb = in*Zo/2 - Vb$

$Vb = 12*35 - 100 = 320$ mv

NOTE THAT THE VOLTAGES ARE NO LONGER BALANCE DUE TO THE Zo DIFFERENCE IN THIS CASE BY 15%

Now consider Bias tolerance with a perfect Zo =100 ohms, but the Vb now being 125 mv.

$Va = ia*Zo/2 + Vb$

$Va = 8*50 + 125 = 525$ mv

$Vb = in*Zo/2 - Vb$

$Vb = 12*50 - 125 = 475$ mv

THE BIAS DIFFERENCE HAS CAUSED A 9.5% DIFFERENCE IN THE ASSERTION AND NEGATION LEVELS.

Due to the variation of the bias and Zo there will always be an asymmetrical waveform unless the design values for the difference current exactly matches the real loaded cable and bias being used.

From SPI 2 Page 9 the following values are given.

Cable impedance 110 - 135
Bias = 112.5 +- 12.5
Assume a design drive level of 492.5 mv drive levels (this is the average of the assertion and negation drive level range).

Currents become: ia = 6.20 ma
in = 9.88 ma

Now consider the four extremes of the specification:

Case 1: Low Impedance/Low bias	110 ohms / 100 mv
Case 2: High Impedance/Low bias	135 ohms / 100 mv
Case 3: High Impedance/High bias	135 ohms / 125 mv

Case 4: Low Impedance/High bias 110 ohms / 125 mv

The Va and Vn levels for these four cases are listed below:

Case 1:

Va = 441 mv
Vn = 443 mv

Case 2:

Va = 518.5 mv
Vn = 566.9 mv

Case 3:

Va = 543.5 mv
Vn = 541.9 mv

Case 4:

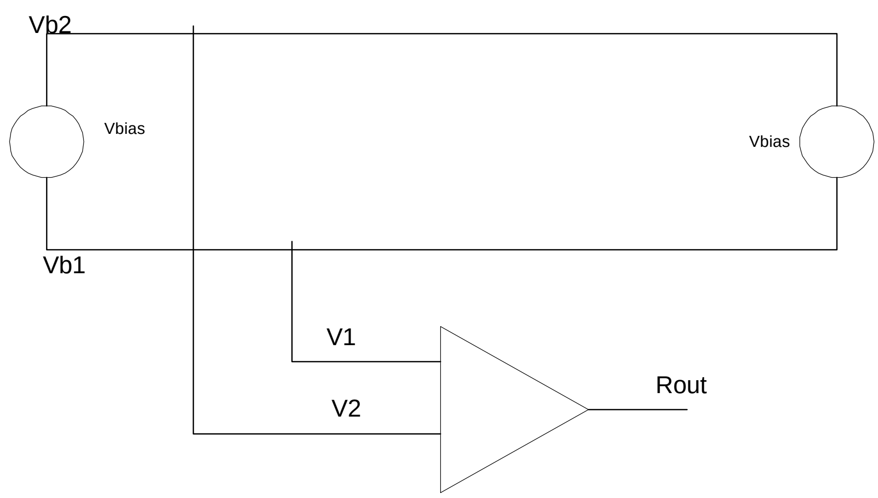
Va = 466 mv
Vn = 418 mv

Case 2/4 are the worst case and result in asymmetry of 9.3% and 11.3%. Even using the design point of 492.5 mv (a very substantial drive level) the minimum drive level produced is 418 mv which is a 15% reduction. This can come into significance if the design point had been chosen lower in the allowable range.

The above assumes that the loading does not degrade the cable impedance lower than the specification. Higher loading if it reduces the cable impedance more can cause even more degradation of the signal. In Table 15 of SPI 2 there is a min/max cable loading of 85 to 135. Doing the same analysis for the two worst cases and again designing for the 492.5 mv drive yields Case 2 and Case 4 mismatches of 13.4% and 22%, with a minimum drive level of 342.5 mv (from a design point of 492.5), a 30% reduction before any cable transmission losses are taken into effect, and before any issues with the receiver are taken into effect.

Now consider the receiver response.

RECEIVER



Receiver output:

Ro = 1 if V1 > V2
= 0 if V1< V2

After square waves are driven into the cable at high enough frequency (40 MHz) the resultant wave at the receiver resembles a sine wave more than a square wave. Thus V1 and V2 can be written as follows:

$$V1 = Vb1 + Vo1*\sin(wt)$$
$$V2 = Vb2 + Vo2*\sin(wt + 180) \qquad \text{NOTE 1.}$$

Note that Vo1 and Vo2 are zero to peak values.

Therefore

$$Ro = 1 = Vb1 + Vo1*\sin(wt) > Vb2 + Vo2*\sin(wt + 180)$$
$$= 0 = Vb1 + Vo1*\sin(wt) < Vb2 + Vo2*\sin(wt + 180)$$

$$Ro = 1 = Vb1 - Vb2 + Vo1*\sin(wt) > Vo2*\sin(wt + 180)$$
$$= 0 = Vb1 - Vb2 + Vo1*\sin(wt) < Vo2*\sin(wt + 180)$$

$$\text{But } \sin(wt + 180) = -\sin(wt)$$

$$Ro = 1 = Vb1 - Vb2 + Vo1*\sin(wt) > - Vo2*\sin(wt)$$
$$= 0 = Vb1 - Vb2 + Vo1*\sin(wt) < - Vo2*\sin(wt)$$

$$Ro = 1 = Vb1 - Vb2 + Vo1*\sin(wt) + Vo2*\sin(wt) > 0$$
$$= 0 = Vb1 - Vb2 + Vo1*\sin(wt) + Vo2*\sin(wt) < 0$$

Assume Vb1 - Vb2 = 100 mv and Vo1= V02 = 100 mv (zero to peak). This would be the case if we drove the cable with 400 mv peak to peak signal and suffered a 3 db loss in the cable.

$$Ro = 1 = 100 + 2*100*\sin(wt) > 0$$
$$= 0 = 100 + 2*100*\sin(wt) < 0$$

Looking at the sin function and assuming we were trying to detect a square wave signal (50/50 duty cycle) the signal would be distorted by 16% (50/50 duty cycle would now be 42.5/57.5).

If Vb1-Vb2 goes to 125 mv then the duty cycle is distorted by 40% (50/50 duty cycle would now be 30/70).

Note that if Vb1 does not equal Vb2 we have a more complicated equation that needs to be plotted. Also note that if Vb1- Vb2 = 0 (no bias) then there is NO distortion of the pulse even if Vo1 does not equal Vo2!

Shown below is a worst case analysis combining driver and receiver issues using again Table 15 of SPI 2 for parameters, but with a drive level of 300 mv (well within specification).

From Table 15:

Cable Impedance	85 -135 ohms (design for 110)
Terminator bias	112.5 +-12.5 mv
Output level	300 mv
Attenuation	15%

From before the drive currents for equal amplitude are:

ia = 3.4 ma
in = 7.5 ma

Consider worst case (Case 4 Low Impedance / High Bias) 85 ohms / 125 mv

Va = 269.5 mv (pp)
Vn= 193.8 mv (pp)

These values are pp numbers and the zero to peak numbers are half these.

Now reduce by 15% attenuation factor and apply to receiver.

Va = 228.65 mv pp (which is 114.32 mv op)
Vn = 164.68 mv pp (which is 82.34 mv op)

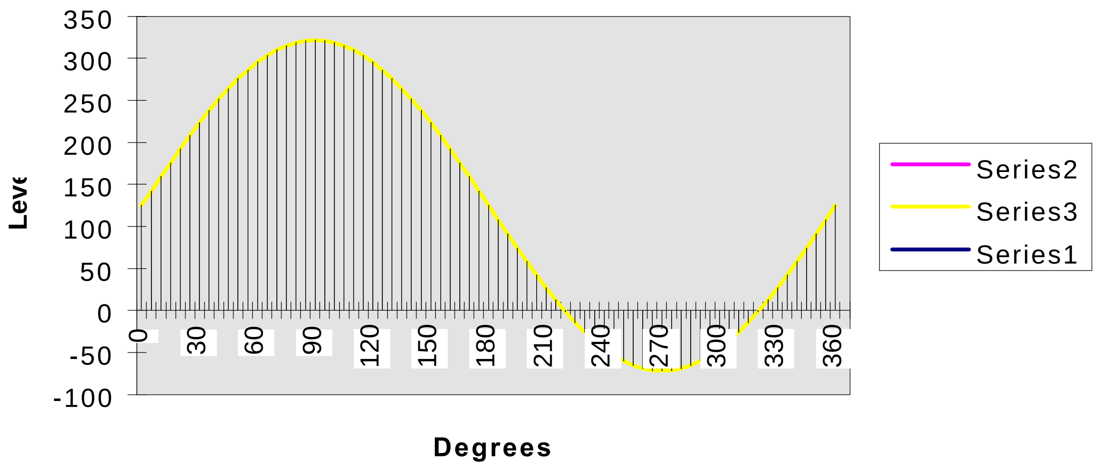
These values are applied to the receiver response function.

Ro = 1 = Vb1 - Vb2 +Vo1*sin (wt) + Vo2*sin (wt) > 0
= 0 = Vb1 - Vb2 +Vo1*sin (wt) + Vo2*sin (wt) < 0

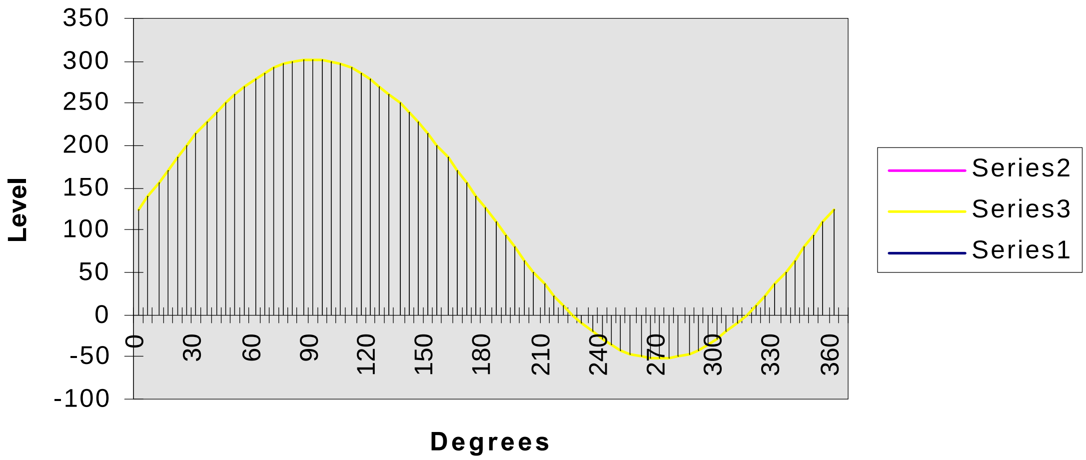
Vb1 - Vb2 = 125 mv

Ro = 1 = 125 + 114.32*sin (wt) + 82.34*sin (wt) > 0
= 0 = 125 + 114.32*sin (wt) + 82.34*sin (wt) < 0

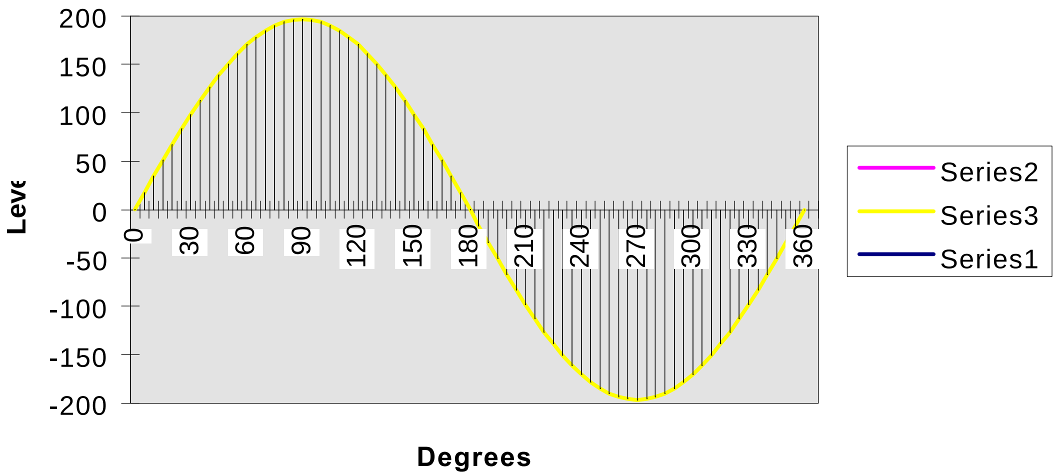
A plot of this function is shown below. From the values the signal distorts from a 50/50 duty cycle by 44% (a perfect 50/50 duty cycle becomes 28/72) allowing for a 30 mv receiver threshold. This most likely would not function and certainly would not function at 80 MHz. This also violates the 4:1 rule for the positive and negative transitions at the receiver.



If the design drive level were reduced to 270 mv which is the limit of the specification today and the same impedance and terminator bias were used the result would be the curve shown below. This shows a distortion 55% and the 50/50 duty cycle would become 22.5/77.5.



Finally if the bias value is reduced to zero even with the NON-EQUAL Vbo and Vb1 values shown above the distortion goes to ZERO. The 50/50 waveform would be exactly detected as 50/50 in spite of unequal assertion and negation values. This is shown in the graph below.



NOTE 1.

The equations for V1 and V2 are not entirely accurate since the deviations above and below the Vb1 and Vb2 levels are not the same. The more exact expression would be as follows:

$$V1 = Vb1 + Vo1*\sin(wt) - Vo1b*\sin(wt)\Big|_{0}^{180}$$

Where Vo1b is some value between 0 and 180 degress and zero from 180 to 360.

$$V2 = Vb2 + Vo2*\sin(wt+180) - Vo2b*\sin(wt+180)\Big|^{180}$$

0

Note that Vo1 and Vo2 are zero to peak values.

Evaluating this expression as before results in the following.

$$Ro = 1 = Vb1 - Vb2 + Vo1*\sin(wt) + Vo2*\sin(wt) - Vo1b*\sin(wt)\Big|_{0}^{180} - Vo2b*\sin(wt)\Big|_{0}^{180} > 0$$

$$= 0 = Vb1 - Vb2 + Vo1*\sin(wt) + Vo2*\sin(wt) - Vo1b*\sin(wt)\Big|_{0}^{180} - Vo1b*\sin(wt)\Big|_{0}^{180} < 0$$

However if these expressions are plotted with appropriate values for Vo1, Vo2, Vo1b, and Vo2b there is no difference in the distortion as shown in the other charts. The differential nature takes out any distortion of the levels of the waveform, but cannot take out the bias voltage effect. In all cases if the bias voltage is taken to zero, the distortion goes to zero.