Linfinity Microelectronics

SCSI Single-Ended Termination X3T10/96-245r2

The purpose of this proposal is to define the SCSI terminator IV space (both sink and source) that best accommodates the range of possible loaded cable impedance based on reflection coefficients, voltage standing wave ratios, and bus settle times. The IV curve will also correct the incompatibility between the SCSI-2 terminator specification and the SPI specification.

The unloaded cable impedance for single ended fast-20 and SCSI-3 are;

80 ohms to 100 ohms Fast-20
84 ohms to 96 ohms Fast-20 req/ack
72 ohms to 96 ohms SPI SCSI-3

The maximum load capacitance per the standard is 25pF. Minimum load capacitance is probably in the 8pF range with a bad designed load being as high as 40pF. The SCSI-3 distance is 6 meters with 8 or 16 devices. The fast-20 distance is 1.5 meter with 5 to 8 devices or 3.0 meters with 4 devices or less. The devices are required to be spaced greater than 0.3 meter apart with a stub length of less than 0.1 meter.

The impedance is Z=(R+jwl/G+jwc)^1/2. At higher frequencies this is approximated as Z=(L/C)^1/2. Although this is only a rough approximation since it doesn't take into account increased resistance (and decrease in inductance) due to the skin effect, proximity effect, radiation losses, and dielectric losses.

Typical values of capacitance for cables run from 12pF/ft to 20pF/ft with the corresponding inductance to yield the correct impedance. For a 96 ohm cable good values of L and C are L=141nH/ft and C=16.2pF/ft. For 72 ohm cable these could be L=105nH/ft and C=20pF/ft. Within reason any combination of the above values can be used as starting points to calculate loaded bus impedance. Obviously the higher capacitance cables show less effect of loading but they can also have more high frequency degradation of impedance due to the reduced inductance at frequency.

The delay time for the lower impedance cable is,
T=(105nH/ft*20pF/ft)^1/2 = 1.44ns/ft
This can be used to approximate the maximum spacing that can be used and have distributed loads. If the spacing between loads is less than the rising edge of the signal then the load capacitance can be assumed to be distributed across the cable. For SCSI the driver rise and fall times vary from about 3ns (520mV/ns 0.7V to 2.3V) to slower (a bad driver could have rise/fall times in the 1ns range). This yields a device spacing range of **0.3m<** spacing<**0.8m** to appear as a distributed load.

If the maximum load capacitance of 25pF is used at 1ft spacing the effective loaded impedance becomes;
Zeff=(L/C+C')^1/2 = (105nH/ft/45pF/ft)^1/2 = 48 ohms.
This yields an overall impedance range of 48 ohms to 96 ohms.

Using the above range for the possible cable impedance then the effect of the terminator can be examined. The two aspects of this are the voltage levels for adequate margin (acceptance, attenuation, reflection, and transmission) and the bus time domain properties, reflection coefficients, voltage standing wave ratio, and bus settle times. The three tables show calculations of the following parameters.

REFLECTION COEFFICIENT: Gref=Zt-Zc/(Zt+Zc)
Zt is the terminator impedance and Zc is the loaded cable impedance.

Voltage standing wave ratio (VSWR): VSWR=1+|Gref|/(1-|Gref|)
The standing waves are at quarter wavelengths (lamda/4) and the wavelength can be approximated by Lamda=1/(f*(LC)^1/2). Where to capture the majority of the harmonic content f=0.5/Tr (driver rise time) can be used.

Bus settle delay: The bus settle delay was calculated for voltage mode drivers and current mode drivers. Two different points were calculated for each. The percentage of the signal after 25ns and how long does it take the bus to settle within 10% of the final value.

For the voltage mode drivers;
Mag(t)=(Grefdr*Grefterm)^t/T
The reflection coefficients are from the driver and from the terminator. The variable t is the time selected for settling i.e. 25ns. T is the one way propagation delay T=x(LC)^1/2. The reflection coefficient from voltage mode drivers can be high especially if drivers in the 7 ohm range or so are used. The converse of this is that the strong drivers also give a good high voltage because of the acceptance function. The time for the bus to settle to within 10% is given by;
t=Tlog(0.1)/log(Grefdr*Grefterm)

For the current mode drivers;

Mag(t)=(Grefterm*Grefterm)^t/T
t=Tlog(0.1)/log(Grefterm*Grefterm)

In this case the settling time is influenced by the terminators.

The three cases that the parameters were evaluated for are;
Case 1: 48 ohm loaded bus impedance
Case2: 72 ohm loaded bus impedance
Case3: 96 ohm bus impedance

The range of termination resistance used is **20 ohms to 140 ohms.**

Case 1
48 ohm cable impedance (L=105nH/ft C=45pF/ft)

Termination impedance 20 ohms to 140 ohms
Cable length 6 meters
One way propagation delay T=18(105nH/ft*45pF/ft)^1/2 = 39 ns
Voltage mode driver on resistance 7 ohms

Term Z	**Ref Coeff**	**VSWR**	**Bus settle (volt driver)**		**Bus settle (current dr)**	
			Mag(@25ns)	10% settle (ns)	Mag(@25ns)	10% (ns)
20	-0.42	2.45	0.48	78	0.33	52
25	-0.32	1.96	0.4	64	0.24	40
30	-0.24	1.63	0.33	52	0.16	32
35	-0.17	1.4	0.26	43	0.1	25
40	-0.1	1.23	0.19	35	0.05	20
45	-0.04	1.09	0.1	26	0.02	14
50	0.01	1.02	0.04	18	0	10
55	0.06	1.12	0.13	29	0.02	16
60	0.1	1.22	0.19	35	0.05	20
65	0.14	1.3	0.24	40	0.08	23
70	0.18	1.43	0.27	44	0.1	26
75	0.21	1.53	0.3	48	0.13	29
80	0.24	1.63	0.33	52	0.16	31
85	0.27	1.73	0.36	56	0.18	34
90	0.29	1.83	0.38	60	0.21	37
95	0.32	1.9	0.4	63	0.23	39
100	0.34	2.04	0.42	66	0.25	42
105	0.36	2.14	0.43	69	0.27	44
110	0.38	2.24	0.45	72	0.29	47
115	0.4	2.35	0.46	75	0.31	49
120	0.42	2.45	0.48	78	0.33	52
125	0.44	2.55	0.49	80	0.35	54
130	0.45	2.65	0.5	83	0.36	57
135	0.47	2.76	0.51	86	0.38	59
140	0.52	2.86	0.52	88	0.39	61

If the criteria is set as a reflection coefficient must be less than +/-0.3 and the bus must be settled to within 10% within 50ns then the acceptable terminator impedance range for this case is **35 ohms to 75 ohms.** In this case the wavelength is 2.77ft. So there is a potential for standing wave problems (at 0.7ft). This points to the issue that for incident wave switching device placement (ISI concerns) and proper termination become critical to signal quality.

Case 2
72 ohm cable impedance (L=130nH/ft C=25pF/ft)

Termination impedance 20 ohms to 140 ohms
Cable length 6 meters
One way propagation delay T=18(130nH/ft*25pF/ft)^1/2 = 32 ns
Voltage mode driver on resistance 7 ohms

Term Z	**Ref Coeff**	**VSWR**	**Bus settle (volt driver)**		**Bus settle (current dr)**	
			Mag(@25ns)	10% settle (ns)	Mag(@25ns)	10% (ns)
20	-0.56	3.6	0.55	96	0.41	65
25	-0.48	2.88	0.49	80	0.32	51
30	-0.41	2.4	0.43	68	0.25	42
35	-0.35	2.06	0.37	59	0.19	35
40	-0.29	1.8	0.32	51	0.14	29
45	-0.23	1.6	0.27	44	0.1	25
50	-0.18	1.44	0.22	39	0.07	22
55	-0.13	1.31	0.18	33	0.04	18
60	-0.09	1.2	0.13	28	0.02	15
65	-0.05	1.1	0.08	23	0.01	12
70	-0.01	1.03	0.03	17	0	9
75	0.02	1.04	0.04	18	0	9
80	0.05	1.1	0.09	24	0.01	13
85	0.08	1.8	0.12	27	0.02	15
90	0.11	1.25	0.15	31	0.03	17
95	0.14	1.32	0.18	34	0.05	19
100	0.16	1.4	0.21	37	0.06	20
105	0.19	1.46	0.23	39	0.07	22
110	0.21	1.53	0.25	42	0.09	24
115	0.23	1.6	0.27	44	0.1	25
120	0.25	1.67	0.29	47	0.11	27
125	0.27	1.74	0.31	49	0.13	28
130	0.29	1.8	0.32	51	0.14	30
135	0.3	1.88	0.34	53	0.16	31
140	0.32	1.94	0.35	55	0.17	32

If the reflection coefficient is less than +/-0.3 and the bus settles to within 10% in under 50ns then the termination impedance must be within **45 ohms to 125 ohms.** This is the most centered of the three cases and probably gives the best range.

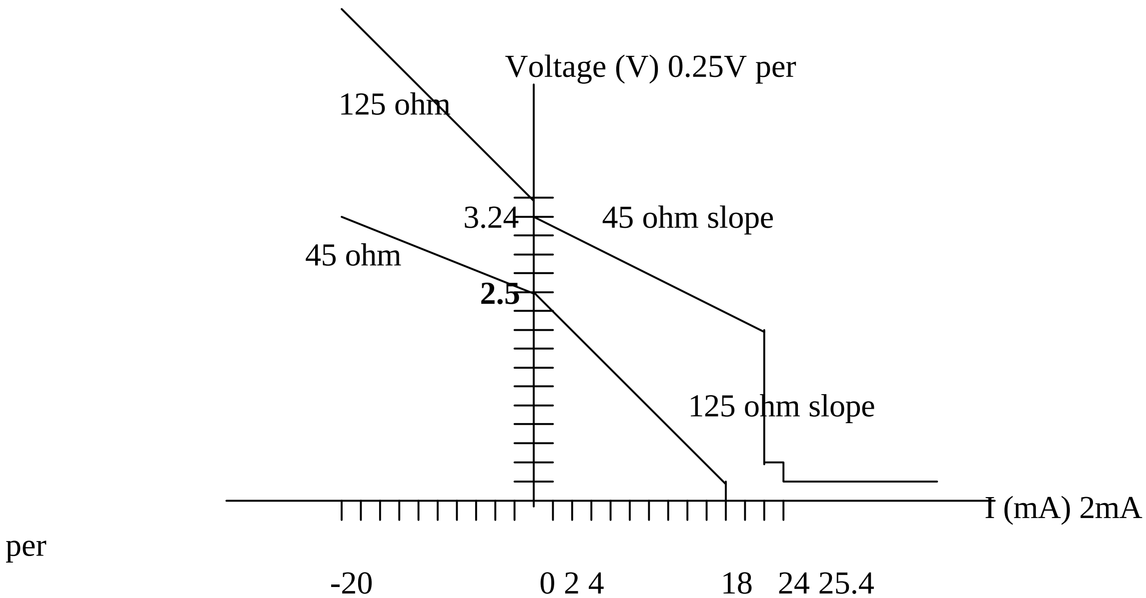
Case 3
96 ohm cable impedance (L=141nH/ft C=16.2pF/ft)

Termination impedance 20 ohms to 140 ohms
Cable length 6 meters
One way propagation delay T=18(141nH/ft*16.2pF/ft)^1/2 = 27 ns
Voltage mode driver on resistance 7 ohms

Term Z	Ref Coeff	VSWR	Bus settle (volt driver)		Bus settle (current dr)	
			Mag(@25ns)	10% settle (ns)	Mag(@25ns)	10% (ns)
20	-0.65	4.8	0.59	110	0.46	74
25	-0.59	3.84	0.53	92	0.37	58
30	-0.53	3.2	0.48	78	0.3	48
35	-0.46	2.74	0.43	68	0.24	41
40	-0.41	2.4	0.38	60	0.19	35
45	-0.36	2.1	0.34	54	0.15	31
50	-0.31	1.92	0.3	48	0.12	27
55	-0.27	1.75	0.26	43	0.09	24
60	-0.23	1.6	0.22	39	0.07	21
65	-0.19	1.48	0.19	35	0.05	19
70	-0.16	1.37	0.16	31	0.03	17
75	-0.12	1.28	0.13	28	0.02	15
80	-0.09	1.2	0.09	24	0.01	13
85	-0.06	1.13	0.06	21	0.01	11
90	-0.03	1.07	0.04	17	0	9
95	-0.01	1.01	0	12	0	6
100	0.02	1.04	0.02	15	0	8
105	0.04	1.09	0.05	19	0	10
110	0.07	1.15	0.08	22	0.01	12
115	0.09	1.2	0.09	24	0.01	13
120	0.11	1.25	0.11	27	0.02	14
125	0.13	1.3	0.13	29	0.02	15
130	0.15	1.35	0.15	31	0.03	16
135	0.17	1.4	0.17	32	0.04	18
140	0.19	1.46	0.18	34	0.04	19

The best range to meet the above criteria is an impedance range of **50 ohms to 140 ohms.**
The ranges from the three examples are;
35 ohms to 75 ohms (48 ohm cable impedance)
45 ohms to 125 ohms (72 ohm cable impedance)
50 ohms to 140 ohms (96 ohm cable impedance)
The range of approximately 45 ohms to 125 ohms gives the best coverage is these three examples.

TERMINATOR IV CURVE



The terminator IV characteristics are defined by a 45 ohm resistive slope that goes from 0mA at 3.24V to 24mA at 2.16V. The maximum current between 0.2V and 0.5V is 25.4mA. The region below 0.2V is open to allow undershoot clamps. The lower limit is defined by a 125 ohm resistive slope that goes from 0mA at 2.5V to 18.4mA at 0.2V. This effectively excludes the 220/330 passive termination (15.5mA @0.5V with Vterm= 4.25V).

The region for sink current is also bounded by a 125 ohm resistive slope for the upper limit and a 45 ohm resistive slope for the lower limit. The upper limit is offset to allow a 6mA point at 4V (derived from (4V-3.24V)/125ohms=6mA).

This kind of approximation can be used for any reasonable values of unloaded cable impedance, loads, and system configuration. The analysis also show that as speed increases it becomes increasingly difficult to properly terminate a multipoint system that is required to switch incident wave. Since the drivers are no longer open drain large reflections are not needed to obtain adequate high voltage levels and only slight over termination is preferable, probably 0% to 10% greater than the loaded bus impedance (maximum) is the preference.

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