



TECHNICAL INFORMATION

AC TERMINATION FOR SIGNAL BUSESSES

by Ben Smith
AVX Corporation
801 17th Avenue South
Myrtle Beach, SC 29578
Office: (843) 946-0504
Fax: (843) 946-0504
email: tbsmith@sccoast.net

Abstract:

The predominant direction of modern electronic system design is towards higher speed and efficiency. This is not to say that efficiency was not an issue in previous designs, but as clock speeds increase, many elements that once were treated as ideal cannot be treated in this manner any longer. Digital system designers are faced with critical issues dealing with maintaining signal integrity while balancing numerous other inhibiting factors. Perhaps one of the more menacing non-ideal effects can be seen in signal transmission through bus lines. Gone are the days when a trace of metal could be treated as a loss less element. Today's high speed busses require a thorough evaluation using transmission line techniques. Factors such as propagation delays, signal reflections, and power consumption must be taken into account when designing high speed digital systems. Effective signal line termination maximizes the performance of the whole system by improving signal integrity while abiding by all other constraints. The termination technique dealt with in this paper is AC termination which is simply the connection of a resistor in series with a capacitor to ground.

AC TERMINATION FOR SIGNAL BUSESSES

by Ben Smith
 AVX Corporation
 801 17th Avenue South
 Myrtle Beach, SC 29578
 Office: (843) 946-0504
 Fax: (843) 946-0504
 email: tbsmith@sccoast.net

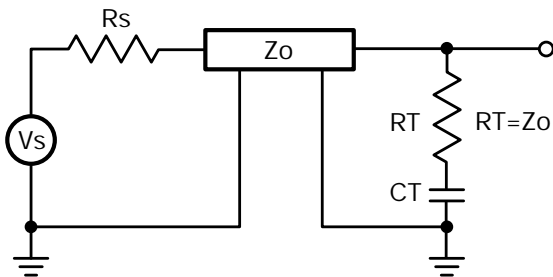
Introduction: AC Termination Basics

The principal function of a bus terminator is to maintain signal integrity while minimizing propagation delays and power consumption.

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Equation 1: Load Reflection
 If $Z_L = Z_0$ then Reflection = 0

Complete signal integrity is achieved by eliminating all reflections on the bus or transmission line. As can be seen by Equation 1 (Load Reflection Coefficient), the load impedance must equal the impedance of the transmission line to suppress reflections at the load. The logical choice would be to simply terminate the signal line with a resistor or resistor network equal to the characteristic impedance of the line. Unfortunately, in today's high speed low power systems this is not a viable solution because the resistor or resistor network consumes too much DC current



V_s is the source Voltage
 R_s is the source Resistance
 Z_0 is the Transmission Line Characteristic Impedance

Figure 1. AC Termination Configuration

resulting in power loss. An alternative is AC termination shown in Figure 1. Essentially, the resistor provides the impedance match needed to minimize reflections at the load. The capacitor's function is to block the DC average current thus alleviating problems dealing with power consumption. Obviously AC termination does not come without some constraints. The disadvantages are propagation delays and potential jitter errors that must be accounted for by the designer in the timing budget.

Methodology: Choosing a Capacitor

Ultimately, bus termination component values are contingent upon the actual input signal's rise time. If the rise time is greater than twice the

If $t_r > t_d$ then termination is not necessarily needed
 If $t_r < t_d$ then termination is needed

loaded propagation delay of the bus, then termination is not necessarily needed. With relatively short lines, the signal is still rising during the signal's propagation and the reflections that are induced add to the rising edge of the signal. If the rise time is less than twice the loaded propagation delay then termination is needed. The reflections of longer lines appear as an overshoot and undershoot which degrades signal integrity.

Choosing a capacitor for AC termination is by no means a trivial process. Tradeoffs must be analyzed for each specific system. If the RC time constant is too small then the received signal will exhibit a ringing (overshoot and undershoot) effect. If the RC time constant is too large potential jitter and power consumption become issues that the designer must confront. With this in mind, a general rule of thumb is that the RC time constant should be larger than twice the loaded propagation delay. In some instances this might not be the most desirable choice. In regards to noise margins, if some overshoot and undershoot are allowed, noise margins are increased due to the higher and lower voltage levels that the load sees. By allowing higher and lower voltages, the system state changes are more flexible thus increasing the system's immunity to noise.

Each specific design has its own unique attributes that must be evaluated from the designers perspective. In the case where there is only one device load, the calculations for the capacitor are not as extensive in that loading does not need to be considered. In this case

$$V_{diff} = E_i [1 - e^{-\frac{t}{\tau}}]$$

Equation 2: Capacitor Calculation

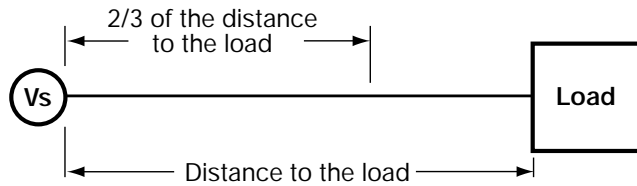
Where E_i is the incident wave related to the source b

$$\text{Equation 3} \quad E_i = V_s \times \frac{Z_0}{Z_0 + R_s}$$

Where V_{diff} is the difference in reference to E_i

Where $t = 2 \times \text{time delay}(t_d)$ and $\tau = 2Z_0C$

Equation 2 is used to determine an effectual value for a given source impedance and allowable voltage overshoot or undershoot. Equation 3 illustrates that the performance of the terminator is significantly affected by the input source's resistance. The designer must recog-



First Load extension should be at least 2/3 distance to the load
Other Loads should be separated by .5 inch spacings

Figure 2. Two-thirds rule used in loaded network design

nize the limitations of the system and address this circumstance accordingly.

Different problems arise when the network is loaded with more than one load. When the bus is heavily loaded, at certain points on the line, reflections cause oscillations that are detrimental to logic translation. One method of minimizing reflection problems is the two-thirds rule which is shown in Figure 2. By using the two-thirds rule and spacing the loads at .5in distances from one another, reflection problems due to load clustering are avoided. Equations 4 and 5 are then used to adjust the propagation delay and characteristic imped-

$$\text{Equation 3: } Z_o = Z_o / \sqrt{1 + \frac{CD}{CO}} \text{ ohms}$$

$$\text{Equation 4: } td = td \times \sqrt{1 + \frac{CD}{CO}} \text{ ns/inch}$$

Where CD is the load distributed capacitance and CO is the trace intrinsic capacitance

ance. Finally, Equation 2 is used to calculate the value of the capacitor needed. There is limitation to this process, however, because the waveform's integrity is maximized only for the end load. The other loads on the network may not have acceptable time delays or voltage levels. The designer is again confronted with the aspect of accepting some overshoot at the end load by adjusting the RC time constant to provide the rest of the loads with a sufficient waveform. Timing budgets will also have to be scaled to meet specific criteria.

Recent advances in technology have allowed cofiring resistive material systems with common dielectric material systems. In conventional cofired chip carriers using LTCC materials, typical dielectric thickness ranged from 80-100 μ m. AVX's new revolutionary material system allows for dielectric thickness control as low as 10-15 μ m using very stable Class I dielectrics. Significant gains in volumetric efficiency, device resiliency, and

electrical performance are apparent accolades of the new technology.

Conclusions

The objective of bus termination is simply to provide the load with an appropriate control signal while diminishing potentially adverse effects caused by signal transmission. In essence, AC termination is an extremely viable solution to bus termination. AC termination maintains signal integrity, minimizes power consumption, reduces crosstalk, and improves bus reliability. AC termination can be used to terminate both clock and data signal busses in any electronic system that utilizes CMOS and/or TTL technology. AC termination is not recommended for use in memory systems due to the varying characteristic impedances of memory lines, and high current drivers such as ECL. Also, AC termination does have a disadvantage in that a long string of successive like signal states can cause jitter errors because the capacitor charges towards the driver level and when switched, takes a longer time to charge or discharge to the appropriate level. In conclusion, each specific design comprises of numerous unique features and must be thoroughly evaluated and simulated by the designer to find the best possible solution. Nevertheless, AC termination provides substantial benefits to most applications and is a very effective method of bus termination.

Design Considerations

The following contains a few design strategies that help to alleviate some design constraints.

- Make sure that the signal driver has sufficient current and phase margin
- Use the two-thirds rule and make sure the loads are evenly distributed
- Make the minimum space between the loads .5in
- Avoid stubs and T's that cause impedance discontinuities
- Account for the loading of the loads as well as the loading for sockets and vias
- Ensure that minimum distances are required during layout
- Avoid bundled parallel signal lines whenever possible
- Ensure that there are no ground faults between circuitry connections
- Design with scaled loading effects in mind

Bibliography

- [1] "Transmission Line Effects in PCB Applications," Motorola Application Notes, AN-1051 1990.
- [2] Vu, Mai, "Signal Reflection and Pedestal Effect of a Heavily Loaded Net," EDN, May, 1996.
- [3] Collin, Robert E., "Foundations for Microwave Engineering," 2nd ed., McGraw-Hill Book Company, New York, 1992.

USA

**AVX Myrtle Beach, SC
Corporate Offices**
Tel: 843-448-9411
FAX: 843-626-5292

AVX Northwest, WA
Tel: 360-699-8746
FAX: 360-699-8751

AVX North Central, IN
Tel: 317-848-7153
FAX: 317-844-9314

AVX Mid/Pacific, MN
Tel: 952-974-9155
FAX: 952-974-9179

AVX Southwest, AZ
Tel: 480-539-1496
FAX: 480-539-1501

AVX South Central, TX
Tel: 972-669-1223
FAX: 972-669-2090

AVX Southeast, NC
Tel: 919-878-6223
FAX: 919-878-6462

AVX Canada
Tel: 905-564-8959
FAX: 905-564-9728

EUROPE

**AVX Limited, England
European Headquarters**
Tel: ++44 (0) 1252 770000
FAX: ++44 (0) 1252 770001

AVX S.A., France
Tel: ++33 (1) 69.18.46.00
FAX: ++33 (1) 69.28.73.87

AVX GmbH, Germany - AVX
Tel: ++49 (0) 8131 9004-0
FAX: ++49 (0) 8131 9004-44

AVX GmbH, Germany - Elco
Tel: ++49 (0) 2741 2990
FAX: ++49 (0) 2741 299133

AVX srl, Italy
Tel: ++390 (0)2 614571
FAX: ++390 (0)2 614 2576

AVX Czech Republic, s.r.o.
Tel: ++420 (0)467 558340
FAX: ++420 (0)467 558345

ASIA-PACIFIC

**AVX/Kyocera, Singapore
Asia-Pacific Headquarters**
Tel: (65) 258-2833
FAX: (65) 350-4880

AVX/Kyocera, Hong Kong
Tel: (852) 2-363-3303
FAX: (852) 2-765-8185

AVX/Kyocera, Korea
Tel: (82) 2-785-6504
FAX: (82) 2-784-5411

AVX/Kyocera, Taiwan
Tel: (886) 2-2696-4636
FAX: (886) 2-2696-4237

AVX/Kyocera, China
Tel: (86) 21-6249-0314-16
FAX: (86) 21-6249-0313

AVX/Kyocera, Malaysia
Tel: (60) 4-228-1190
FAX: (60) 4-228-1196

Elco, Japan
Tel: 045-943-2906/7
FAX: 045-943-2910

Kyocera, Japan - AVX
Tel: (81) 75-604-3426
FAX: (81) 75-604-3425

Kyocera, Japan - KDP
Tel: (81) 75-604-3424
FAX: (81) 75-604-3425

Contact:

NOTICE: Specifications are subject to change without notice. Contact your nearest AVX Sales Office for the latest specifications. All statements, information and data given herein are believed to be accurate and reliable, but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied. Statements or suggestions concerning possible use of our products are made without representation or warranty that any such use is free of patent infringement and are not recommendations to infringe any patent. The user should not assume that all safety measures are indicated or that other measures may not be required. Specifications are typical and may not apply to all applications.

© AVX Corporation



<http://www.avxcorp.com>

S-ACTSB2.5M499-R