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Effective Routing of Multiple Loads

by Barry Olney

IN-CIRCUIT DESIGN PTY LTD | AUSTRALIA



In a previous Beyond Design, [Impedance Matching: Terminations](#), I discussed various termination strategies and concluded that a series terminator is best for high-speed transmission lines. Different terminating strategies have advantages and disadvantages depending on the application, but in general, series termination is excellent for point-to-point routes, one load per net. In summary, series termination reduces ringing and ground bounce.

But, what if there are a number of loads—how should these transmission lines be routed? For perfect transfer of energy and to eliminate reflections, the impedance of the source must equal the impedance of the trace(s) to the load.

Bifurcated transmission lines—traces that are split into two or more T-sections—are sometimes used to distribute signals to multiple loads. The impedance of the bifurcated line is

not constant along the trace route, as the traces branching from the T-section are virtually in parallel when you consider the equivalent AC circuit. In this case, proper termination has not been provided and an impedance discontinuity can be seen at the branch point. In Figure 1, a 50 ohm signal from the driver is split into two transmission lines of 50 ohms and then into the loads. At branch (A), the two 50 ohm traces in parallel equate to a 25 ohm equivalent trace, and a mismatch in impedance. Figure 2 illustrates the resultant waveform of the unmatched transmission line.

Bifurcated transmission lines with matched impedances are a better choice. Rather than having the traces all the same width, the branch traces are reduced in order to match the impedance at the branch. The impedance of the traces after the branch then becomes $2 \times Z_0$ or 100

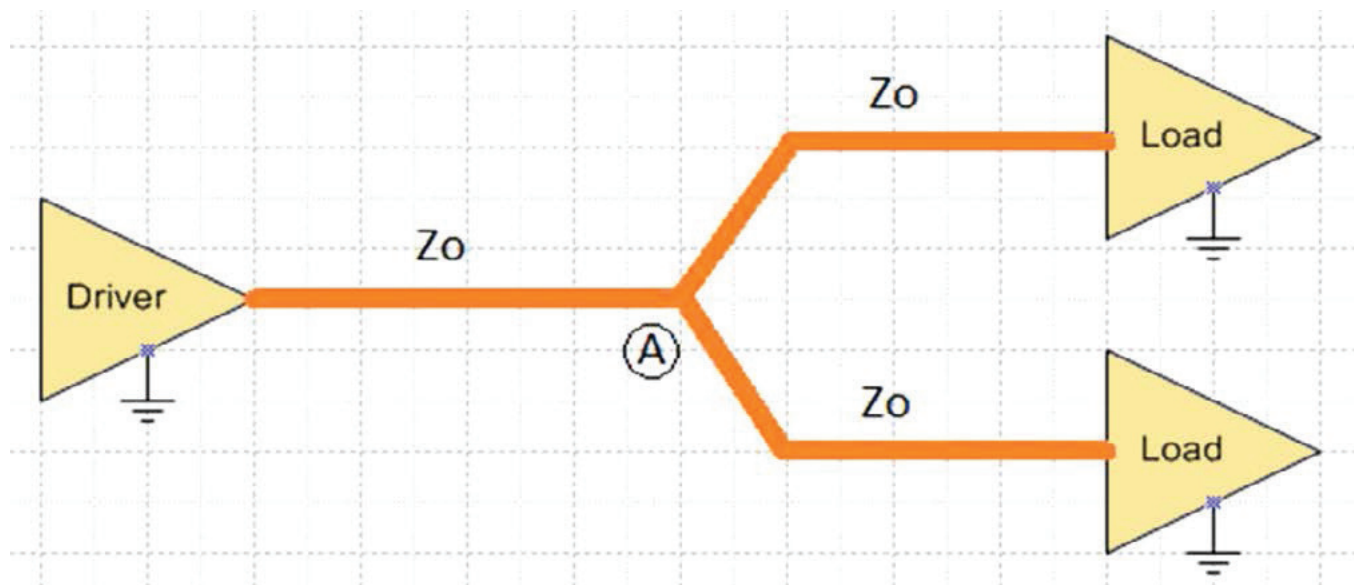


Figure 1: An unmatched bifurcated transmission line.

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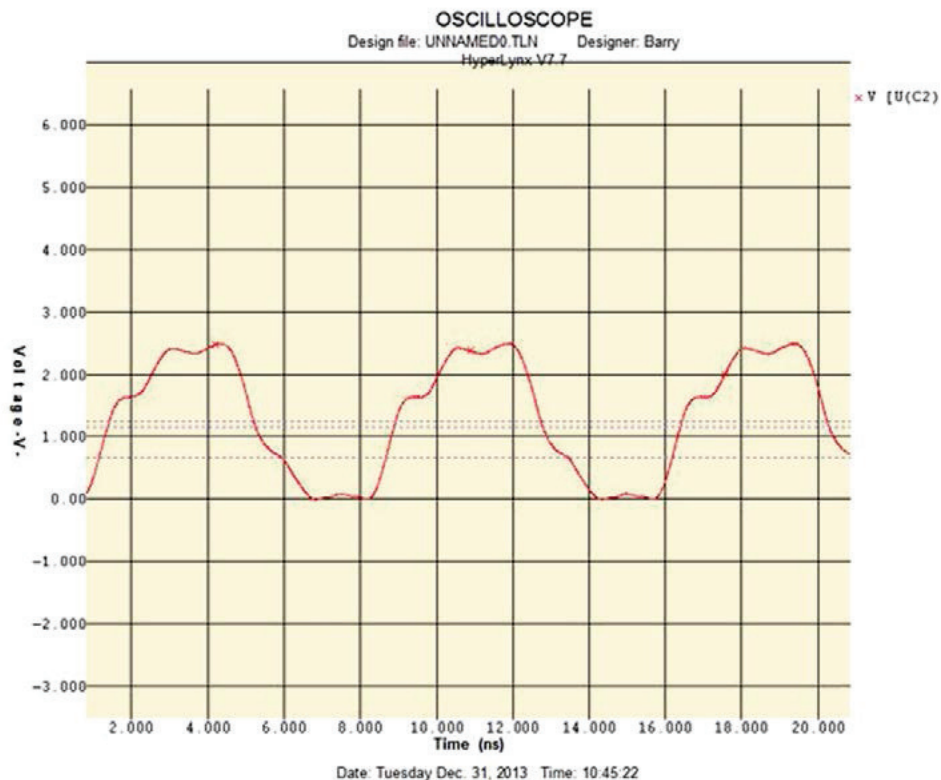


Figure 2: The resultant waveform of the unmatched line.

UNITS: mil ICD STACKUP PLANNER FX – www.icd.com.au 1/13/2014

Differential Pairs > 50/100 ohm

Layer No.	Via	Description	Layer Name	Material Type	Dielectric Constant	Dielectric Thickness	Copper Thickness	Trace Clearance	Trace Width	Current (Amps)	Characteristic Impedance (Zo)
		Soldermask		Dielectric	3.3	0.5					
1	8	Signal	Top	Conductive			1.4	12	24	1.15	51.89
		Prepreg		Dielectric	4.3	14					
2		Plane	GND	Conductive			1.4				
		Core		Dielectric	4.3	39					
3		Plane	VCC	Conductive			1.4				
		Prepreg		Dielectric	4.3	14					
4		Signal	Bottom	Conductive			1.4	12	4	0.31	104.69
		Soldermask		Dielectric	3.3	0.5					

Figure 3: The ICD Stackup Planner solves the impedance of 24 mil trace of 52 ohms compared to a 4 mil trace of 104 ohms.

ohms, and since these are in parallel the load seen at the branch is 50 ohms.

This would work fairly well if we could just halve the trace width. But, the width of the trace is not directly proportional to the impedance and a field solver is required to calculate the correct width required. For instance, a 24 mil trace of 52 ohms has to drop to 4 mil to

double in impedance given the same substrate. This is solved by the ICD Stackup Planner Field Solver in Figure 3. The ICD Stackup Planner can be downloaded from www.icd.com.au.

This configuration also requires parallel pull-down resistors of $2 \times Z_0$ at each load. These end terminators ensure that the transmitted pulse progresses once down the line and then

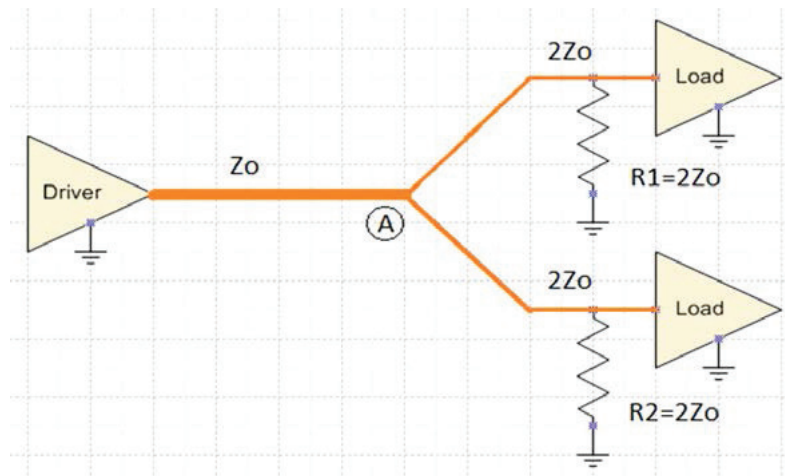


Figure 4: A matched bifurcated transmission line.

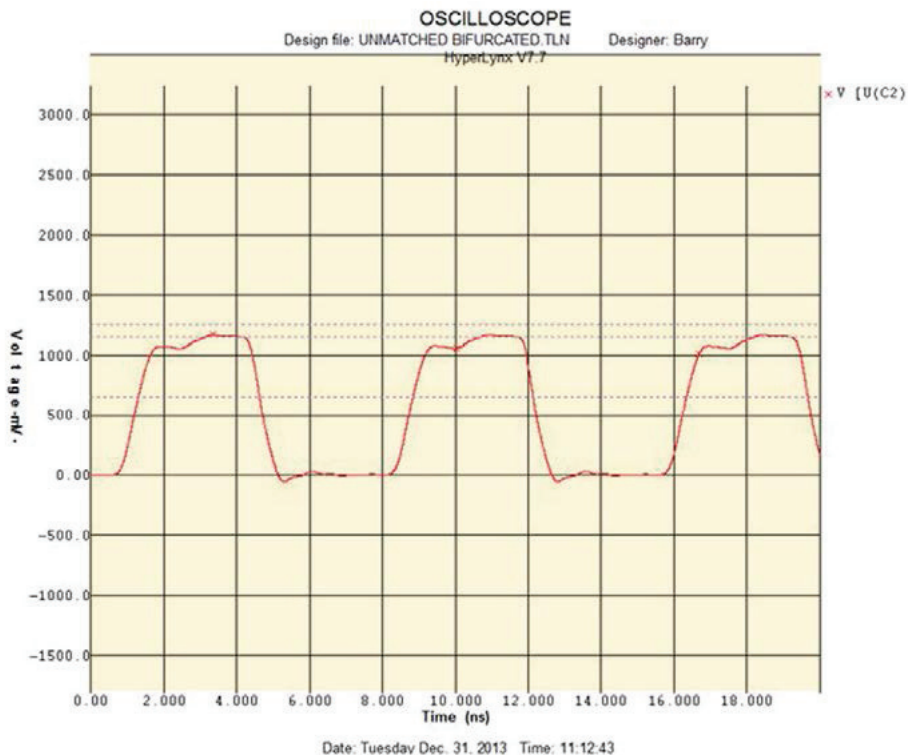


Figure 5: The resultant waveform of the matched line.

stops—preventing reflection—which is what impedance matching is all about.

Figure 5 illustrates the improved waveform of the matched bifurcated line of Figure 4. This technique, for matching branched lines, is not often used due to the difficulty of fabricating traces of widely varying impedance on the same substrate. Also, space limitations beneath FPGAs

limit the width of the thicker trace. Another issue with this technique lies with the loop return currents created within the network. If one of the bifurcated traces is located on a different layer to the other, the return current will be referenced to different planes. When this occurs, a potentially large loop area is created, with a corresponding increase in radiated emissions. GND

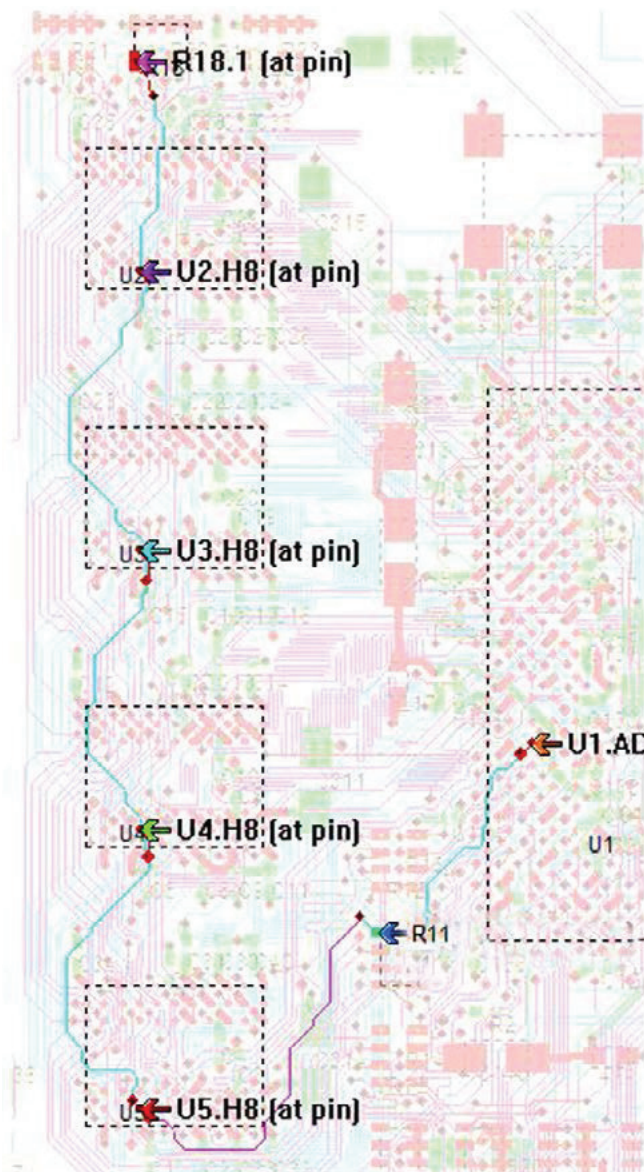
EFFECTIVE ROUTING OF MULTIPLE LOADS *continues*

Figure 6: Multi-drop address routing.

stitching vias may help alleviate this problem.

We've covered differential clock and strobe routing in previous columns, but let's look at address routing. Fly-by topology—as used in double data rate design—uses a daisy-chain or multi-drop topology on address, command and control signals.

Fly-by topology reduces simultaneous switching noise (SSN) by deliberately causing flight-time skew between the data and strobes at every chip/SDRAM requiring controllers to compensate for this skew by adjusting the timing per byte lane.

In this case, a series terminator (R11) is employed close to the driver and a parallel 100 ohm VTT pull-up (R18 resistor network) at the end of the loads. If the distance from the source to the first load is short, then the series terminator may not be required. But, this should be determined by simulation. The ideal location for end terminators is past the last load—with no side branch or stub—as depicted.

Stub length should be kept to a minimum. You can see how the address line, highlighted in Figure 6, is routed directly over the memory/load pin with a very short stub going off to each load. Since this stub is extremely short, compared to the transmission line length and length of the rising edge, an impedance mismatch is avoided. Short stubs, and their associated receiver capacitance, act like simple capacitive loads which tend to roll-off the rising edge.

This configuration is ideal for DDR design but what if there is a slower rise-time clock that needs to be distributed to a number of loads?

Star routing is ideal for distributing clocks to multiple loads and is also used for power distribution on signal layers. The routing fans-out from a central point and connects to each load. But, with distributed loads also comes unmatched lengths between the loads. If a single series terminator is used, close to the source as in Figure 7, the different trace lengths cause different delays to each load which is unavoidable unless the lengths are matched. This also creates reflections which can be seen in Figure 8. Reflections occur whenever the impedance of the transmission line changes along its length. This can be caused by unmatched drivers/loads, layer transitions, different dielectric materials, stubs, vias, connectors and IC packages. By understanding the causes of these reflections and eliminating the source of the mismatch, a design can be engineered with reliable performance.

In Figure 9, three individual series terminators are used in conjunction with three different trace lengths. Figure 10 illustrates the resultant clean waveform.

If all the trace lengths, of the star configuration, are matched to length/delay then these reflections do not occur. So there is a choice: match the lengths or use individual series ter-

EFFECTIVE ROUTING OF MULTIPLE LOADS *continues*

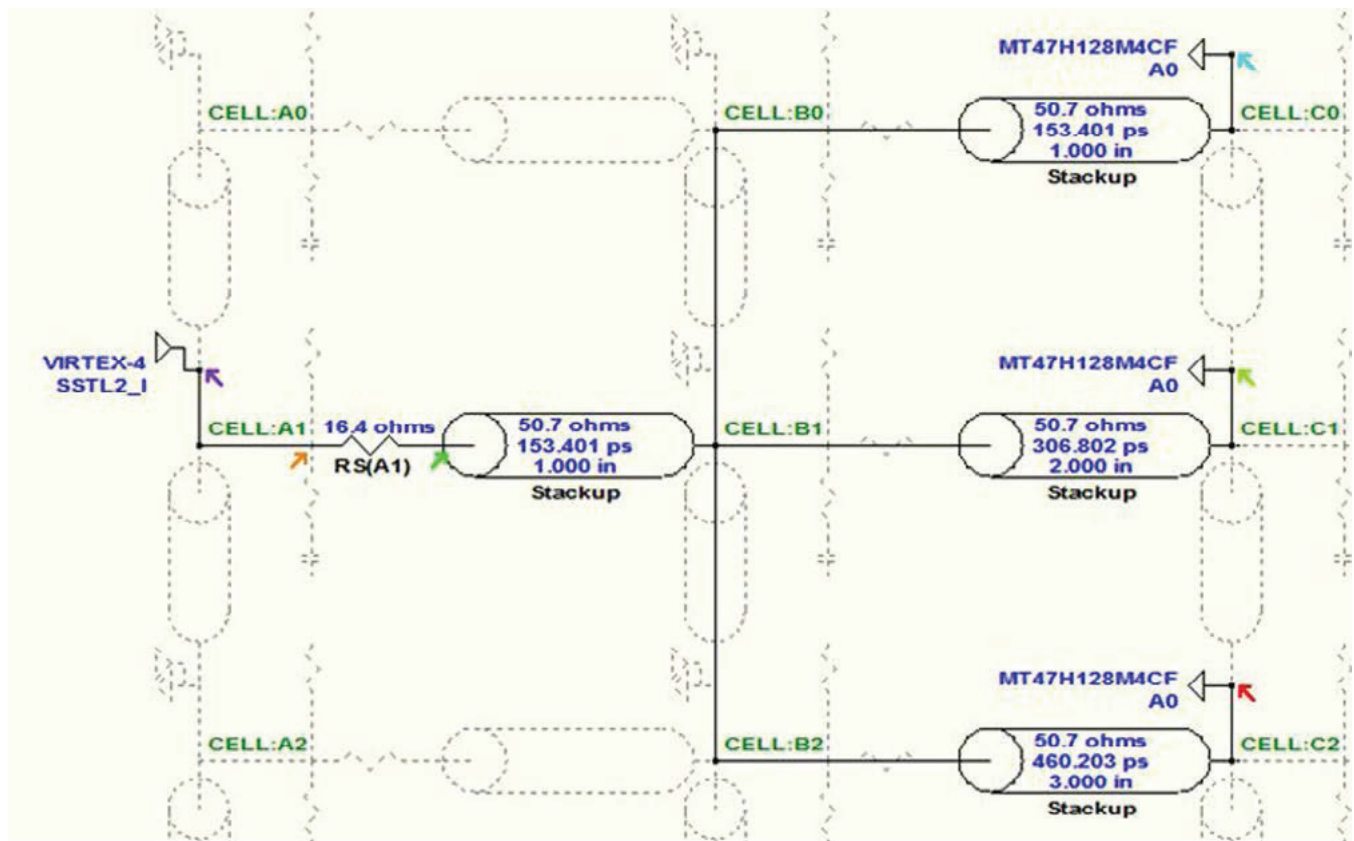


Figure 7: A single series terminator close to the source.

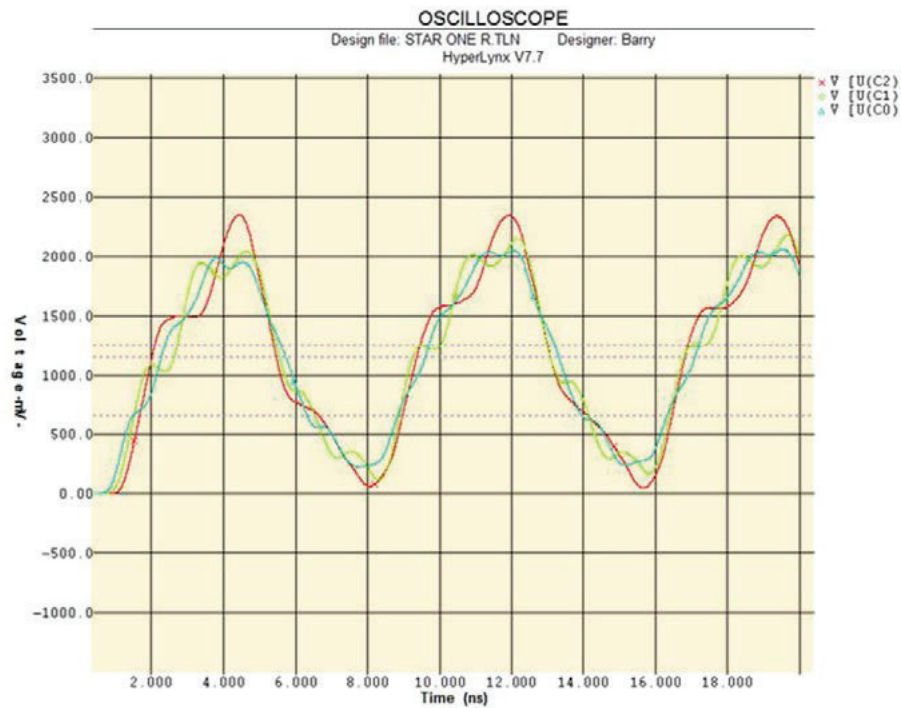


Figure 8: Reflections of the unmatched lines.

EFFECTIVE ROUTING OF MULTIPLE LOADS *continues*

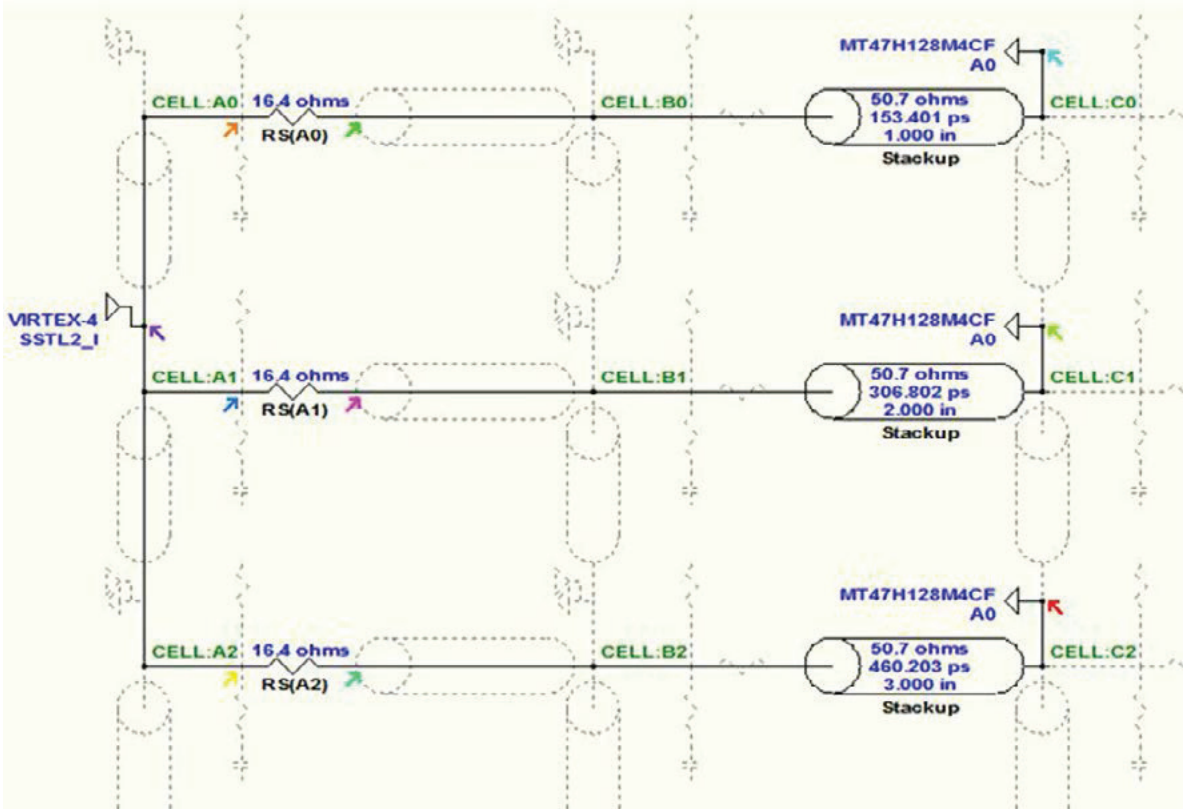


Figure 9: Individual series terminators at the source.

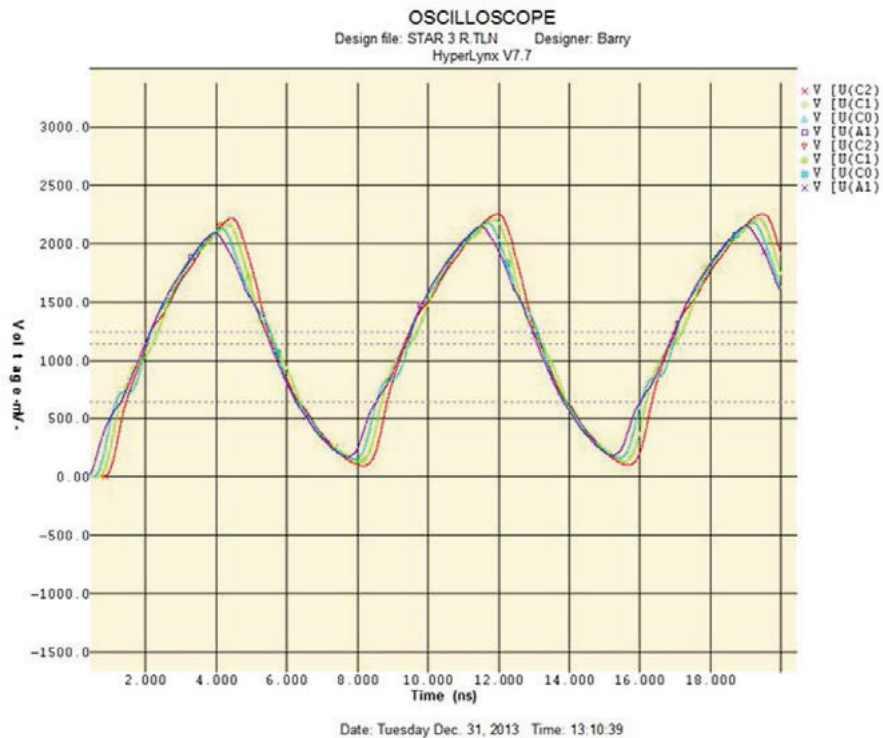


Figure 10: The resultant waveform of individual series terminators.

EFFECTIVE ROUTING OF MULTIPLE LOADS *continues*

minators close to the source to dampen the reflections.

Points to Remember

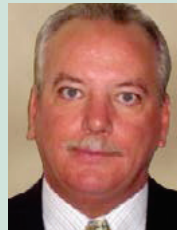
- A series terminator is best for high-speed transmission lines.
- Bifurcated transmission lines—traces that are split into two or more T-sections—are sometimes used to distribute signals to multiple loads.
- At the branch, the two 50 ohm traces in parallel equate to a 25 ohm equivalent trace—and a mismatch in impedance.
- Trace width is not directly proportional to impedance.
- Bifurcated transmission lines with matched impedances are a better choice.
- The end terminators ensure that the transmitted pulse progresses once down the line and then stops, preventing reflection.
- Matching branched lines are not often used due to the difficulty of fabricating traces of widely varying impedance on the same substrate.
- If one of the bifurcated traces is located on a different layer to the other, the return current will be referenced to different planes potentially creating a large loop area and EMI.
- Fly-by topology employs a series terminator close to the driver and a parallel 100 ohm VTT pull-up at the end of the loads.
- Star routing is ideal for distributing clocks to multiple loads and is also used for power distribution on signal layers.

- Reflections occur if the trace lengths of star routing are unmatched.

- The choice is this: Match the lengths or use individual series terminators, close to the source, to dampen the reflections of a star route.

PCBDESIGN**References**

1. Barry Olney—Advanced Design for SMT, [Beyond Design: Impedance Matching: Terminations](#), [Beyond Design: Differential Pair Routing, PCB Design Techniques for DDR, DDR2 & DDR3, Part 1](#), [PCB Design Techniques for DDR, DDR2 & DDR3, Part 2](#)
2. Howard Johnson—High-Speed Digital Design
3. Mark Montrose—[EMC and the Printed Circuit Board](#)
4. The ICD Stackup Planner and PDN Planner—www.icd.com.au



Barry Olney is managing director of In-Circuit Design Pty Ltd (ICD), Australia. This PCB design service bureau specializes in board-level simulation, and has developed the ICD Stackup Planner and ICD PDN Planner software. To read past columns, or to contact Olney, [click here](#).

Energy Harvesting Systems to Reach \$375M by 2020

Energy harvesting systems offer an attractive alternative to battery power for portable devices. According to a recent report from Navigant Research, worldwide revenue from energy harvesting systems will grow from \$283 million in 2014 to nearly \$375 million in 2020.

Another important application for energy harvesting is pervasive sensor networks, where thousands of sensors monitor all measurable commodities,

in real time. These devices diligently work to provide important information about temperature, humidity, security, machine health, structural health, and much more. As an alternative technology to power these networks, energy harvesting offers several advantages over conventional power supplies.

The report, “Energy Harvesting,” analyzes existing and emerging energy harvesting technologies in depth, looking at nine end-use consumer and industrial application segments and the four most successful transduction methods for converting ambient energy. An Executive Summary of the report is available for free download [here](#).