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FPT
FORCED PERFECT TERMINATION

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INTRODUCTION

Transmission line termination has traditionally been a difficult process to implement although the theory governing reflections due to impedance mismatch is well understood.

In practice, tolerances of the transmission line and the termination impedances, points of discontinuities at the connectors metal-to-metal contacts, and in the case of SCSI, numeral connection breaks all contribute to making a perfect termination impossible. Even a reasonably good termination at a reasonable cost is difficult.

Indeed, waveforms captured at various points in our SCSI setup display poor signal quality. Not all bus configurations meeting the SCSI specs can function without errors. These errors causes failures during data transfers.

FPT is a proposed solution to the signal quality problem and a new way of looking at transmission line termination.

THEORY

TRANSMISSION LINE TERMINATION

According to classical transmission line termination theory, mismatch occurs when a pulse travels down a transmission line and runs into a termination impedance that is either greater than or less than the characteristic impedance of the the line. If the end termination is greater than the line impedance, a positive reflection results. If the end termination is less than the line impedance, a negative reflection results.

Although it is difficult to match perfectly, one can usually accept something less than ideal. However, as devices began to switch and respond faster and faster, and as more of them get connected to the line as with SCSI, we need something that more closely approaches the ideal termination. The concept that follows finds its first application with SCSI.

FPT THEORY

FPT is a terminator that self-terminates. One that matches itself to the line automatically, thereby removing all reflections at the end points. In theory, if the line impedance and all causes of mismatching happen to look like 100 ohms then our terminator should turn itself into a 100-ohm terminator.

In contrast with the conventional approach to the matching problem, FPT represents a subtle but significant departure in design concept. It is observed that equality, in this case that between the line impedance and the termination impedance, is difficult to obtain in nature but that inequality readily exists.

It is therefore conceivable that a good design based on the naturally occuring inequalities might be easier to realize. The following mathematical construct legitimizes the approach:

IF $(a > b)$ AND $(a < b)$ THEN

$$(a = b)$$

In the match/mismatch problem there are only 3 possible orthogonal states (less than, greater than and equal to). These states are mutually exclusive, the existence of one precludes the existence of the other two. FPT seeks to eliminate two of these states by forcing their co-existence. If we can say that the termination impedance is at once too high and too low, then it must be perfect. This argument is the theoretical basis for FPT.

DESIGN IMPLEMENTATION

Going from theory to engineering design requires a modified view of the concept of simultaneity. This is so because it would indeed be difficult to put something at the end of the line that has -in a strict sense- an impedance simultaneously greater than and less than the line characteristic impedance.

In the same way that spatial integration causes a field of black and white dots to look grey, temporal (time) integration will ensure practical simultaneity. Whatever is put at the end of the line needs only to switch between the greater-than state and the less-than state fast enough and temporal integration would occur. Then for all practical purposes, the simultaneity of the states would result.

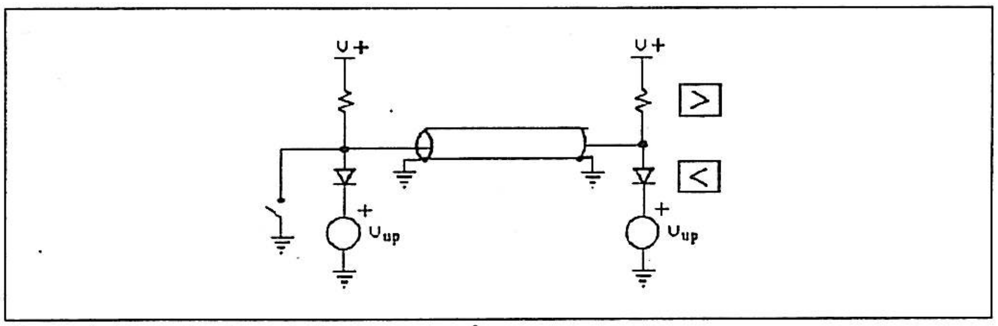

Figure 1. Basic Implementation.

Figure 1 shows the basic implementation: a resistor representing a greater-than element and a diode connected to a voltage source representing the less-than element. When the pulse reaches the end of the line, rising from ground to some upper voltage V-high (equal to the up voltage plus a diode drop), it will rise beyond the target voltage because we have a positive mismatch. But when the target voltage is exceeded, the diode turns on, the termination impedance drops to zero and the pulse heads for ground instead. But it really cannot go too far, since the diode will turn off, the impedance will again be too high and the cycle repeats. Thus the pulse is caught between two opposite states by the feedback action of t the diode-resistor network. In effect, the termination impedance is simultaneously too high and too low. The pulse is forced to chose the only state left, the state of minimum conflict which is that of perfect termination.

It might also be useful to regard the diode as a variable impedance element that is under the feedback control effect of the dual state conflict, in such a way that its impedance when put in parallel with the greater-than resistive element results in an impedance that matches the line perfectly.

The circuit as shown looks like a clamp, and it is indeed convenient sometimes to look at it as a clamp. But it is much more than that in its action. Figure 2 shows FPT's theoretical pulse response. It also shows that a clamp would not have been able to correct the problem. Instead, it is simply understood that the distorted signal is an artifact that resulted from mismatching, a condition that is removed by FPT.

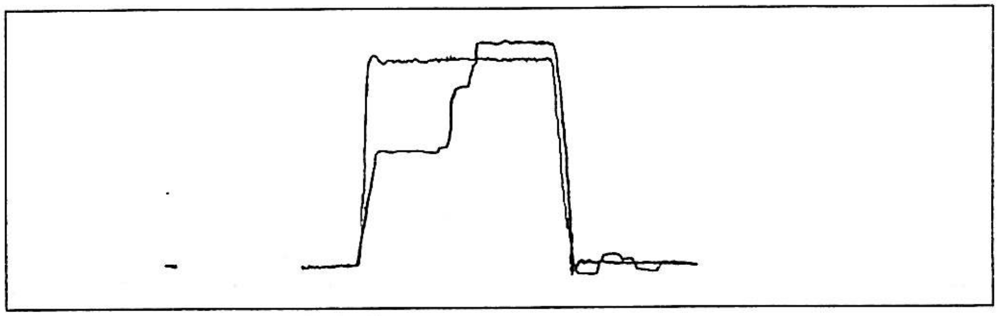

Figure 2. FPT Theoretical Pulse Response.

It should noted that a diode can be added to correct for distortions in the downward swing of the pulse as well. For optimum results, this diode should be connected to one diode drop above ground.

FPT was implemented for SCSI and the following pulses were captured using a digital signal analyzer. The system has 2 devices internal and 5 devices externals. The signal quality problem using standard terminators is shown in figure 3.

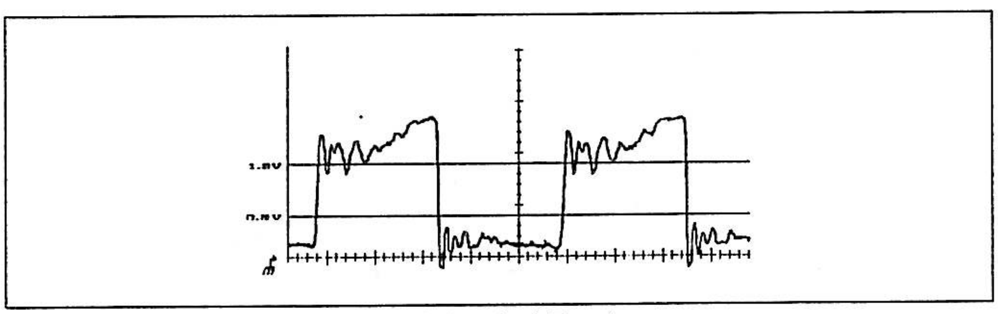

Figure 3. SCSI Pulse Performance with Standard Terminators.

Figure 4 and 5 shows the FPT-corrected pulse response. Figure 4 shows the response at the far internal end of the SCSI chain, after 2 internal devices.

Figure 4. FPT-corrected SCSI Pulse Performance. (Far Internal End)

Figure 5 shows the response at the far external end of the SCSI chain, after 5 external devices.

Figure 5. FPT-corrected SCSI Pulse Performance. (Far External End)

FPT as applied to SCSI is limited to making the 2 end points perfect. The performance in the middle varies with systems. In all of ours, the improvement to the worst-case device was dramatic, albeit imperfect. Systems with FPT run without errors.

PROPERTIES AND POTENTIAL BENEFITS

FPT theory implies that the termination impedance no longer needs to perfectly match the cable characteristic impedance. Termination impedances will be chosen to satisfy speed, power and other requirements. Manufacturing tolerance requirements will be looser.

With FPT, bus bandwidth may be extended, less expensive cables and connectors can be used. Even cable extensions with different characteristic impedances can be used.

EMC performance will improve since reduced ringing should lead to reduced EMI which lessens the need for EMI countermeasures.

Intentional mismatch give FPT regenerative power to compensate for cable loss, and helps in long distance transmission. A quick look at the 2 endpoints with FPT using 100 feet of twisted pair cable shows no signal degradation.

All of this indicates a potential for cost savings and performance improvement.

CONCLUSION

The concept has been implemented. Results indicate that the theory is sound and that the endpoints can be made perfect.

For SCSI implementation, the maximum allowed number of devices can be used with good performance. The endpoints are perfect and the worst signal along the line is also very good, a dramatic improvement over conventional termination.

Appendix A. ACTUAL CIRCUITS

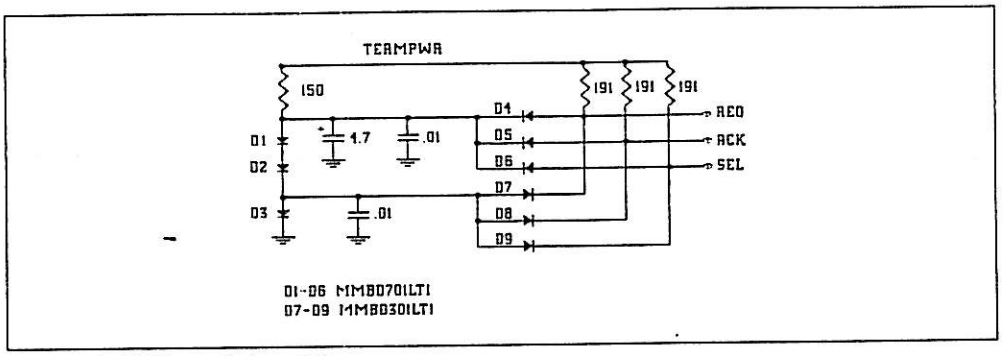

Figure 6. FPT applied to 3 lines

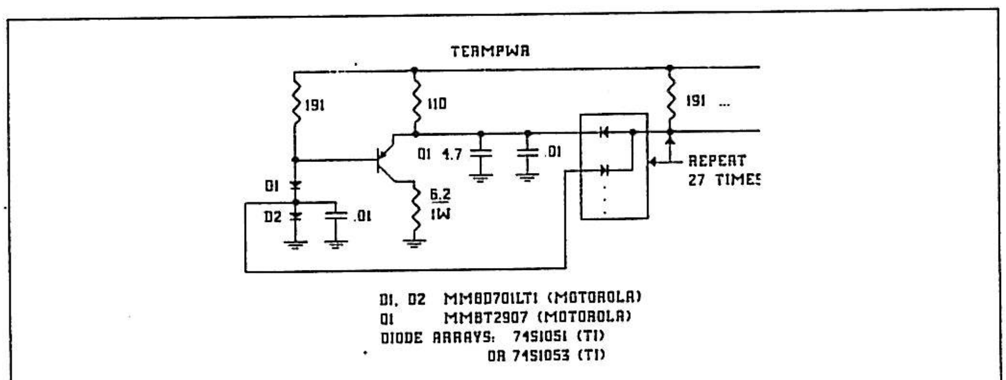

Figure 7. FPT applied to 27 lines