Design and Analysis of Improved Multi-Module Memory Bus using Wilkinson Power Divider

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***Abstract*— Branch connections in multi-module memory bus are usually sources of impedance mismatching, resulting in resonance in the branch stub. An effective way has been proposed to reduce stub resonance by using Wilkinson power divider. The effect of Wilkinson divider has been verified by experiments in both frequency and time domains.**

Keywords- Wilkinson power divider, branch connection, stub resonance, memory bus, multiple module

I. INTRODUCTION

As processor speed increases further, bus rates throughout the system must correspondingly increase. The goal of a computer's memory hierarchy is to achieve a balance between economy and performance. Memory bus architectures is pushing printed-circuit-board and packaging technologies to their bandwidth limits. Today, the main memory in a typical personal computer is a DRAM that connects to the processor through a multi-bit interface on the chip set, which also supports other high-bandwidth interfaces to connect peripherals and graphics to the processor. DDR (double data rate) SDRAM is a standard, in which data is triggered by both edges of the clock. Fig. 1 illustrates the basic physical features of a SDRAM bus implementation with two memory modules. Two module connectors are soldered to the bus from the controller chip. Modules containing from one to eight SDRAM chips plug into each connector on the bus. Also, the on-die termination (ODT) scheme is utilized on both the chipset and the DRAM [1]. This conventional low-cost module and packaging technologies is challengeable to be applied to future generations of high-bandwidth memory architectures.

Branch connections for a one-to-many connection line, the stubs, are usually sources of impedance mismatching, resulting in inter-symbol interference (ISI), which limits the speeds of the latest high-speed digital systems. Previously, some interconnect scheme have been proposed to enhance the signal integrity in multiple I/O interface. They are such as, the capacitive coupled interface (CCI) [2], the RF/Wireless interface (RFI) [3], and crosstalk transfer logic (XTL) interface [4]. They are more immune to the stub effects than the direct digital connection in a high-speed one-to-many signaling. However, those interconnect schemes use new signaling waveforms different from the digital signal, and require signal modulations or new receiver circuits for data communication. The new signaling scheme may cause other problems in the signal integrity. In this paper, an effective way is proposed to reduce stub effects in direct multiple I/O connection, by using Wilkinson power divider.

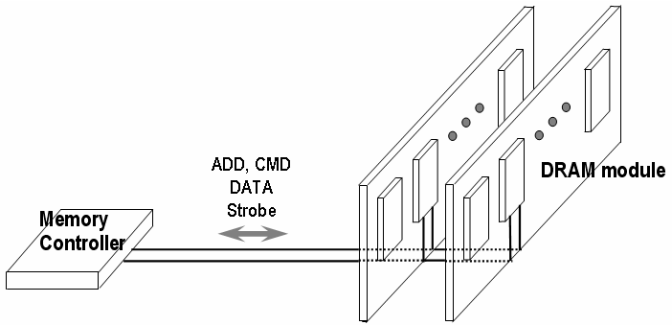
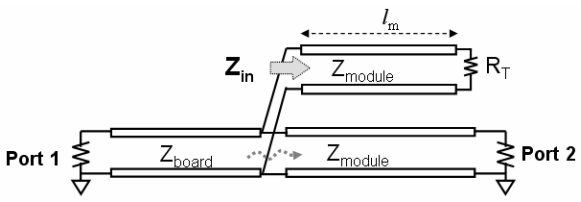


Figure 1. Memory bus with multiple SDRAM modules

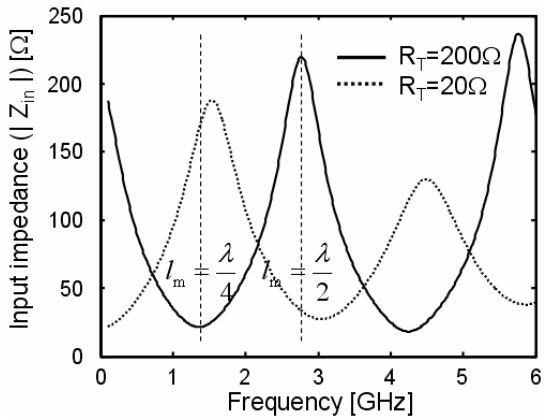
II. RESONANCE IN BRANCH CONNECTION

Resonance is induced by impedance mismatching in the memory bus of Fig. 1. Fig. 2 describes how the resonance is induced. If termination impedance (R_T) of a branch is not perfectly matched to the impedance of the branch trace (Z_{module}), a signal from chipset to the DRAM is reflected at the termination. Some of the reflected wave is transmitted to the other branch, and another some is reflected again at the junction. So resonance condition is built up between two branches at a certain frequency. In more details, impedance is discontinuous at the junction of branches in the multi-module bus. The input impedance seen into a branch varies periodically with frequency when the termination impedance (R_T) is not same as the characteristic impedance of the branch trace (Z_{module}). As shown in the simulated results of Fig. 2 (b), the input impedance is extreme at frequencies at which the length of branch is multiple of a quarter-wave length. Therefore, signal transmission from the chipset to DRAM in the other branch also varies periodically by the changing impedance. The signal transmission can be represented as the scattering parameter ($|S_{21}|$) from the chipset to the DRAM, which is depicted in Fig. 2 (c). It is high, when the input impedance (Z_{in}) of the other branch is high. The DRAM feels less stub

connection if input impedance of the stub is high and is close to that of open connection. The signal transmission, however, significantly degrades when the input impedance of the branch stub is low and strong reflection occurs at the junction. The resonance between two branches, which has been mentioned so far, degrades signal quality significantly in multi-module bus structures.



(a)



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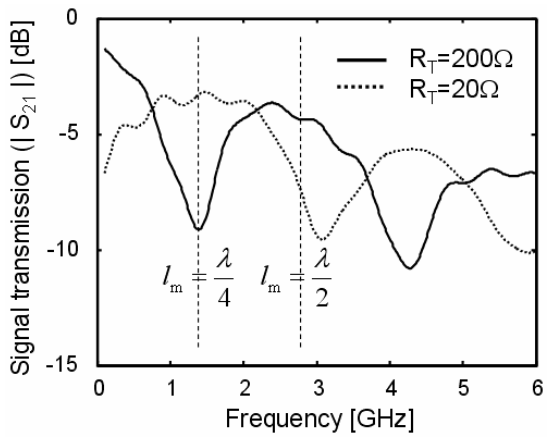
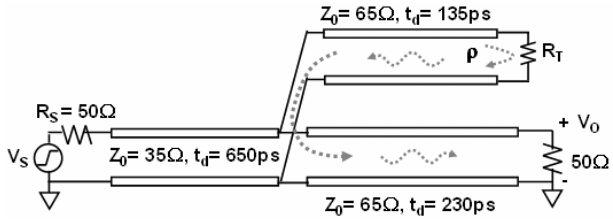


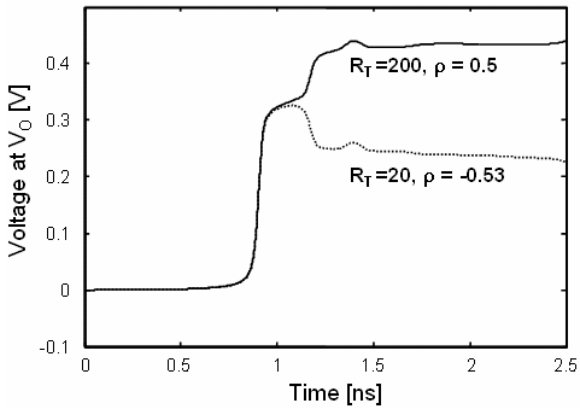
(c)

Figure 2. Resonance induced in multi-module memory bus. (a) Memory bus with two modules, where Z_{board}=35Ω, Z_{module}=65Ω (b) Simulated input impedance into the stub in the cases of R_T=20Ω and 200Ω (c) Corresponding simulated S_{21} parameter from the chipset to a DRAM

The signaling distortion by stub reflection can also be analyzed in time domain using time domain reflection (TDR) analysis. The wave reflected at the termination of one branch reaches the other termination of the other branch as shown in Fig. 3 (a). Also, the reflected wave is reflected at the junction and is reflected at the termination again, which reaches the other termination in the end. As a result, the polarity and magnitude of the reflected wave depends on the termination impedance and the period the reflection depends on the length of the branch. Fig. 3 (b) depicts the voltages observed at a termination in cases with two termination impedances (R_T) at the other branch. If the period of source voltage is same as the period of the reflection, then resonance occurs and the output voltage is significantly degraded.



(a)



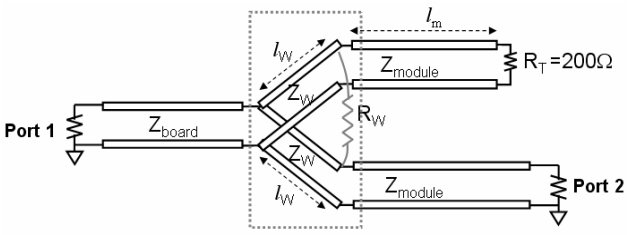
(b)

Figure 3. Time domain reflection (TDR) analysis (a) Voltage wave reflected from the mismatched termination. 't_d' represents the delay time at each branch section and 'ρ' represents the reflection coefficient. (b) Output voltage at the other termination. It depends on the reflected wave.

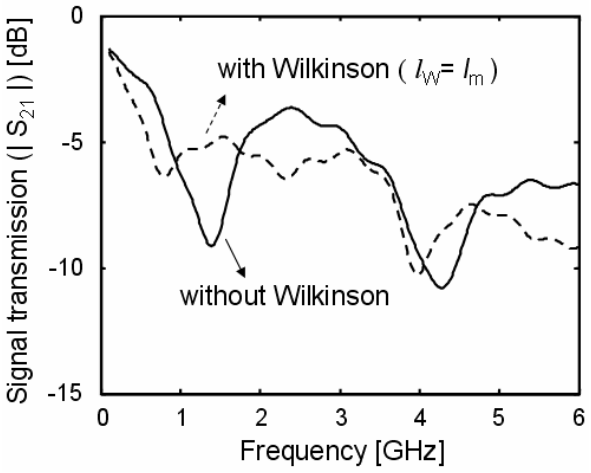
III. Application of Wilkinson Power Divider in Branch Connection

To avoid stub resonance effects, the termination impedance including ODT in all branches should be perfectly matched to the branch lines. This is not an easy solution in a memory bus with multiple DRAM chips and multiple banks. In this paper, the effective and easy way to remove stub reflection is proposed by using Wilkinson power divider. Wilkinson divider provides the isolation between the output ports at a given target frequency region. Also, it has the useful property of being lossless when the output ports are matched; that is, only reflected power is dissipate. If two modules are isolated from each other, the reflected wave from one branch does not reach the other branch and the resonance effect by stub reflection will not be presented.

The proposed multi-module memory bus using Wilkinson power divider is illustrated in Fig. 4 (a), for the case that termination impedance of a branch is larger than the characteristic impedance of the branch trace. (R_T=200) The length of transmission line in Wilkinson divider is decided to be a quarter-wavelength of the reflected wave which needs to be isolated. The first resonance arises when the length of the other branch stub is a quarter-wavelength and the input impedance is small. Therefore the length of Wilkinson divider is the same as the stub length to avoid the resonance. Also, it has been found that the impedances of traces and the shunt resistor are selected as (1, 2), in order to apply Wilkinson power divider to a multi-module memory bus with any given trace impedances. With the values of impedance in the equations, Wilkinson power divider dissipates a wave flow from a branch to the other branch and ideally isolates two branches at the target frequency. The scattering parameter (S_{21}) in the proposed multi-module memory bus using Wilkinson divider is simulated in Fig. 4 (b). The first resonance is significantly mitigated, which may be critical in the eye opening and timing margin. Consequently, it enhances the signal integrity from the chipset to DRAM.



(a)



(b)

Figure 4. Application of Wilkinson power divider in the multi-module bus (a) Memory bus with Wilkinson divider, where l_w=l_m, Z_W=65Ω, and R_W=130Ω (b) Simulated S_{21} parameter with and without Wilkinson divider, respectively

$$Z_W = \sqrt{2Z_{board} \cdot Z_{module}} \quad (1)$$

$$R_W = 2Z_{module} \quad (2)$$

IV. CORRELATION TO MEASUREMENT

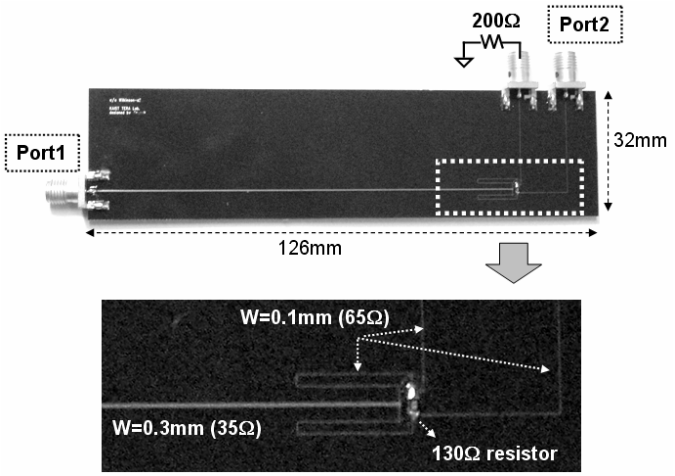


Figure 5. Test vehicle of branch connection with Wilkinson divider

Test vehicles were designed, fabricated and measurements performed in both frequency domain and time domain to verify the performance enhanced by using Wilkinson divider. Fig. 5 illustrates the photo and dimension of the test vehicle. A trace from the port 1 branches into two traces through the Wilkinson power divider. The traces consist of microstrip lines routed on dielectric material (FR4) with thickness of 0.1mm. The experimental setup is the same as that in Fig. 2 and 4. As shown in Fig. 6, Wilkinson divider reduces the resonance at about 1GHz significantly. Wilkinson divider at the junction isolates the port 2 from the reflected wave and the resonance is reduced.

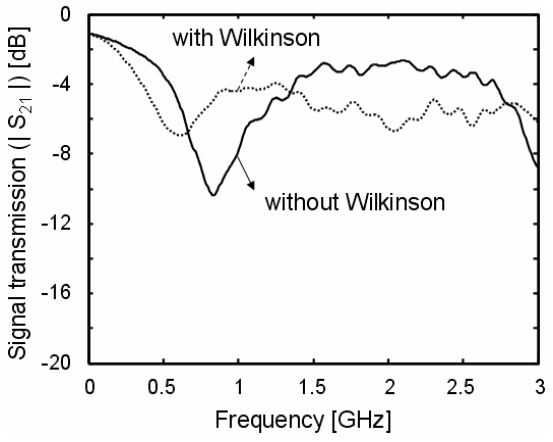
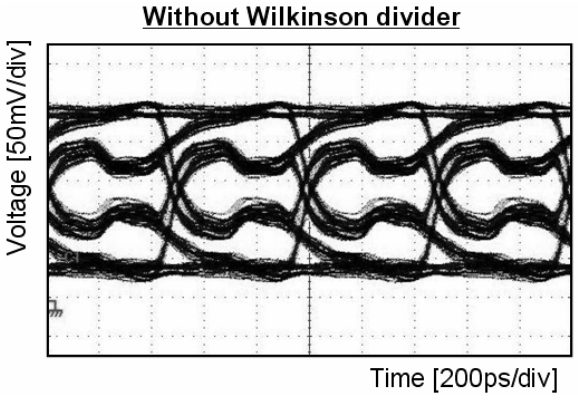
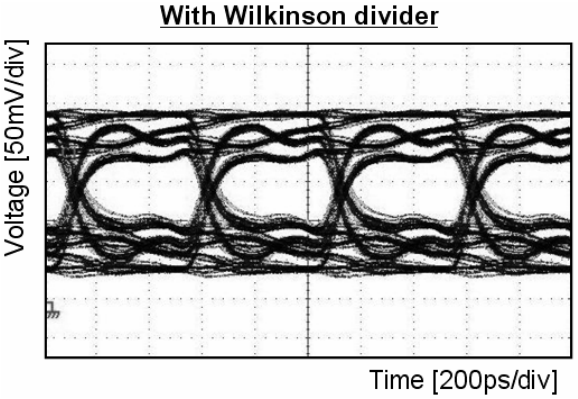


Figure 6. Measured S_{21} parameter with and without Wilkinson divider

Eye-diagrams were also measured in time domain. 2Gbps pseudo random bit sequence (PRBS) was incident to port 1 and the output signal was measured at port 2 using an oscilloscope. It has been found that the reflected wave observed in Fig. 7 (a) is noticeably mitigated in Fig. 7 (b) by using Wilkinson divider.



(a)



(b)

Figure 7. Eye diagram measured in port 2 (a) without Wilkinson divider (b) with Wilkinson divider

V. CONCLUSION

Branch connections in multi-module memory bus are usually sources of impedance mismatching, resulting in resonance in the branch stub. To reduce the stub resonance in a direct multiple I/O connection, an effective way has been proposed by using Wilkinson power divider. The effect of Wilkinson divider has been verified by experiments in both frequency and time domains. Both of S_{21} parameter and eye-diagram are improved.

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