SPECTRUM MANAGEMENT OF PULSE TRANSMISSION BY HIGH-CUT FILTER USING MAGNETIC LOSS

Taro Miura and Shiro Nakagawa*

TDK Techno Corporation and TDK Corporation*
2-15-7 Higashi-Owada, Ichikawa, Chiba, 272-8558, Japan

ABSTRACT

Operation problems of a 200-MHz-clock computer bus were analyzed by the time domain transmission of pulse in the bus. An absorptive high-cut filter was fabricated and installed to solve the problems. In the process of determining the operating conditions, we came upon a new concept for spectrum management.

INTRODUCTION

The need to increase the data processing speed of a personal computer has become very pressing. This need had usually been fulfilled by increasing the clock speed of the processor. Currently, the processor clock frequency is more than 1 GHz while the clock frequency of the bus has been limited to 133 MHz. The major difference between the two clock times have prevented speeding up of the computer. Recently, a proposal to operate a 200-MHz-clock bus by using a voltage sensitive resistor between the bus and its driver was made [1]. However, the difficulty in developing such a resistor has hindered the realization of this proposal.

A new proposal to achieve the 200 MHz operation based on transmission analysis of the pulse in the bus is presented in this paper. First, measurements to study the pulse transmission in the bus were made. The results showed that pulse delay and resonance prevented the operation of the bus. The observed pulse delay and the resonance were analyzed by the linear circuit approach since a digital circuit is not a nonlinear binary circuit but a linear circuit providing a level at which logic 0 or 1 can be discriminated. The analysis shows that an appropriate spectrum control, here called spectrum management, should be made to operate the bus. Although the frequency spectrum is important, most discussions will concern the time domain. This difference was due to the fact that the pulse in the time domain could not be described using time-independent spectrum analysis data.

Secondly, the development of an absorptive high-cut filter for the spectrum management is described. Theoretical analysis of the filter proves that the filter characteristics can be approximated by an appropriate strip line model. Finally, the installation of the filter to the bus confirmed the 200 MHz operation. The result was expanded to an absorptive high-cut line filter to obtain a faster clock bus.

PULSE TRANSMISSION IN THE BUS

A computer bus is a group of multibranch lines connecting peripheral devices of a computer. In an earlier work, Kato simulated the pulse transmission of a 200-MHz-clock bus using a unit line extracted from the bus [1]. The structure of the unit bus and the result are shown in Fig-1.

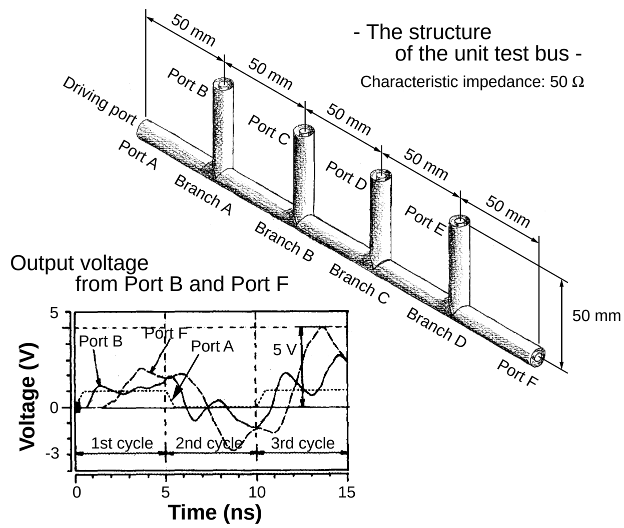

Fig. 1. Simulated pulse transmission in the unit bus

He concluded that the higher harmonics in the pulse reflected from irregularities such as branches made a distorted pulse in the bus which increase the pulse delay longer than 2.5 ns which is the limit of the 200 MHz clock operation. He also pointed out that a peak observed in the third cycle of port F was a resonance in the bus and the voltage became sufficiently high to break ICs. He proposed the use of a voltage sensitive resistor to reduce the distortion. However, significant distortions remained in the simulation even when a virtual resistor was incorporated.

To study the pulse propagation in the bus, a time domain transmission analysis using the same unit line as shown in Fig. 1 was carried out. The result is shown in Fig. 2. This result showed that the output voltage of port B initially rose. However, the port voltage fell after a while, followed by continual increase and decrease of the output. Although the last voltage occurs at port F, the output increased monotonically. If the transition time is defined as the time taken for a monotonically increasing port voltage to exceed the logic

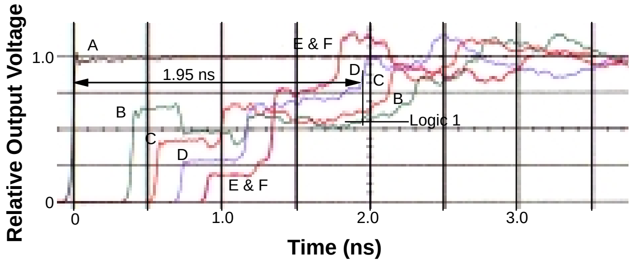

Fig. 2. Step pulse transmission in the unit test bus

1 level, 55 % of the input voltage in this case, the transition times of port F and port B in Fig. 2 were 1.35 ns and 1.95 ns, respectively.

The bus consists of lines and branches, the transmission of the step pulse in the bus is understood to involve the reflection and transmission of the pulse at the branches and the ports. The branch having a half-value of the line impedance, 25 Ω in this case, causes a -9.5 dB reflection of a negative pulse and separates the rest of the pulse into two lines with the attenuation of 3.5 dB. The open port at the end of the branch line reflects the input pulse completely as a positive pulse. Combining the transmission and the reflection described above, it could be explained that the decrease of voltage at port B was caused by the negative pulse reflection from the branches and the voltage rise was made from the reflection at the open ports. Complete pulse buildup is not accomplished until the pulse reflected from the rest of the port arrived at port B. In contrast, the transmitted pulse and the reflected pulses from the open ports, both positive, arrived at port F. Consequently, the pulse buildup first at the most distant port F and last at the nearest port B.

The same pulse as shown in Fig. 1 was applied to the bus to confirm the simulation. The result is shown in Fig. 3.

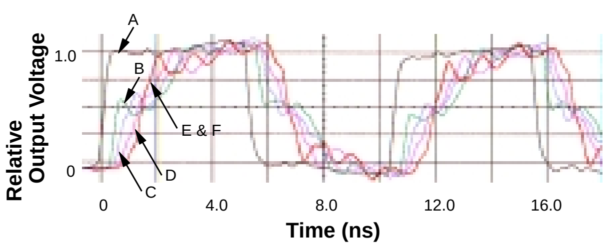

Fig. 3. Transmission of pulse in the unit test bus

A comparison of Fig. 1 and Fig. 3 reveals that the pulse buildup process was the same. Fine ripples in the figure indicates that resonance was generated in the bus. The average period of ripples, 1.2 ns here, corresponds to the resonance frequency of about 800 MHz. This value was also confirmed by resonance frequency measurement of the bus. Although the pulse front of port F in the experiment exhibited a peak, its value was not as high as predicted by the simulation. This difference would be a result of the different receiving port resistances in the simulation and the experiment, open and 50 Ω, respectively. If the receiving port in the experiment were sufficiently high, the voltage would become twice the observed value which would be sufficient to break the gates of ICs.

The pulse delay and the resonance discussed above were due to the line structure of the bus, ignoring the impedance matching. A bus constructed with an impedance matched line would show only traveling time delay and no resonance. However, a matched line requires the talkers and the listeners in the bus to be fixed. A bus in which the talkers and the listeners change their roles on occasion could never be constructed using a matched line and yet allow the reflected wave to travel in the line. The above consideration lead to the conclusion that the excess delay and the resonance caused by the reflected pulse are unavoidable in the bus. The only countermeasure may be the suppression of the resonance to avoid breakdown of the IC and enable operation of the bus.

For rapid buildup of the pulse, the bus should have a broadband transmission characteristic. However, the higher harmonics cause resonance. To achieve rapid pulse buildup and to avoid resonance, the allowed spectrum in the bus should be limited up to the resonance frequency. Even if a sharp edge is lost from the pulse as a result of the spectrum restriction, it can be recovered again in a logic IC. The suppression of resonance to avoid the breakdown of the IC will be the most important task. Such a spectrum control for the operation of a circuit could be called spectrum management. Spectrum management using an appropriate element should be established to construct a high-speed bus.

ABSORPTIVE HIGH-CUT FILTER

A. Characteristics and Structure of Filter

A high-cut filter showing a small reflection at the cut-off band would be appropriate for spectrum management of the bus, if the cut-off frequency could be adjusted at the resonance frequency. A conventional high-cut filter that is reflective at the cut off band could not remove the unwanted spectrum. The high-cut filter for spectrum management should be absorptive at the cut-off band. A TEM transmission line constructed on a material showing loss above the cut off frequency could satisfy the required characteristic. Currently, a meander line is used to fabricate this type of filter [2]. A non-inductive line structure of the meander line increases the size of the filter difficult to be used in practice.

A helical TEM line embedded in the material gave a bigger inductance than the meander line and contributed to reducing the size of the filter. The dimensions of 2 mm length, 1.2 mm width and 1.2 mm height, usually presented as 201212, were selected. The production process of the filter and an example of its installation are shown in Fig. 4.

The substrate material was selected considering the char-

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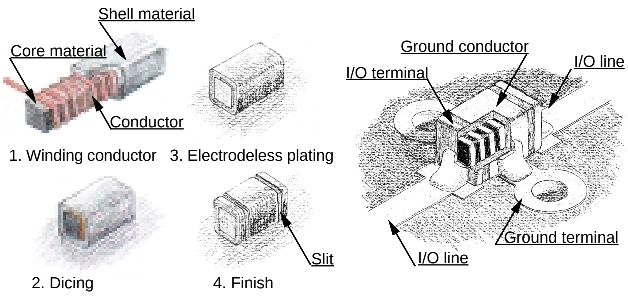

Fig. 4. Production and installation of the high-cut filter

acteristic impedance of the TEM line given by the equation shown below,

$$Z_0 = 120\pi\sqrt{\frac{\mu_r}{\varepsilon_r}}\,F(\frac{W}{h}) \quad \Omega \qquad (1)$$

where μ_r is the relative permeability and ε_r the relative permittivity of the material. The equation shows that the line impedance is a product of the material's characteristic impedance and a form factor F defined by the ratio of the material thickness W and the line width h.

Materials absorptive at higher than 800 MHz were found amongst both ferromagnetic and ferroelectric materials. Considering the convenience in the production, magnetic material was selected. Then the characteristics of several kind of magnetic materials such as ferrite and resin compounds of fine iron powder were compared. Finally, a resin compound containing fine iron powder with 85 wt-% was selected. The electromagnetic characteristics of the compound are shown in Fig. 5.

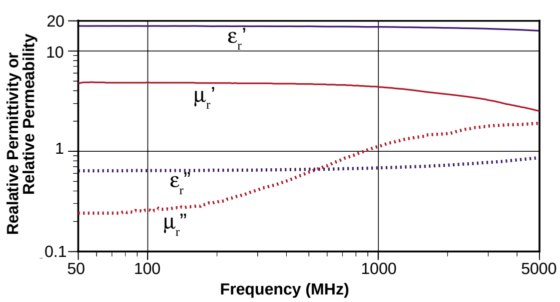

Fig. 5. Material constant of iron powder resin compound

The cut off frequency of 800 MHz given by the -3 dB decay frequency and the maximum reflection of - 10 dB were defined as the required specifications of the filter. Various filters were made on experimental basis. The S-parameters of the filter required to satisfy the specifications are shown in Fig. 6.

B. Model of the Filter

Although several ways of obtaining the characteristic impedance of the filter using an RF structure simulator have been sought, very complicated procedures for positioning

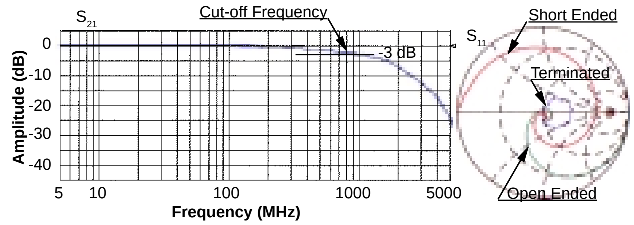

Fig. 6. S-parameter of the high-cut filter

the line model in the simulator have prevented actual trial. As an alternative method, a theoretical calculation using a simple line model is discussed. If the spacing between adjacent lines and the width of the lines are sufficiently larger than the thickness of the substrate, most of the electromagnetic energy is stored around the line and the mutual coupling between the lines is negligible. In such a case, the transmission line would be approximated by a microstrip line embedded in a magnetic material, as shown in Fig. 7. The characteristic impedance of the filter is calculated by substituting the electromagnetic constant of the iron resin compound and the dimensions of the line shown in Fig. 7 in (1) with the form factor of the microstrip line given by Yamashita [3]. The calculated result is shown in Fig. 7.

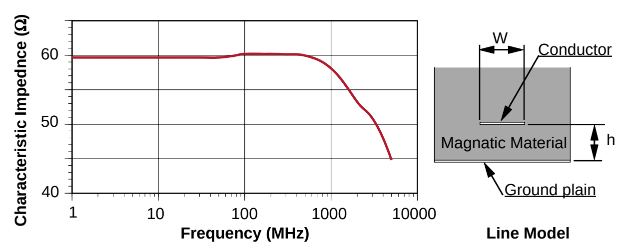

Fig. 7. Characteric impedance of line model

Line impedance higher than 50 Ω in the pass band was also read from S_{11} of the terminated filter, as shown in Fig. 6. If different materials are used for the core and the shell, the theoretical characteristic impedance should be calculated using the method described by Yamashita [3]. The theoretical calculations showed that the S-parameters of the filter strongly depend on the material characteristics. The degree of freedom in the filter design is only in the form factor and the line length. However, this is a novel filter that removes unwanted spectra with small reflection, e.g. big absorption. If the primary object of this filter is absorption of unwanted spectrum, the restricted design freedom would be acceptable. In spite of these limitations, appropriate selection of the core-shell material and the form factor would enable various filter designs.

ABSORPTIVE HIGH-CUT FILTER IN BUS

Suppression of the resonance in the bus was expected upon installing the absorptive high-cut filter fabricated as described above. As a preliminary test, a filter was installed in each port of the unit bus. Although sufficient resonance damping was established, a long delay caused by the filter increased the buildup time to longer than 5 ns. This delay was too long to operate the 200-MHz-clock bus. For damping of the resonance, it would be sufficient to install a filter in the bus to absorb the unwanted spectrum The filter was installed at the center of the line, considering the symmetry of the bus. The result is shown in Fig. 8.

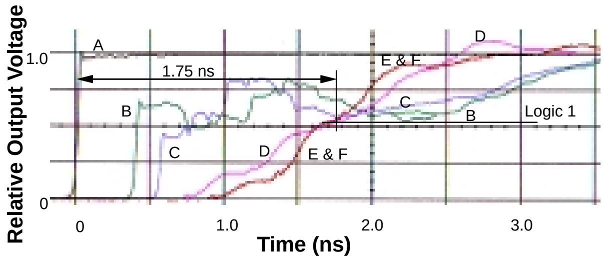

Fig. 8. Pulse transmission in the bus with high-cut filter

The fact that the fine ripples seen in Fig. 2 vanished means that the resonance was suppressed by the filter. Unexpectedly, the transition time was reduced from 1.95 ns to 1.75 ns. Comparing the results to those in Fig. 2, the pulse buildup at port B and port C became earlier than those at port D and Port E. This was due to the fact that the negative pulse fronts reflected from branch C and D were absorbed by the filter. This result also suggested that a small filter installed in each branch would result in a smoother pulse shape and a shorter pulse buildup time.

The idea of a small-filter array was expanded to a filter distributed on the bus. The time domain transmission analysis was carried out on the bus covered by a thin sheet of the iron resin compound with a ground plane. The thickness of the sheet was adjusted to give the same form factor as the absorptive high-cut filter used in this experiment. The structure of this bus is illustrated in Fig. 9. The result of step pulse transmission is shown in Fig. 10.

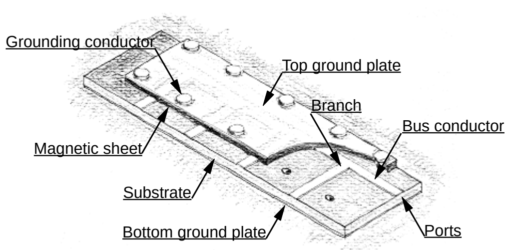

Fig. 9. Structure of high-cut filter line bus

Unlike the case of the lumped element filter, the ripple on the pulse was removed and equally smooth pulses appeared at each port. The transition time was reduced to 1.55 ns which is sufficient to drive a 250-MHz-clock bus. A radiation test has shown that this bus structure attenuated the radiation by more than 10 dB. Thus the analysis of the absorptive high-cut line has proved that this line not only optimized the operation of the bus but also reduced the electromagnetic interference.

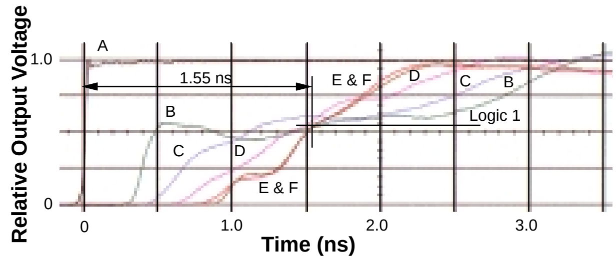

Fig. 10. Pulse tranmission in the high-cut filter line bus

CONCLUSION

The time domain transmission measurement to analyze the 200-MHz-clock bus problems explained that the pulse delay and the resonance in the bus by combining the reflection and the transmission of the pulse from the branch of the line. The final step in solving the problems was to remove spectra higher than the resonance frequency of the bus since the pulse in the bus contains unwanted spectra itself.

These considerations expanded the technology of controlling spectrum in the bus to the concept of the spectrum management. For spectrum management in the bus, an absorptive high-cut filter was fabricated using the loss dispersion of magnetic material. The installation of the filter into the bus confirmed that 200-MHz-clock operation is possible. The filter not only suppressed the resonance in the bus but also accelerated pulse buildup by absorbing the negative pulse reflected from the branches. The result enabled the expansion of the lumped element filter to a distributed filter that covered the bus. The absorptive high-cut line thus fabricated drove the 250-MHz-clock bus. The absorptive high-cut filter presented here will be an essential element of the high-speed bus.

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