A New Approach
For High Speed Data Transmission Monitoring

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Abstract
This paper describes a new approach for high speed serial data transmission monitoring. Concept is considered for PCB interconnections with differential signaling. Method allows to overhearing transmitted impulses without necessity utilization connectors connected to monitored line. Main benefit of this solution is that method doesn’t impact on transmission in observed line.

1. Introduction
Many high speed data applications demand digital data monitoring in development phase. Frequently adding dedicated debugging connectors for data monitoring only for debugging process is troublesome. Extra connectors insert disturbance in transmission line (cross-talks, impedance mismatch). Otherwise, usually in final debugging, PCB modification for adding measurement junctions is impossible. Desirable is to create methods which enable monitoring without intervention on PCB and testing transmission deterioration.

The concept of line-monitor is shown in the block diagram in Fig.1. First of all, it is necessary to develop contact-less probing method which has not essential impact on tested line in transmitted signal band. This goal can be achieved by proper high frequency coupler design. Decoupled signal have to be equalized in wide band by active equalizer. This operation allows to compensate non-constant coupler characteristic. Additionally, equalizer increase decoupled signal level and allows to trigger the flip-flop. Equalizer and flip-flop assure appropriate impulses slopes positions.

2. Coupler
Coupler design consideration is investigated for microstrip dual-line with differential signaling. In this case signal is transmitted in two microstrip coupled lines on PCB (Fig. 2). Dual line transmission with differential signaling has strong EMI advantage.

Fig.1. Monitoring system block diagram

Fig.2. Microstrip coupled lines with differential signaling
Coupler concept for differential signal decoupling

Fig. 3. Coupler concept for differential signal decoupling

Decoupling factors

Fig. 4. Decoupling factors

Coupler topology is performed on PCB 2 which is overlaid on tested lines (PCB 1). The method of differential signal probing bases on fact that values of decoupling coefficients are related as follows: $C_{A'}[dB] >> C_{BA'}[dB]$ and $C_{B'B}[dB] >> C_{AB'}[dB]$ (Fig. 4). Taking advantage of this relations, we can make an assumption that signal in line $A'$ depends only on signal in line $A$ (and $B'$ on $B$). On the basis of this conclusions we can claim that differential signal from lines $A'$ and $B'$ depends only on differential signal from $A$ and $B$.

3. Coupler impact improvement

Coupled microstrip lines can be modeled by equivalent circuit model (Fig. 5). We can consider two cases: work with even and odd mode. Even mode sets up that two lines work with two signals with the same amplitude and phase, odd mode - signals with the same amplitude and opposite phase. For two modes we can synthesize other circuit equivalents. We can observe symmetry in this structures: for even mode symmetry point is open, and short for odd mode. We can calculate full capacitance for single strip $C_{e\text{full}}$ and $C_{o\text{full}}$:

$$C_{e\text{full}} = C_{G1}$$

$$C_{o\text{full}} = C_{G1} + 2C_{S}$$

Differential signaling imposes situation when line works with odd mode. This approach can be extended for coupled lines with coupler considerations (Fig.6a). Model takes into account capacitances between strips working with signals with opposite phase ($C_S, C_1, C_2$) and capacitances between strips and ground plane ($C_{G1}, C_{G2}$). $C_S$ is not equal to $C_{G2}$ because of differences in effective dielectric constant. Capacitances between transmission lines and coupler produce transmission lines impedance mismatch. Relations between inter-strip capacitances are as follows:

$$C_2 < C_1 < C_S$$

$C_{e\text{full}}, C_{o\text{full}}$ and $Z_{0o}, Z_{0e}$ are related as follows:

$$Z_{0o} = \frac{\omega}{\beta_0 C_{e\text{full}}}$$

$$Z_{0e} = \frac{\omega}{\beta_0 C_{o\text{full}}}$$

To minimize influence of coupler to transmission line, another coupler topology was considered. Much better properties in this aspect are special for configuration composed of two sections shown in Fig.6b and Fig.7. This solution implements two separated couplers. In this concept inter-strip capacitances: one $C_1$ and $C_2$ was reduced. As was shown in relation above, this operation minimize $C_{e\text{full}}, Z_{0o}$ influence. That is why coupler influence to transmission line was minimized and transmission line mismatch problem was improved.

4. Simulations

For non-disturbed conditions work for line in transmission band and desirable decoupling characteristic achievement, geometrical dimensions have to be properly fixed. Coupler design is considered for FR-4 laminate ($\varepsilon=4.4, H=1.55\text{mm}$),
Fig. 6. Circuit equivalent for microstrip coupled lines with coupler

and monitored transmission line ($L=214\text{mm}$, $W=2.72\text{mm}$, $S=0.8\text{mm}$) shown in top of Fig. 7. The impedance parameters of this transmission line at 3GHz are: $Z_e=61.5\Omega$, $Z_o=40\Omega$, $Z_0=50\Omega$. Monitored line with coupler topology is shown in Fig. 7. Coupler design was analyzed with Agilent ADS software. For reliable parameters assessment all results was compared to transmission line without coupler.

Numerical test demonstrates good properties of proposed circuit configuration. In 3.5GHz band mismatch for transmission line with coupler ($S_{11}$) has similar character and values to configuration without coupler ($S_{33}$). Decoupling characteristic is easy to equalize in this band ($S_{11}$). Transmission line attenuation is on the similar level for line with coupler ($S_{21}$) and line without coupler ($S_{43}$). These facts indicate that there is possibility of coupler geometry optimization for non-disturbed monitoring of transmission line in desirable band (beyond transmitted signal band coupler impact on line is not critical). Next test concerns time domain simulation monitoring for various data rates (1Gb/s, 2Gb/s, 3Gb/s). Test circuit is shown in Fig. 8. Test points are located on the coupler output ($V_c$) and in specific planes on transmission line: line input ($V_i$), coupler input ($V_i$), coupler output ($V_o$), line output ($V_o$). We can observe that front of time domain coupler output voltage $V_c$ grows and falls down at the moments when differential signal in monitored line has growing and falling slope. After equalization this signal can be used for flip-flop triggering to steep edge reconstruction.

5. Conclusion

The design consideration described in this paper demonstrate new approach for high speed serial data transmission monitoring. Appropriate coupler design with equalization circuit and flip-flop can be used for contact-less PCB transmission line diagnosis. Main aspects of coupler impact mineralization on monitored line was considered. For the future, IC equalizer design is planed (Cherry-Hooper topology). For practical usability improvement adaptive equalization algorithm must be created. Auto-adaptation mechanism is necessary for possibility of different transmission lines monitoring.
6. Bibliography And Authors

Bibliography