Propagation and Mismatch Analysis of 50 GHz Guided Pulses based on Optical Sampling

Dong-Joon Lee, Joo-Gwang Lee, Jin-Seob Kang, and No-Weon Kang

Center for Electromagnetic Wave, Korea Research Institute of Standards and Science
209 Gajeong-ro, Yuseong-gu, Daejeon 305-340, Rep. of Korea, dongjoonlee@kriss.re.kr

Abstract
We present a method to explore propagation behavior and mismatch characteristics of 50 GHz pulses using a pulsed optical sampling technique. The system employs a minute, external crystal sensor that is suitable for ultrabroad band sensing – even up to the THz regime. The external scheme of the sensor enables fast pulse detection at arbitrary points over a transmission line. In this paper, the propagating incident pulse and its reflected responses from standard mismatch loads are measured at various locations of a microstrip transmission line. In addition, the evolution of the pulses and their spectral responses are also discussed.

Keywords: Sampling Oscilloscope, Electromagnetic Pulse Measurement, Electro-Optic Sampling

1. Introduction
Optical sampling techniques have been widely used for fast electromagnetic pulse measurements where conventional on-wafer probing methods are challenging [1-3]. This is because the optical technique usually employs femtosecond pulsed lasers and electro-optic (EO) crystals as sampling sources and sensors. Such an optical method with dielectric media realizes ultrafast pulse probing with reasonably less invasiveness. Furthermore, unlike electrical on-wafer probes, the EO probes enable non-contact sensing; they are not required to land on dedicated measurement points, and thus probing at arbitrary locations over microwave device under tests is possible.

We at KRISS (Korea Research Institute of Standards and Science) have recently developed a time domain electro-optic sampling system for 20 GHz band pulse analysis and have utilized it to explore mismatch characteristics of a microwave device under testing in both the temporal and spectral domains [4]. In this paper, we present an upgraded system for generation and detection of 50 GHz band pulses. The performance of our system is presented by exploring pulse evolutions over a microstrip transmission line.

2. Optical Sampling System for EM pulse Scoping
The optical probing system for high-speed electromagnetic pulse measurement is illustrated in Fig. 1. The basic scheme is the 'pum-probe' experiment that is widely used in pico-second (~ THz band) pulse sensing based on optical techniques. The system employs a femto-second-scale pulsed laser with a ~0.1 ps duration. We split the pulses in half. One half of the pulses are used as an excitation beam to generate 50 GHz EM pulses through a fast photodiode. The other half of the pulses serve as an optical sampling beam that can be temporally and spatially overlapped with the EM pulses with a programmable delay line.
Figure 1: High-speed EM pulse measurement system based on electro-optic sampling: (a) system schematic (b) probing part

A minute $x$-cut LiTaO$_3$ tip was used as an external electro-optic (EO) sensor [4]. The sensor is vertically mounted along the center of the transmission line. This is to effectively measure the normal electric field components of the EM pulses while they propagate along the line. As the EM signal and optical sampling pulse reconcile in the EO sensor medium, the polarization of the original sampling pulse becomes modulated according to the existence of the EM pulse fields. This modulated polarization indicates the quantity of EM-optical pulse interactions with respect to the temporal position of the sampling pulse. Translating the stepper motor in the sampling path, the sampling pulse can scan across the EM pulse. Thus, the original EM pulse waveform can be plotted on a computer screen by reconstructing the sampled trace.

Figure 2: Electromagnetic pulse sampling on a microstrip transmission line. (photograph of Fig. 1(b))

To investigate pulse evolution along the microstrip line, we generated 50 GHz pulses at port 1 from a photodiode that is excited by ~0.1 ps optical pump pulses. The 50 GHz pulses are launched along the 200 mm long microstrip transmission line and then propagate until they are reflected back at port 2. The traveling pulses were measured at three distinct points $a$, $b$, and $c$ (5 mm, 10 mm, 15 mm away from port 1) over the center of the transmission line.

The three measured pulses are shown in Fig. 3. for 1 ns duration. The comparison of each pulse can provide quite useful information regarding the characteristics of the transmission line. The waveforms of the primary pulses – compared to those at different locations, as shown in Fig. 3(a) – indicate the lossy and dispersive nature of the line as the pulses propagate. For instance, the incident pulse at point $a$ is less dispersive than those at point $b$, and $c$ as it is closer to the original pulse – launched at port 1.

The dispersion and attenuation of the guided pulses are primary factors of pulse waveforms that govern the bandwidth of the pulse. For instance, the spectra of the three measured pulses are extracted by Fourier analysis and shown in Fig 3 (b). The results indicate that the bandwidth of the 50 GHz launching pulse has been significantly eroded. This information should help to characterize the
broadband transmission line by allowing us to infer its propagation constant at the frequency of interest.

Figure 3: Pulse evolution over the transmission line at point a, b, and c in Fig. 2: (a) measured pulses (b) transformed spectra.

Furthermore, the propagating pulses toward port 2 can be utilized to analyze the mismatch characteristics of the line. For instance, Figure 4 shows the reflected pulses from port 2 with respect to the incident pulse measured at point c. The measured pulses consist of three parts: the first one is the incident pulse that runs toward port 2 and serves as a reference for the reflected pulses. The second and third ones are respective echoes from the connector and calibration kits. All three incident pulses have identical waveforms, while their reflections are quite different depending on standard loads.

Figure 4: Mismatch pulse measurements with various terminations at port 2: (a) measured pulses (b) transformed spectra

The reflected pulses interact with the incident pulse and then modulate the original spectra, which are solely determined by the incident spectra. With respect to the primary pulse, the relative amplitude and shape of the secondary pulse heavily influences the overall spectra associated with the temporal separation and phase relation. As the reflective pulses from open (or short) termination have the same (or opposite) polarity with respect to the incident pulses, the pulses constructively (or destructively) build up at a very low frequency. Then, each open and short spectrum is modulated periodically in a complementary way for higher frequency. For 50-ohm termination cases, a mild ‘open terminated’ spectral modulation is observed due to the connector mismatch pulses, as shown in
Fig. 4(a). Excluding such mismatch effects by time gating, the spectra for ideally matched termination can be extracted, as was shown in Fig. 3 (b) (dashed line).

3. Conclusions

We presented a measurement method for guided high-speed electromagnetic pulses on a transmission line using a time-domain pulsed electro-optic sampling system at KRISS. The photonic probing scheme enables portless and ultrabroad band pulse sensing, and thus this system has realized fast pulse probing at arbitrary locations on a signal line. The evolution of the 50 GHz guided pulse propagation and the spectro-temporal mismatch analysis of a transmission line were presented based on time domain reflectometry using our system.

References


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