Calibrating photoreceiver response to 110 GHz

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Abstract- **We have measured the magnitude and phase responses of a photoreceiver to 110 GHz using a calibrated electro-optic sampling system. The frequency range of the calibration is limited only by our 1 mm coaxial connectors.**

In this paper, we present a method for accurately characterizing the response of a commercially available photoreceiver to 110 GHz, nearly three times the bit rate of 40 Gb/s optoelectronic systems. In our electro-optic sampling system, ultrashort laser pulses sample high-speed electrical waveforms on a coplanar waveguide (CPW) via the electro-optic effect. Standard microwave techniques are used to calibrate the response of a photoreceiver at a reference plane that is physically removed from the sampling plane.

Figure 1 shows a schematic diagram of our electro-optic sampling system, which we reported in [1,2] and which is similar to those described in [3]. The mode-locked fiber laser produces a train of ~100 fs duration pulses at 1550 nm. Part of the laser beam excites the photoreceiver (the device under test). The electrical impulses generated by the photoreceiver then propagate through the probe head and onto a coplanar waveguide fabricated on an electro-optic y-cut $LiTaO_3$ wafer. The sampling beam passes through a variable optical delay and is focused through a small gap in the CPW. The sampling beam is linearly polarized at an angle of 45° to the x-axis of the $LiTaO_3$. The electric field between the CPW conductors changes the polarization of the optical beam passing through the wafer via the electro-optic effect. We use lock-in detection with the polarization state analyzer to measure this change in polarization, and we record the temporal evolution of the electrical waveform on the wafer by scanning the delay in the sampling beam.

The 1550 nm photoreceiver is a waveguide photodiode with an integrated 50 Ω matching resistor and bias network and a bandwidth of ~80 GHz. The photoreceiver is packaged with a 1.85 mm coaxial electrical connector; however, we attach a 1.85 mm to 1 mm coaxial adapter in order to provide a 1 mm coaxial reference plane for our electro-optic sampling system, which is compatible with our microwave measurements up to 110 GHz.

Earlier results from this system [1,2] were limited to 30 GHz primarily because of the presence of slot modes that were excited in the CPW. To extend the response to 110 GHz, we average the voltage measured in both the top and bottom gaps of the CPW to eliminate the slot-mode resonance, and we also fabricate the CPW on a thin substrate in order to eliminate any problems due to microstrip-like surface-wave modes supported by a thick substrate[2]. In addition, we apply an anti-reflection coating to the substrate to reduce errors due to multiple optical reflections.

In order to correct the measured waveform for the distortions due to the probe head, CPW, and CPW resistor, we apply the frequency-domain impedance mismatch corrections described in [1, 2]. We first characterize the photoreceiver, the CPW load, and the probe head with a calibrated vector network analyzer (VNA). All of the VNA measurements are performed with 1 mm coaxial connectors, providing electrical information up to 110 GHz. The electrical equivalent circuit for the measurements, shown in the bottom part of Fig. 1,

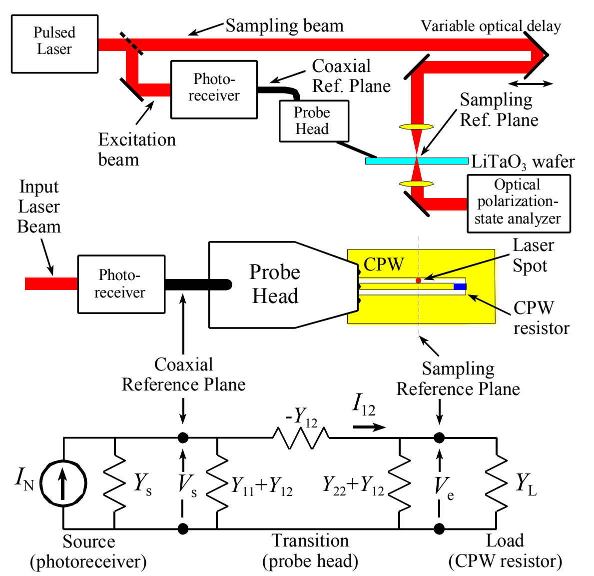

Fig 1. A schematic diagram of our electro-optic sampling system (top), a top-view schematic (center), and an electrical equivalent circuit (bottom).

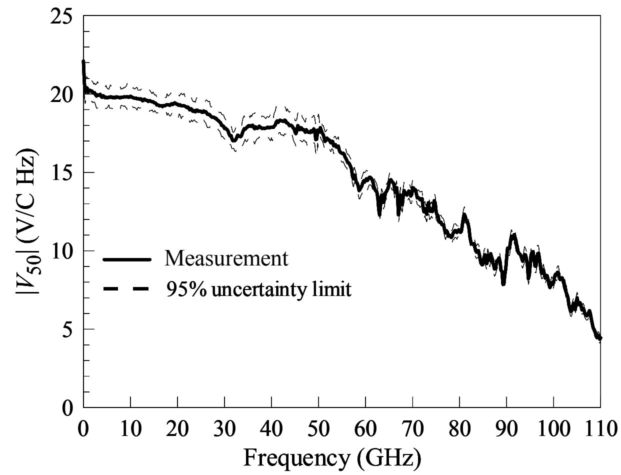

Fig. 2. Magnitude of photoreceiver response. Voltage spectral density is normalized to the optically generated charge in the photoreceiver.

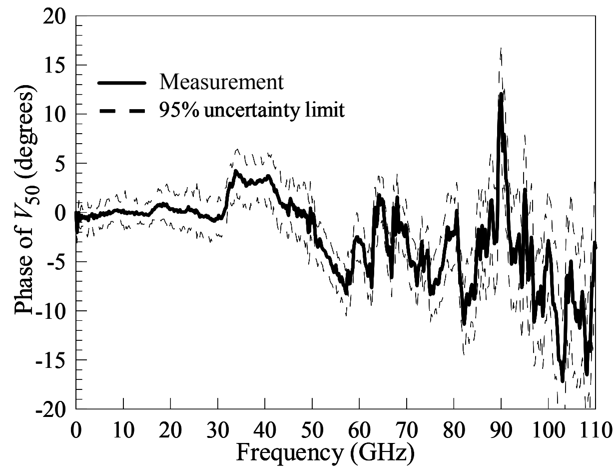

Fig. 3. Phase of the photoreceiver response with linear delay removed.

is based on admittances calculated from the VNA measurements. From this model and the voltage measured at the sampling reference plane in the CPW gap, we calculate the voltage, $V_{50}\left(f\right)$, that the photoreceiver would generate with a perfect 50 Ω load at the coaxial reference [2].

Figure 2 shows the magnitude of the response, $V_{50}\left(f\right)$, of the photoreceiver at the 1 mm coaxial connector, and Figure 3 shows the phase of the response of the photoreceiver, after removing the linear delay. The voltage spectral density is normalized by the optically generated charge in the photoreceiver. The signal to noise ratio for this data is better that 700:1, and at 110 GHz the signal to noise ratio is greater than 150:1.

The dashed lines in Figs. 2 and 3 show the 95% confidence intervals determined from a Monte-Carlo simulation that we constructed to estimate the uncertainty in our measurements. The simulator accounts for the error introduced into the electrical mismatch corrections by the systematic errors in the on-wafer TRL calibration identified in [4], the instrument drift as measured by the calibration comparison method [5], errors due to cable bending estimated from our measurements, and the errors in the coaxial calibration [6]. The simulator also accounts for the error in the measurements due to positioning of the optical beam in the gap of the coplanar waveguide, multiple optical reflections between the two faces of the $LiTaO_3$ wafer, the finite temporal width of the optical pulses, the finite radius of the optical beam, and the finite time that the optical pulses take to traverse the electric field in the coplanar waveguide [3].

The linearity of the electro-optic system enables us to study the nonlinearity of the photoreceiver, which can be masked by the intrinsic nonlinearity of other systems used for high-speed measurements, such as oscilloscopes. In addition, many nonlinear processes in photoreceivers effectively act as a low-pass filter and can be clearly observed with the electro-optic sampling system because of the very high frequencies available. We will present results showing the capability of this system for studying nonlinear photoreceiver response even at low optical excitation powers.

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