Time-domain laser-based characterization of high-speed photodetectors

Paul Struszewski and Mark Bieler
Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany
paul.struszewski@ptb.de

We present a procedure to characterize the time- and frequency-domain responses of high-speed photodetectors (PDs). For this purpose, we utilize an all-optical laser-based vector network analyser (VNA). This device features a novel measurement technique [1] with which we are able to obtain complex scattering parameters at the measurement plane. This allows for full mismatch correction being crucial for characterization of high-frequency devices. The analysis of the time-domain measurements includes several deconvolution operations. We demonstrate that in our case the usage of a Tikhonov regularisation algorithm [2] is essential to overcome the ill-posed problem of deconvolution. This results in a numerically demanding analysis for a dynamic system with time traces having several thousand data points. In order to quantify the uncertainty of PD responses constituting a highly multivariate problem, we apply a Monte-Carlo simulation according to the GUM [3]. Our technique not only enables accurate calibration of PDs but will also prove to be important for general waveform metrology applications.

The experimental setup is based on an optical pump-probe technique applied to a coplanar waveguide (CPW) [4] on top of a gallium arsenide (GaAs) substrate, see Fig. 1. The electrical field of an ultrashort voltage pulse is detected by an optical femtosecond pulse (1600 nm center wavelength) employing the electro-optical effect of the GaAs substrate [1]. Varying the time-delay between the optical probe beam and the voltage pulse enables accurate sampling of the time-domain shape of the ultrashort voltage pulses. By measuring the voltage pulses at different positions on the CPW we are able to determine the reflection coefficient at the coplanar measurement plane. This allows for the specification of scattering parameters in analogy to typical electrical VNAs.

The calibration of the PDs is done in two steps. First, ultrashort voltage pulses with frequency components exceeding 500 GHz are generated by an optical pump pulse (800 nm center wavelength) and propagate along the waveguide. From the reflection coefficient at the measurement plane the complex scattering parameters of the coplanar-coaxial link, i.e., of a certain fraction of the CPW and the microwave probe, are obtained. Second, the PD is connected to the coaxial end of the microwave probe and the voltage pulses generated from the PD are recorded at the CPW measurement plane. The measured time traces and their uncertainties are propagated through a nonlinear equation using Monte-Carlo simulations to obtain the best estimate and the coverage interval of the PD response, see Fig. 1(b). Typically our measurements/analysis features a frequency resolution of 500 MHz, a bandwidth up to 500 GHz and a dynamic range of more than 40 dB. In order to validate our technique, we have ongoing comparisons with electrical VNA measurements and with measurements performed by other National Metrology Institutes.