Echo Cancellation in Pulsed Terahertz Integrated Circuits

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***Abstract*—A signal processing algorithm based on the propagation and reflection mechanisms is proposed for echo cancellation in pulsed terahertz integrated circuits.**

I. INTRODUCTION

IN pulsed Terahertz Integrated Circuits (TIC), generation, propagation, and detection of picosecond THz pulses are conducted on a single substrate with printed metal patterns. Transmission lines and other planar components are formed by the metallic patterns for guiding and controlling THz pulses. At the detection point, the reflected pulses coming from discontinuities interfere, and are detected, along with the main THz pulse. In many applications, interference of the reflected pulses with the main pulse is not desirable, as they disturb the temporal and spectral characteristics of the desired THz signal. For example, in on-chip THz spectroscopy applications [1], this type of interference produces unwanted artifacts in the spectra, which can be observed in power spectral density of the signal using the Fourier method. These artifacts can mask the spectral absorption features of the sample under test. Furthermore, they reduce the effective bandwidth as the signal energy is distributed in a wider time window.

Picosecond THz pulses contain a broadband frequency spectrum suitable for material spectroscopy and sensing. As the THz pulses interact with the sample under test, the rotational and vibrational resonance modes of molecular and crystalline structures of the material show up as absorption signatures in the spectrum, whereas in the temporal domain these signatures appear as small variations in the tail of the main pulse. Therefore, the temporal data collected after the main pulse also contain spectroscopic information. The spectral resolution should be high enough to resolve all the existing absorption signatures. This can be achieved by increasing the time interval of the recorded signal. However, the maximum of the time interval is limited because of the interfering echoes arriving from the chip discontinuities.

The standard solution to avoid the effects of the echoes, with the cost of decreasing the spectral resolution, is to simply cut off the data in the time domain before the first echo occurs. Echo cancellation techniques can be applied as an alternative solution to reduce the effects of the reflection on the resolved spectrum without compromising the spectral resolution.

In this paper, we propose a method to properly remove the echoes from the time domain data based on the propagation and reflection mechanisms in TICs. Using this method, the spectral resolution of the recorded signal is preserved, while the effects of the echoes on the resolved spectrum are reduced to a large extend. The signal processing techniques are applied to minimize the effects of the echoes.

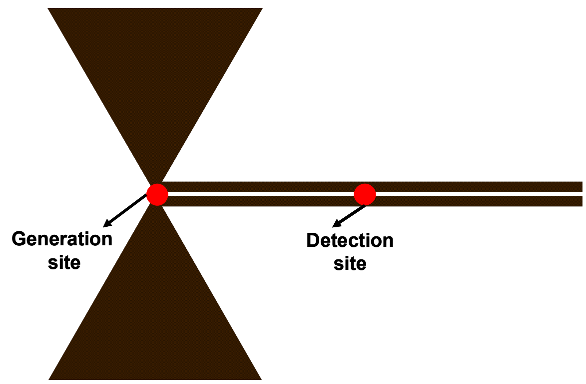

Fig. 1 TIC structure containing a coplanar stripline transmission line with open end on one side and a bow-tie antenna on the other side. The generation and detection sites of the THz pulse are shown on the graph.

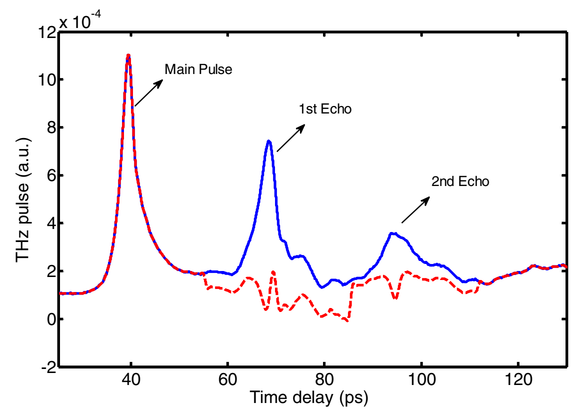

Fig. 2 Measured THz signal with two line echoes (solid line) and the signal after echo cancellation (dashed line).

II. METHODOLOGY

Fig. 1 shows a TIC containing a coplanar stripline (CPS) transmission line with open end on one side and terminated to a bow-tie antenna on the other side. The CPS is 2.7mm long with the metal traces of 20μm width, separated by 10μm. The substrate is a 100nm-thick low-temperature grown GaAs (LTG-GaAs) grown on a 150μm-thick S.I. GaAs. A standard pump-probe measurement setup is used for on-chip THz pulse generation and detection. The laser source is a 780 nm Ti:sapphire femtosecond laser with pulse duration of 100 fs, and 80 MHz repetition rate. It illuminates the generation site on the chip for pulse generation. A part of the energy of the generated THz pulse is coupled into the CPS, and propagates toward the detection site. In this analysis, the antenna is treated as a loading impedance for the CPS. The probe beam passes through a variable delay line, and is focused on the center of the CPS (detection site) for pulse detection. The detected THz pulse including the main pulse and two echoes is

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shown in Fig. 2 (solid line). In Fig. 2, the first echo is the result of the reflection of the main pulse from the open end, and the second echo is due to the reflection of the first echo from the antenna side. The goal is to cancel the echoes, and simultaneously preserve the spectroscopic information of the main signal which extend and interfere with the echoes.

We combine the propagation and the reflection mechanisms in the form of an impulse response function given by (1) for analytical reconstruction of the echo pulses from the incident pulses. To the best of authors' knowledge this combined model has not been proposed before.

$$\tau_i(t) = F^{-1}[\exp(-\alpha(\omega)\Delta l_i - j\beta(\omega)\Delta l_i)\cdot\Gamma_i(\omega)] \qquad (1)$$

where F^{-1} represents the inverse Fourier transform, ω is the angular frequency, $\alpha(\omega)$ and $\beta(\omega)$ are the attenuation and phase constant of the transmission line, respectively, $\Gamma_i(\omega)$ (i=1,2) is the reflection coefficient at each end of the line, and Δl_i is the round-trip length between the detection site and each reflecting end. Here, i=1 and i=2 describe the open side and the antenna side, respectively.

When the dispersion is negligible, the model parameters in (1) can be estimated from the time-domain measurement data. This can be done by subtracting the reflections from the signal, using the fact that they are variations of the main pulse. Correlation techniques can be used to estimate the time and power of each reflection. The targeted bandwidth information is used to maintain the integrity and the desired properties of the THz signal in the process. Fig. 2 (dashed line) shows the results of applying this method to cancel the echoes.

When the dispersion is not negligible, i.e. pulse distortion is significant, model parameters $\alpha(\omega)$, $\beta(\omega)$, and $\Gamma_i(\omega)$ should be estimated from the combination of time-domain measurement data and the full wave electromagnetic analysis of the TIC. Fig. 3 shows the impulse response of the combined propagation-reflection model calculated from (1). For this graph the model parameters are obtained in the frequency range of 0-350GHz with 5GHz step size from full wave electromagnetic simulation using Momentum ADS, a commercial EM simulator based on the method of moment [2]. The impulse response in Fig. 3 can be ideally described as the echo pulse detected at the detection site due to an incident impulse which leaves the same site at t=0 towards open circuit side (i=1) or the antenna side (i=2). As seen in Fig. 3, the echo pulse is more distorted when it reflects back from the antenna side. This observation is in consistent with the fact that the phase of the reflection coefficient $\Gamma_2(\omega)$ at the antenna side is a nonlinear function of the frequency, and its magnitude is frequency dependent as opposed to the open circuit reflection coefficient. Each echo pulse is reconstructed from its preceding pulse convolved with the corresponding impulse response as

$$p_1(t) = p_0(t) \otimes \tau_1(t) \qquad (2)$$

$$p_2(t) = p_1(t) \otimes \tau_2(t) \qquad (3)$$

where $\otimes$ represents the convolution operator, $p_1(t)$ and $p_2(t)$ are the first and second echo pulses, respectively, $p_0(t)$ is the main pulse gated with an appropriate time window.

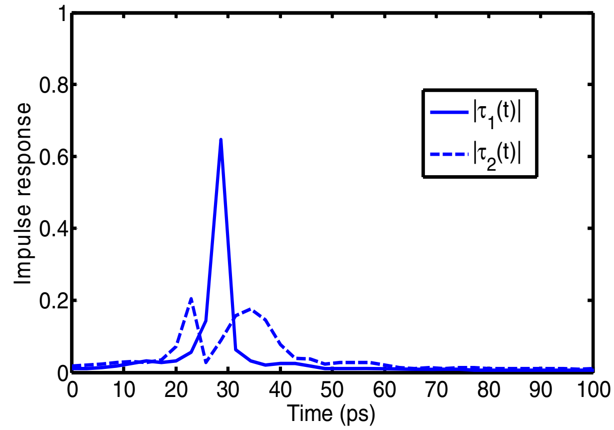

Fig. 3 Impulse response of the combined propagation-reflection model calculated from (1) for open side (τ_1(t)) and the antenna side (τ_2(t)).

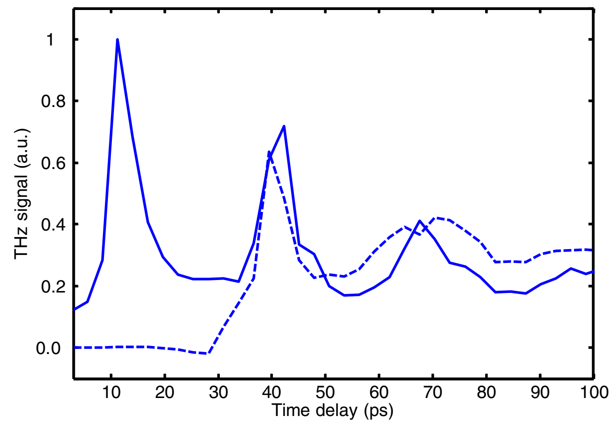

Fig. 4 Reconstructed echoes (dashed line) are compared with the measured THz signal (solid line).

Fig. 4 shows the reconstructed echoes, $p_1(t)+p_2(t)$, along with the measured THz signal. The reconstructed signal fits the measured echoes fairly well. However, further improvement can be obtained by increasing the frequency range, for which the model parameters are calculated. Narrow frequency range degrades the time resolution in the calculated impulse response, and causes pulse widening. A proper frequency range can be estimated from the power spectral density of the measured signal within which the signal has its energy content. Moreover, considering the higher order propagation modes of the transmission line can improve the form of the reconstructed signal.

ACKNOWLEDGEMENT

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