1D- and 2D-Electro-Optic Field Mapping to Study Nonlinear Effects in NLTs

Th. Braasch, G. David*, R. Hülsewede, and D. Jäger
Sonderforschungsbereich 254, Fachgebiet Optoelektronik
Gerhard-Mercator-Universität Gesamthochschule Duisburg
Kommandantenstraße 60, D-47057 Duisburg, F.R.G.
Phone: +49-203-379-2340, Fax: +49-203-379-2409
*now with Center for Ultrafast Optical Science, University of Michigan,
Ann Arbor, MI 48109 - 2099

Introduction — In the past, electro-optic sampling has successfully been used to characterize quantitatively circuit-internal field distributions inside monolithic microwave integrated circuits (MMICs) [1,2,3]. To demonstrate the capabilities of this technique for the analysis of circuits, in this paper the electro-optic probing technique is applied to analyze wave propagation effects in nonlinear transmission lines (NLTs) both, in the frequency domain and the time domain.

Results — The experimental setup used consists of a direct electro-optic measurement system, i.e., a pulsed laser and a Pockels cell, in combination with a confocal laser scanning microscope. The electric field distribution is probed electro-optically and the probe stage can be moved in two dimensions enabling the two-dimensional detection of the electrical signal. Additionally, the intensity of the reflected beam is detected providing the front surface reflectivity of the device under test (DUT). The experimental results offer the possibility to analyze the electric field distribution as well as to determine the microscopic details of the scanned interface region. Thus, the electro-optic signal can be normalized to the individual reflectivity of the particular measurement point revealing the absolute value of the voltage between the device's top and bottom side. The spatial resolution for this setup is measured to be less than 0.5 μm [4]. For the time domain measurements the electrical signal is generated using the optical pulses of the laser in order to provide a constant phase relation between the electrical signal and the optical pulses.

Fig. 1 shows a schematic view of an examined NTL. The line consists of a coplanar transmission line (CPW) periodically loaded with up to 20 Schottky diodes. Two types of devices have been investigated. Either a layer structure for varactor diodes was grown on GaAs or a structure optimized for HFETs was grown on InP. The microwave signal is launched to the NTL via an on-wafer probe.

![Fig. 1 Sketch of a nonlinear transmission line](image)

Fig. 2 depicts the spatial distribution of the incident fundamental electrical signal at 15 Ghz, measured in the frequency domain. The amplitude decreases while propagating along the
NLTL. In contrast, the amplitudes of the second, third, and fourth harmonic with frequencies up to 60 Ghz, which are also generated, increase indicating that they are produced along the transmission line. The obvious standing wave patterns are caused by an impedance mismatch at the end of the line and phase mismatching of the harmonics.

![Graph showing electro-optic signal vs propagation distance](image)

**Fig. 2:** Electro-optic signal of the fundamental microwave at 15 GHz and of its higher harmonics along the center conductor of an NLTL from input to output.

![Imagery of NLTL and field mappings](image)

**Fig. 3:** NLTL consisting of 10 Schottky diodes in a CPW: (a) metallization structure; results of 2D field mappings at (b) 6 GHz, (c) 12 GHz and (d) 18 GHz.
Two-dimensional field mappings of the same device are shown in Fig. 3. Here, the fundamental frequency was set to 6 GHz. In addition to the decrease of its amplitude and to the increase of the amplitudes of the higher harmonics in the direction of propagation, these results reveal unsymmetrical distributions of the electro-optic signals. We contribute this effect to the excitation of parasitic propagation modes [3].

In the time domain, the evolution of a shock wave and of solitons along the NLTL is the counterpart to the frequency domain’s generation of higher harmonics. The electro-optic probing technique is capable of studying and demonstrating this effect as well, as elucidated in Figs. 4(a) to 4(d). Here, the development of a sinusoidal electrical input signal of 6 GHz propagating along the NLTL at the 1st, the 5th, the 10th and the 14th diode, respectively, is presented. As can be seen, shock waves, which are generated due to the interaction of the higher harmonics, have been generated with fall times down to 5 ps.

![Waveform Images](image.png)

**Fig. 3:** Generation of a shock wave along an NLTL, frequency: 6 GHz, (a) waveform at the 1st diode, (b) the 5th diode, (c) the 10th diode and (d) the 14th diode

**Conclusions** — In summary, the electro-optic measurement technique has been used to internally investigate wave propagation effects along nonlinear transmission lines enabling circuit-designers to get an insight into the in-circuit electrical characteristics of complex microwave devices. In particular, the generation of harmonics and the formation of shock waves have been demonstrated showing, that this method is suitable to examine internal field distributions of MMICs in both, frequency domain and time domain.

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References


