

Week 1, THZ transmission lines

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Main objective:

Develop an efficient but accurate model in matlab of a transmission line suitable for THz .

Week Goals:

1. Read 5 papers and write a summary to gain an idea about THz transmission lines.
2. revise Matlab, solving diff equations and past year basics (simulation).
3. Start to look at modelling transmission lines using finite difference time domain (FDTD).

Introduction to the Finite-Difference Time-Domain (FDTD) Method for Electromagnetics.
Chapter2: 1D FDTD Modeling of the Transmission Line Equations

Transmission lines guide electromagnetic energy from a source to a load and come in various forms, such as twisted pair lines, coaxial cables, and multi-conductor waveguides. Transmission line modelling is often simplified as a one-dimensional approximation, representing line voltages and currents along the line's axis. The governing time-dependent equations describe the behaviour of these voltages and currents.

$$\frac{\partial I(x, t)}{\partial x} = -C \frac{\partial V(x, t)}{\partial t}, \quad \frac{\partial V(x, t)}{\partial x} = -L \frac{\partial I(x, t)}{\partial t},$$

In the equations, ($V(x, t)$) represents the voltage at position (x) along the transmission line at time (t), and ($I(x, t)$) is the current at that same position and time. (L) is the inductance per unit length (in henries per metre, H/m), and (C) is the capacitance per unit length (in farads per metre, F/m). For simplicity, a lossless transmission line is assumed. The two equations governing voltage and current can be combined into the wave equation, which describes the propagation of voltage along the transmission line.

$$\frac{\partial^2 V(x, t)}{\partial x^2} = LC \frac{\partial^2 V(x, t)}{\partial t^2}.$$

A corresponding wave equation is derived for the line current, with a well-known solution that is expressed as the superposition of forward and backward travelling waves.

$$V(x, t) = A^+ f\left(x - t/\sqrt{LC}\right) + A^- f\left(x + t/\sqrt{LC}\right)$$

Where F is any function and A is the amplitude of the forward and backward wave. These values are determined by the initial conditions and boundary conditions of the end of the transmission lines.

A Nonlinear Transmission Line with Harmonic sub-THz Power Generation in a 40 nm CMOS Technology.

This paper presents a broadband power generation system using a nonlinear transmission line (NLTL) technique in 40 nm CMOS technology, covering a frequency range from 10 GHz to 0.15 THz. The design incorporates 110 elementary sections with varactors embedded in the NLTL for harmonic generation, achieving sub-THz output while being fully compatible with CMOS technology. The total area of the power generation system is compact at $588 \times 660 \mu\text{m}^2$, and with a 6 dBm input at 10 GHz,

the output power spans frequencies from 20 GHz to 150 GHz, with -37 dBm at 100 GHz and -40 dBm at 150 GHz.

The design utilizes a grounded slow-wave coplanar waveguide (GSW-CPW) topology to shield the lossy silicon substrate, enhancing the transmission line's nonlinearity and harmonic generation properties. The varactor, a standard component in bulk CMOS technology, helps sharpen the input signal edge and generate harmonics, extending the output to the sub-THz range. Measurements confirm that the system generates harmonic signals from 20 GHz to 150 GHz, making it suitable for high-frequency applications like fast sampling and sub-THz imaging systems.

Low Loss Microstrip Transmission-Lines using Cyclic Olefin Copolymer COC-substrate for Sub-THz and THz Applications .

This paper presents a low-loss microstrip transmission line (MSL) with compact coplanar waveguide (CPW) transitions designed for sub-terahertz applications. The MSL is fabricated on a thin 10 μm cyclic olefin copolymer (COC) dielectric layer with a gold ground plane on a silicon substrate. The design aims to improve transmission efficiency between CPW and MSL for frequencies in the sub-terahertz range, validated by both simulations and experimental results using a vector network analyzer (VNA). Key transmission parameters were measured for various MSL lengths, demonstrating minimal transmission loss, with approximately -2 dB loss for a 1.96 mm MSL across the 140-220 GHz range.

The study highlights that transmission losses increase as the MSL length increases, with a 4.96 mm line exhibiting a loss of -4.5 dB at lower frequencies (below 180 GHz). The insertion loss is calculated to be around -0.7 dB/mm at 180 GHz, with potential for further improvement through parameter adjustments. This novel CPW-to-MSL transition design, which requires no via holes, offers broad applications in terahertz wireless communication systems, supporting the development of filters, antennas, and other components for frequencies up to 1 THz and beyond.

Turning THz Communications into Reality: Status on Technology, Standardization and Regulation

Terahertz (THz) communications, especially beyond 275 GHz, are gaining interest due to their potential to offer ultra-high data rates (up to 100 Gbit/s) for applications like 5G backhaul/fronthaul links, wireless data centres, and intra-device communications. The development of THz technology has advanced through research on channel modelling, hardware demonstrators, and standardisation efforts. IEEE published the 802.15.3d-2017 standard, the first wireless communication standard in the 300 GHz range, to address these emerging needs. Additionally, the ITU-R is preparing regulations for spectrum allocation, with the World Radio Conference 2019 (WRC-2019) focusing on securing the THz spectrum for land-mobile and fixed services while protecting passive services such as radio astronomy.

Efforts in THz channel characterization, including measurements with Time-Domain Spectroscopy (TDS), Vector Network Analysis (VNA), and Time-Domain Channel Sounding (CS), are critical for system development. Recent hardware demonstrations, such as photonic and electronic approaches for signal generation and reception, have achieved wireless data transmission at 300 GHz and beyond. High-gain antennas with electronic beam steering have been developed to address the high path loss at these frequencies. The standardisation process continues, with IEEE and ITU-R working on

identifying additional applications and regulatory frameworks to support the deployment of THz communications globally.

A Numerical Method to Simulate THz-Wave Generation and Detection of Field-effect Transistors.

This paper presents a numerical simulation method for analysing THz-wave generation and detection in field-effect transistors (FETs), focusing on devices with a two-dimensional electron gas (2DEG). By using hydrodynamic equations based on the continuity and Euler equations derived by Dyakonov and Shur, the method improves the understanding and optimization of THz devices. Terahertz technology is crucial for applications such as remote sensing, biomedical imaging, and space communication. FET-based THz generation offers key advantages like frequency tunability, compact design, and the ability to function at room temperature. The numerical method transforms the equations into a dimensionless form using characteristic parameters and applies central-difference and forward-difference techniques for solving grid-based problems, offering flexibility for various boundary and initial conditions in either THz generation or detection scenarios.

The simulation results show how different oscillation modes behave under varying parameters, demonstrating stable oscillations and shock waves during THz generation, while resonance features are dominant in THz detection. The method aligns well with theoretical predictions, especially for resonant detection, and is versatile enough to support non-quasi-static (NQS) simulations, making it practical for future FET-based THz device modelling.

Characterization and Modelling of THz Schottky Diodes

Schottky diodes are essential components in THz frequency applications, commonly used in mixers, multipliers, and increasingly for direct detection systems. Optimising the performance of these devices requires precise characterization and modelling techniques. Modelling typically involves two approaches: circuit simulation and electromagnetic (EM) simulation. In circuit modelling, the Schottky diode's nonlinear junction is described using parameters such as series resistance, ideality factor, and junction capacitance, and is often complemented with lumped elements to form an equivalent circuit. However, at THz frequencies, where physical dimensions can affect performance, circuit models may become inaccurate. Therefore, 3D EM simulators are used to model the mechanical structure of the diode, which is then integrated with the nonlinear junction model to achieve greater accuracy in performance predictions.

Characterization techniques such as current-voltage (I-V), capacitance-voltage (C-V), and S-parameter measurements are used to determine key electrical and thermal parameters of the diode, like saturation current, series resistance, and junction capacitance. For high-frequency diodes, self-heating effects must be considered during I-V characterization, as they can impact the accuracy of the derived parameters. These characterization methods provide the necessary data for refining circuit models, ensuring that devices perform optimally in high-frequency applications. Although advanced topics such as wafer-level characterization and low-noise measurements are not covered in this discussion, the techniques outlined are crucial for improving the efficiency and performance of Schottky-based THz devices.

- Solving differential equations on Matlab.
- Simulation of transmission lines using simulink in matlab.