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# General Introduction

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In this book, we define TeraHertz (THz) waves as the part of the electromagnetic spectrum with wavelengths ranging from 3 mm down to 30 μm, that is, from 100 GHz to 10 THz covering the upper part of millimeter waves (30–300 GHz), the whole range of submillimeter waves (300 GHz to 3 THz), and the lower end of infrared waves (from 3 THz to visible light).

THz science and technology is a relatively young area both in research and applications. THz applications started from radio astronomy in the 1970s. This was based on the property that molecules and atoms can be identified by their radiation spectrum caused by their rotational and vibrational resonances. Since then the THz band has found many other potential applications because it provides unprecedented bandwidth and opportunities for completely new sensor applications. It is feasible and potential for many ground-based commercial applications as well as for Earth science applications: remote sensing of the Earth's surface and atmosphere, broadband high data-rate indoor (e.g., smart home) and short-range outdoor wireless communications, short-range, long-range, and multi-function automotive radars and ultra wide band (UWB) high-resolution radars, telematics for road traffic and transport, both between vehicles and between vehicles and infrastructures, imaging for security, medical, and other purposes.

In free space, transmission of THz waves typically requires line-of-sight between the transmitter and the receiver. The length of a terrestrial communication hop cannot be very long since the water vapor of the atmosphere is highly absorbent, ranging from not more than a few meters to hundreds of meters. On the other hand, this high attenuation enables one to limit THz-communication distances to secure distances. Depending on the relative humidity (between 25 and 100%), the atmospheric attenuation at sea level and at a temperature of 25 °C ranges from 0.3 to 1 dB km$^{-1}$ at 100 GHz and from 50 to 250 dB km$^{-1}$ at 700 GHz. At water vapor absorption peaks, for example, at 557 GHz, the attenuation may reach values over $10^4$ dB km$^{-1}$.

So far the employment of THz systems for applications has been slow because of the immature technology. The frequency range from 0.1 to 10 THz is often called the terahertz gap, because technologies for generating and detecting this radiation are much less mature than those at microwave or infrared

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frequencies. Mass production of devices at the terahertz gap frequencies and operation at room temperature have mostly not yet been realized. High-power THz waves (beyond the kilowatt levels) with microwave concepts can be generated by using vacuum tube generators, such as backward wave oscillators (BWOs) and free electron lasers (FELs), and lower THz power waves by multiplying semiconductor oscillator frequencies from the microwave or low millimeter wave bands by Schottky diode multipliers to the THz waves. On the other hand, THz radiation with photonics means may be generated by using optically pumped gas lasers or photomixers pumped with two infrared semiconductor lasers. In the latter case, the power of the THz signal is typically only microwatts. Additionally it is possible to generate THz signals of very low power values (nanowatt levels) by ultrashort bias pulsing, and this technique has been very successful in THz characterization of chemical elements.

However, recent strong advances in the development of semiconductor components and their manufacturing technology are making THz systems and applications more feasible and affordable. The terahertz gap is shrinking slowly but definitely due to strong developments from both directions, from microwaves and from photonics.

New approaches to the design and manufacturing of THz antennas are another indispensable basis for developing future applications. THz frequencies require integration of antennas with the active electronics. In most applications, electronic focusing and beam steering is needed or is at least a very valuable asset. One of the main components of a radar sensor is a beam-steering device that scans surroundings for hidden objects. Another application that requires implementation of the same technology is point-to-point wireless communication systems. If beam steering is implemented in receiving and transmitting antennas, a self-adapting mechanism can be elaborated for innovative performance of the future secure high-capacity communication links. Because the RF (radiofrequency) spectrum in the microwave region is highly populated with different communication standards, a possible frequency range for high-capacity communication systems, which require a wide bandwidth, can be found at millimeter wavelengths, for example, at 86, 150, and 250 GHz.

This book is intended to be valuable for researchers in this field, for industrialists looking to open new markets, and particularly also for teaching at university level. Therefore it concentrates on those parts of the subject which are important for these aspects. Other important scientific areas such as THz spectroscopy are not treated in detail, except for the possibility of its use in security by identification of explosive materials.