THz Energy Coupling Between Parallel-Plate Waveguides

K. S. Reichel, N. Sakoda*, R. Mendis, and D. M. Mittleman

Rice University, Department of Electrical and Computer Engineering, MS 378, Houston, TX 77251-1892, USA
****Kobelco, Kobe Steel Group, Shinko Building, 10-26, Wakinohamacho 2-chome, Chuo-ku, Kobe, Hyogo 651-8585, Japan***

Phone: (713) 348-5452 Fax: (713) 348-5686
E-mail: ***daniel@rice.edu***

Abstract: We experimentally study THz energy coupling between an array of identical parallel-plate waveguides located in close proximity, with their unconfined sides facing each other. We observe that the coupling increases as the plate separation increases.

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1. Introduction and Background

Evanescent wave coupling in waveguides and waveguide arrays has been well studied in the visible and infrared, and is an important concept underlying key technologies such as optical fibers, which exhibit coupling when an evanescent field overlaps into the mode profile of an adjacent fiber [1]. Although this concept is very well developed in optics, it has only barely been studied in the terahertz (THz) range, between two adjacent wire waveguides [2]. With broadband pulses and coherent detection of the terahertz field, extending this well-understood phenomenon to another region of electromagnetic spectrum may enable interesting new applications in terahertz wave-guiding. Starting from the well-established physics of evanescent waveguide coupling in optics, we shift into the THz band with an opportunity to shed new light on waveguide coupling, in the limit of very broadband single-cycle pulses.

2. Experimental Setup

To explore waveguide coupling in the THz regime, we chose finite-width parallel-plate waveguides (PPWGs) as the basis for this experiment. PPWGs offer low losses and negligible dispersion, but could exhibit diffractive energy leakage when the plates are narrow and consist of a relatively large plate separation [3]. This suggests that an array of narrow PPWGs is a convenient platform for studying THz energy coupling between waveguides. In optics, if the evanescent wave from a waveguide overlaps into an adjacent waveguide, energy will couple into the adjacent waveguide, causing radiation to propagate along both [4]. To show this experimentally in THz, we constructed PPWG arrays of a fixed waveguide width of 2mm, gap between waveguides of 2mm, and propagation length of 10cm. The arrays consisted of two solid aluminum pieces that were machined to have a series of fins, one set comprising the top plate of each PPWG and the other set comprising the bottom plate of each. This is illustrated in Figure 1. These were assembled at several plate separations (b = 1, 2, 3, and 4mm) by precision micrometer mounts.

To measure coupling across the array, the field emerging from the output of the waveguide array was obtained using a commercial THz time-domain spectroscopy (THz-TDS) system using fiber-coupled photoconductive antennas. Using an aperture on the input, we ensure that the incident THz beam excites only the central waveguide of the array. A total of 57 data points at 0.5mm step intervals were taken along the x-direction of array, shown by the dashed line in Figure 1. At each data point, frequency intensities were obtained by Fourier-transforming the gathered time domain signals. We used a 0.8mm diameter aperture in front of the receiver to improve the spatial resolution. The beam is vertically polarized to excite the fundamental transverse-electromagnetic (TEM) mode [5].

3. Results

We have found the coupling across the array to be more apparent for larger plate separations. In finite-width PPWGs, energy confinement decreases as plate separation increases [3]. Thus when the energy is less confined, there will be more evanescent leakage from the sides of the waveguide which can overlap into adjacent waveguides. For a single waveguide, we would expect the strength to roughly exponentially decrease away from the waveguide. If coupling occurs, we should see increased intensity at positions further away from the central waveguide.

Figure 2 shows a map of frequency intensities across the entire waveguide array for the examined four plate separations. For a small separation of 1mm, we see little to no sign of coupling into the most adjacent waveguides. Separations of 2, 3, and 4mm clearly show coupling into adjacent waveguides, the strength of which increasing as the separation increases. For the 3mm separation we can to see the second most adjacent waveguides excited, and for the 4mm separation we can see the third set excited. The maximum intensity for each plot decreases as plate separation increases, showing that more energy spreads out across the array with greater plate separation. This figure also clearly shows only a small portion of frequencies (~100Ghz-150Ghz) leak out of the excited waveguide to strongly couple into adjacent waveguides. Any asymmetries in the plots come from possible misalignment of the waveguides.

Here we have demonstrated mutual energy coupling across a PPWG array in the THz band. At a small plate separation of 1mm, energy is strongly confined in the excited waveguide leading to low coupling. At increased plate separations, energy is less confined so there is more pronounced coupling into adjacent waveguides.

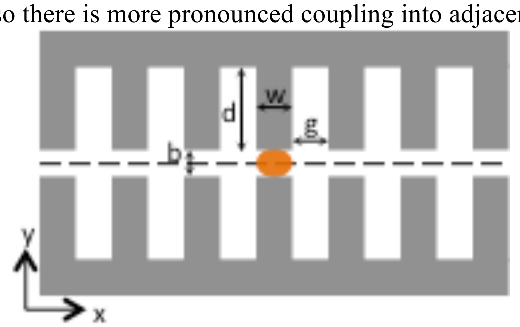

Fig. 1 Design of PPWG array as two identical aluminum pieces with many fins that each acts as an individual finite-width PPWG. The THz beam excites only the central waveguide. Dimensions: plate width w=2mm; gap between g=2mm; depth between d=18mm; variable plate separation b=1, 2, 3, 4mm. The waveguide array extends to a length of 10cm in the propagation direction. The field was measured along the dashed line at the output face, at an interval of 0.5mm.

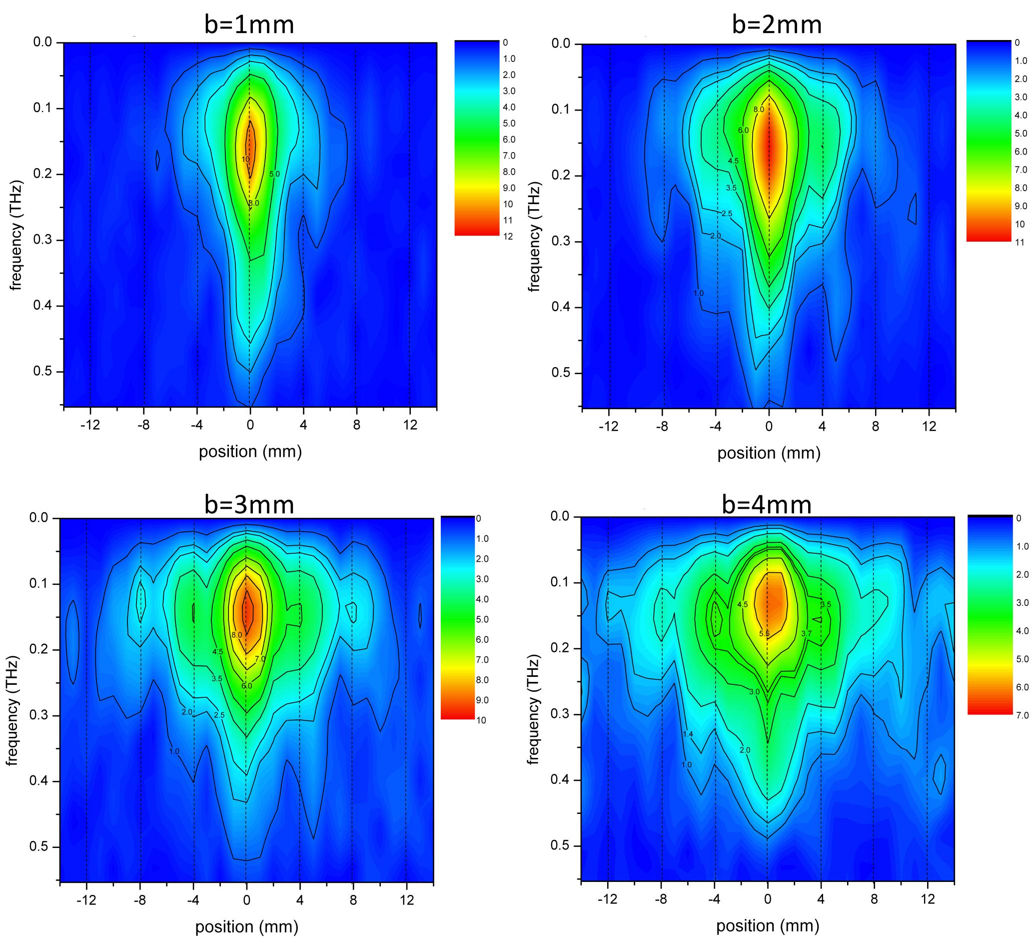

Fig 2. Frequency intensity maps across the PPWG array, at plate separations b=1,2,3,4mm. Dashed lines indicate center point of waveguides.

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