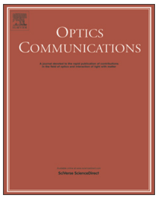
Optics Communications 356 (2015) 431–434

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom



On the Voltage Standing Wave Ratio of barriers

H. Aichmann [a], G. Nimtz [b,*], P. Bruney [c]

[a] KWF Schwalheim, Zur Bitz 1, 61231 Bad Nauheim, Germany
[b] Physikalisches Institut, Universität zu Köln, Zülpicherstrasse,Köln, Germany
[c] Plane Concepts Inc., Silver Spring, MD 20904, USA

ARTICLE INFO

Article history:
Received 15 June 2015
Accepted 19 July 2015

Keywords:
Voltage Standing Wave Ratio of inductive and capacitive barriers
Superluminal group velocity
Universal tunneling time

PACS:
73.40.Gk
03.65.Xp
42.70.Qs

ABSTRACT

The reflection and thus the Voltage Standing Wave Ratio (VSWR) of barriers depend on several barrier properties. Scattering may take place at frequencies below or above the barrier height and may depend on the barrier's capacitive or inductive quality. At frequencies below the barrier height, faster than light (FTL) tunneled signals were observed. This must also occur in optical tunneling couplers presently applied in fiber communications. The tests confirmed the assumption that tunneling waves are virtual, the propagation is FTL, yet causality is nevertheless preserved. It is further noted that FTL propagation with preserved causality has also been measured within the near fields of antennas.

1. Introduction

The VSWR of obstacles (barriers) are usually measured at frequencies below the barrier height. At lower frequencies the barriers act as tunnels. The optical equivalents are evanescent modes. Tunneling has been conjectured to involve virtual particles and waves [1–4]. Evanescent modes are described by imaginary wavenumbers. They are not measurable inside a barrier. In order to make them evident, either the energy of the virtual particle or wave has to be increased up to the barrier's height or the barrier has to be reduced [5]. Of course, in both procedures the virtual character of the particles or waves is lost. Previous experimental tunneling studies with photons and phonons indicated that the virtual waves or particles are non-local and thus spread instantaneously; the barrier traversal time is zero [4]. This strange behavior is opposite to that at frequencies above the barrier height. Zero time within the barrier and the interaction time at the barrier front yield an overall superluminal velocity (see, e.g., Refs. [6–8]). However, a superluminal physical signal velocity does not necessarily violate causality [9,10]; effect does not precede cause.

In this study we investigated the propagation of microwaves by inductive posts in undersized waveguides and in dielectric quarter wavelength lattices. The impedances of barriers were obtained by measuring the Voltage Standing Wave Ratio as a function of frequency.

Evanescent modes are expected in optics in the case of total reflection or in internal frustrated total reflection where, for example, two double prisms or two fiber cables in optical communications are coupled. They are field solutions of the Helmholtz equation, which is mathematically identical with the Schrödinger equation.

2. Experiments

The optical barriers tested here are shown in Fig. 1.

According to quantum mechanics, a particle with mass m observed in the exponential tail of the tunneling probability must be localized within a distance in the order of $\Delta z \approx 1/\kappa = 1/ik$, where k and κ are the real and imaginary wave numbers, respectively. Hence, its momentum must be uncertain by $\Delta p > \hbar/\Delta z \approx \hbar\kappa = [2m(U_0 - W_{\mathrm{kin}})]^{1/2}$, where U_0 is the barrier potential. The particle of energy W_{kin} can thus be located in the nonclassical region only if it is given an energy $U_0 - W_{\mathrm{kin}}$ sufficient to raise it into the classically allowed region [5]. In analogy this holds for electromagnetic waves as is shown in this study. For instance, in a slotted waveguide, a standing wave can be probed through a tiny slot as long as the frequency is higher than the cut-off frequency of the waveguide. Evanescent modes with their imaginary wave numbers are not expected to be detectable below the cut-off

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* Corresponding author.
E-mail address: G.Nimtz@uni-koeln.de (G. Nimtz).

http://dx.doi.org/10.1016/j.optcom.2015.07.089

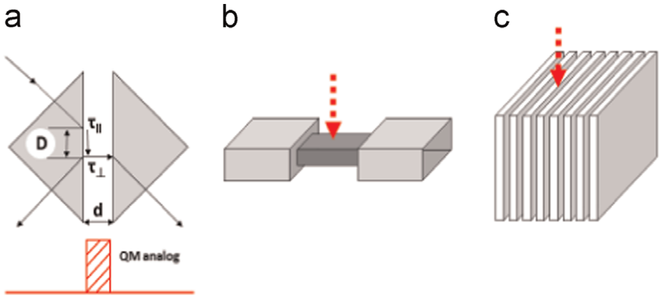

Fig. 1. Three barrier types: (a) Double prisms. Distances D and d equal the Goos-Hänchen shift and the potential barrier length respectively. $\tau_{\parallel}$ and $\tau_{\perp}$ are the propagation times parallel and normal to the prisms, respectively. (b) Undersized waveguide with a barrier length of 40 mm. The frequency cut-off at a low frequency of 9.49 GHz is given by the narrow Ku-band waveguide width (1.8 mm), whereas the larger waveguide X-band has a cut-off frequency of 6.49 GHz (width 22.86 mm). (c) Quarter wave length dielectric lattice. Lattice of 8 quarter wavelength Perspex layers (n=1.6) was investigated. Red arrows indicate the locations of the inserted inductive post. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1

For comparison: reflection time (which equals transmission time for symmetric barriers) at various barriers (mirrors) and for electric and elastic fields. The studied frequency range is 1 kHz to 427 THz. τ is the measured barrier traversal time, and T the empirical universal time, $T=1/\nu$, which equals the oscillation time of the tunneling wave [4,20]. A theoretical analysis and fundamental base of the universal tunneling time is presented in Ref. [21]. Incidentally, the measured near zone traversal time displays a similar universal time behavior Ref. [25].

Tunneling barriers	Reference	τ	$T=1/\nu$
Frustrated total reflection	[4]	117 ps	120 ps
Double prisms	[13]	8 ps	100 ps
Photonic lattice	[14]	2.13 fs	2.34 fs
Photonic lattice	[15]	2.7 fs	2.7 fs
Undersized waveguide	[16]	130 ps	115 ps
Electron field-emission tunneling	[17]	7 fs	6 fs
Electron ionization tunneling	[18]	< 1 as	? as
Acoustic (phonon) tunneling	[19]	0.8 μs	1 μs
Acoustic (phonon) tunneling	[19]	0.9 ms	1 ms

frequency of the waveguide. In general, the dielectric barrier in optics has to be matched to the dielectric medium of the real photon state. There, the potential U_0 corresponds to n_2, where n_2 is the refractive index of the dielectric barrier. In this study the match was achieved by a so-called inductive post that was used as field probe as well [11].

The resonator of a LASER is usually designed with metallic or dielectric mirrors. Metallic mirrors are lossy, whereas mirrors based on evanescent (i.e. tunneling) modes are elastic barriers. The latter property is the reason for their application in high power LASER systems. In special cases, e.g. at microwave frequencies, high pass filters or so called frequency cut-off waveguides may be applied as mirrors. The mirror barriers are sketched in Fig. 1b and c. The smaller reflectivity and the higher losses of metallic mirrors at wavelengths below 1 mm present a handicap in the case of high power LASERs [12].

In this study we compare the complex reflectivity and the transmission behavior of two mirrors at microwave frequencies. The reflectivity of metals is caused by free carriers, whereas that of dielectric mirrors is based on Bragg reflection. In high pass filters, waves have an imaginary wave number below their cut-off frequency like dielectric mirrors have in their forbidden band gap.

Dielectric mirrors are usually 1-dimensional lattice structures as shown in Fig. 1c, where the lattice is built by quarter wavelength layers that differ periodically in their refractive index. A frequency cut-off waveguide is sketched in Fig. 1b. Waves with frequencies below the cut-off value of the narrow guide become evanescent; i.e. the wave number is imaginary and thus the wave propagation vanishes and there is no real wave propagation. The cut-off frequency (i.e. the dielectric barrier height) is determined by the geometry of the guide. For example, waves in H_{10}-mode become evanescent if their wavelength exceeds twice the waveguide width.

The phase shift of the reflected beam at the mirror surface was calculated from the measured geometric shift of the Voltage Standing Wave Ratio (VSWR). The shift of the reflected EM waves is π at a surface with a higher refractive index or at a metal surface. The π step also takes place for quantum mechanical wave functions at a potential barrier.

Quarter wavelength lattices, high pass mirrors, and double prisms exhibit a universal reflection time and virtual transmission in electromagnetic and elastic fields as demonstrated in Table 1.

The experimental set up is shown in Fig. 2. The standing wave patterns of the reflection were measured at microwave frequencies near 10 GHz, i.e. at wavelengths of about 30 mm (this frequency range is called the microwave X-band). Barriers of the mechanical smaller Ku-band waveguide were also studied; they have a cut-off frequency of 9.49 GHz (the corresponding wavelength is 31.6 mm). We measured the VSWR with a slotted X-band line above the cut-off frequency of Ku-band. In addition, the absolute value of the reflectivity R, was measured with a directional coupler/power meter combination for comparison.

The dielectric potential shift of both the undersized waveguide and the dielectric lattice were obtained by using an inductive post [22]. The post was inserted into the waveguide as shown in Fig. 1b and c. It acts as an inductance depending on its geometrical

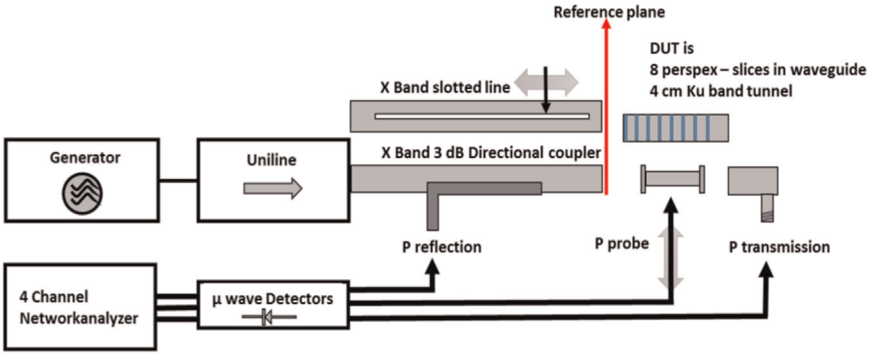

Fig. 2. The set up to measure transmission, reflection, probe power, VSWR and phase with an X-band waveguide slotted line, and alternatively to measure return loss with a directional coupler. Measurement positions: in front, inside, and behind the barrier. Frequency: 8.0–10 GHz; probe 0.4 mm ϕ; maximum probe length 8 mm; hole diameter 1 mm. Devices Under Test (DUT's) are the different barriers.