$V_p \times V_g = c^2$ is like a weighted delta function.

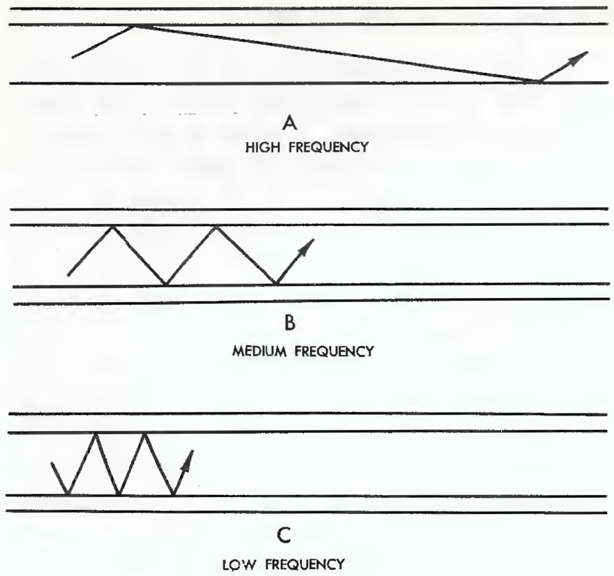

Figure 11–21. Angle at which Fields Cross Waveguide Varies with Frequency

zig-zag arrow at the velocity of light. But because of the long path, the wavefront actually travels very slowly along the waveguide. In Figure 11–21A the frequency is higher, and the wavefront or the group of waves actually travels a given distance in less time than those at C.

The axial velocity of a wavefront or a group of waves is called the *group velocity*. The relationship of the group velocity to diagonal velocity causes an unusual phenomenon. The velocity of propagation appears to be greater than the speed of light. As you can see in Figure 11–22, during a given time, a wavefront will move from point

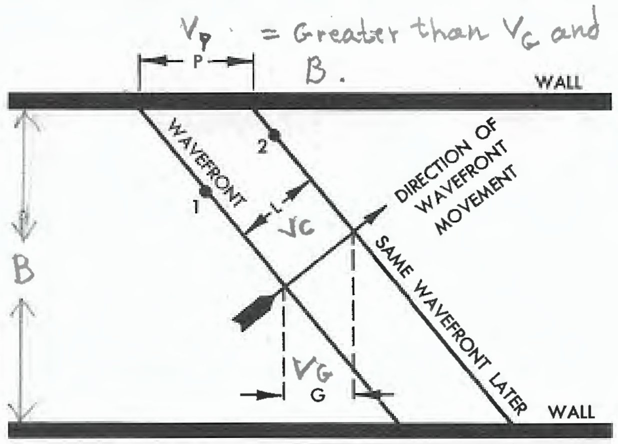

Figure 11–22. Relation of Phase, Group, and Wavefront Velocity

one to point two, or a distance L at the velocity of light (V_c). Due to this diagonal movement (direction of the arrow), the wavefront has actually moved down the guide only the distance G, which is necessarily a lower velocity. This is called group velocity (V_g).

But if an instrument were used to detect the two positions at the wall, they would be the distance P apart. This is greater than the distance L or G. The movement of the contact point between the wave and the wall is at a greater velocity. Since the phase of the r-f has changed over the distance P, this velocity is called the phase velocity (V_p). The mathematical relationship between the three velocities is stated by the equation,

$$V_c = \sqrt{V_p V_g}$$

where

V_c = Velocity of light = 3×10^8 meters/second

V_p = Phase Velocity

V_g = Group Velocity.

And: $V_g = \frac{V_c^2}{V_p}$

This equation indicates that it is possible for the phase velocity to be greater than the velocity of light. As the frequency decreases, the angle of crossing is more of a right angle. In this condition the phase velocity increases. For measuring standing waves in a waveguide, it is the phase velocity which determines the distance between voltage maximum and minimum. For this reason, the wavelength measured in the guide will actually be greater than the wavelength in free space. or, $\lambda_G = V_p \cdot t$. (t = constant)

From a practical standpoint, the different velocities are related in the following manner: If the radio frequency being propagated is sine wave modulated, the modulation envelope will move forward through the waveguide at the group velocity, while the individual cycles of r-f energy will move forward through the modulation envelope at the phase velocity. If the modulation is a square wave, as in radar transmissions, again the square wave will travel at group velocity, while the r-f waveshape will move forward within the envelope.

Since the standing wave measuring equipment is affected by each r-f cycle, the wavelength will be governed by the rapid movement of the changes in r-f voltage. Since intelligence is conveyed by the modulation, the transfer of intelligence through the waveguide will be slower than

The phase vel., V_p, determines directly λ_G since: $\lambda_G = V_p \cdot t$. Then $\lambda_G \propto V_p$.

or $\lambda_G \cdot f = V_p$

the speed of light, as is the case in other types of r-f lines.

Because of the way the fields are assumed to move across the waveguide, it is possible to establish a number of trigonometric relationships between certain factors. As shown in Figure 11–23, the angle that the wavefront makes with the wall (angle θ) is related to the wavelength and dimension of the guide and is,

$$\text{Cos } \theta = \frac{\lambda}{2B}$$

where λ is the wavelength in free space of the signal in the guide, and B is the inside wide dimension of the guide. The group velocity (V_g) is related to the velocity of light (V_c) as follows:

If $\lambda = 2B$; Cutoff is reached.

$$\frac{V_g}{V_c} = \sin \theta = \sqrt{1 - \left(\frac{\lambda}{2B}\right)^2}.$$

NOTE: $\sin \theta^2 + \cos \theta^2 = 1$

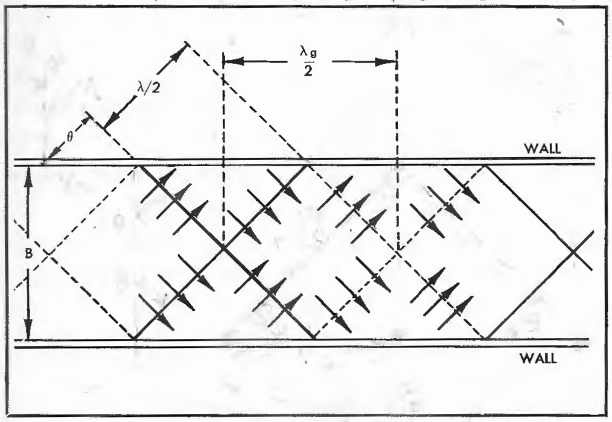

Figure 11–23. Trigonometric Relations Exist between Factors Indicated

Further, since it is possible to measure the wavelength in the guide (λg), the wavelength in space is equal to,

At cutoff; $\lambda_G = \infty$, $V_p = \infty$

$$\frac{\lambda g}{\lambda} = \frac{1}{\sin \theta} = \frac{1}{\sqrt{1 - \left(\frac{\lambda}{2B}\right)^2}}.$$

Solving this for λ, the equation becomes,

$$\lambda = \frac{2B\lambda g}{\sqrt{\lambda g^2 + 4B^2}}$$

After measuring the wavelength and the inside dimension of the waveguide, it is possible to calculate most other quantities associated with the waveguide (Figure 11–23).

$$\frac{\lambda_c}{\lambda_G} = \sin \theta = \frac{V_G}{V_c}$$

OR: λ electron (Compton)

Numbering System of the Modes

The normal configuration of the electromagnetic field within a waveguide is called the *dominant* mode of operation. The mode developed for the rectangular waveguide, as was explained before, is the dominant mode of operation. The dominant mode for the circular waveguide was also shown in Figure 11–16. A wide variety of higher modes is possible in either type of waveguide. The higher modes in the rectangular waveguide are seldom used in radar, but some of the higher modes in the circular waveguide are useful.

For ease in identifying modes, any field configuration can be classified as either a transverse electric mode or a transverse magnetic mode. These modes are abbreviated TE or TM, respectively.

In a transverse electric mode, all parts of the electric field are perpendicular to the length of the guide and no E-line is parallel to the direction of propagation.

In a transverse magnetic mode the plane of the H-field is perpendicular to the length of the waveguide. No H-line is parallel to direction of propagation.

It is interesting to note from these definitions that the wavefront in free space or in a coaxial line is a TEM mode, since both fields are perpendicular to the direction of propagation. This mode cannot exist in a waveguide.

Particle waves act like waveguide parameters for electr waves.

In addition to the letters TE or TM, subscript numbers are used to complete the description of

See figs 11-14

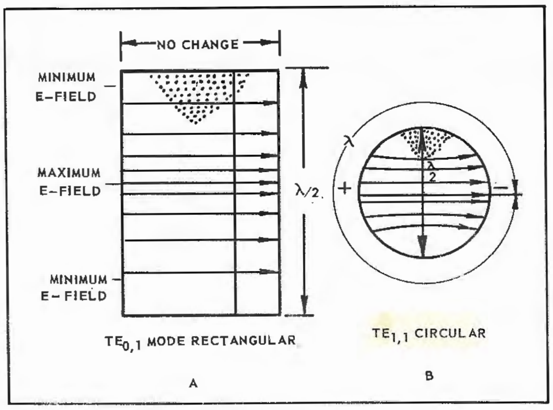

Figure 11–24. How to Count Wavelengths for Numbering Modes

the field pattern. In describing field configurations in rectangular guides, the first small number indicates the number of half-wave patterns of the transverse lines that exist along the short dimension of the guide through the center of the cross section. The second small number indicates the number of transverse half-wave patterns that exist along the long dimension of the guide through the center of the cross section. For circular waveguides the first number indicates the number of full waves of the transverse field encountered around the circumference of the guide. The second number indicates the number of half-wave patterns that exist across the diameter.

Counting Wavelengths for Measuring Modes

In the rectangular mode illustrated in Figure 11–24A, note that all the electric lines are perpendicular to the direction of movement. This makes it a TE mode. In the direction across the narrow dimension of the guide parallel to the E-line, the intensity change is zero. Across the guide along the wide dimension, the E-field varies from zero at the top through maximum at the center to zero on the bottom. Since this is one-half wave, the second subscript is one. Thus, the complete description of this mode is $TE_{0,1}$.

In the circular waveguide in Figure 11–24B, the E-field is transverse and the letters which describe it are TE. Moving around the circumference starting at the top, the fields go from zero, through maximum positive (tail of arrows), through zero, through maximum negative (head of arrows), to zero. This is one full wave, so the number is one. Going through the diameter, the start is from zero at the top wall, through maximum in the center to zero at the bottom, one-half wave. The second subscript is one. The complete designation for the circular mode becomes $TE_{1,1}$.

Several circular and rectangular modes are possible. On each diagram illustrated in Figure 11–25 you can verify the numbering system. Note that the magnetic and electric fields are maximum in intensity in the same area. This indicates that the current and voltage are in phase. This is the condition which exists when there are no reflections to cause standing waves. In previous examples in which fields were developed, the fields were out of phase because of a short circuit at the end of the two-wire line.

INTRODUCING FIELDS INTO A WAVEGUIDE

A waveguide, as was explained before, is a single conductor. Therefore, it does not have the two connections which ordinary r-f lines have, and it is necessary to use special devices to put energy into a waveguide at one end and to remove it from the other. In a waveguide, as with many other electrical networks, reciprocity

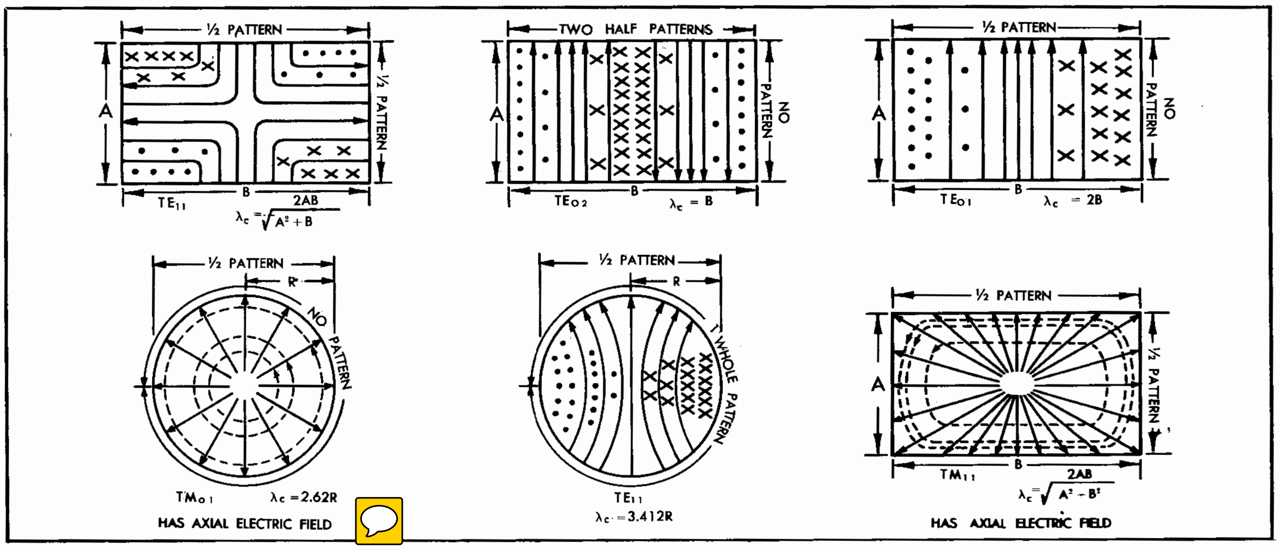

Figure 11–25. Various Modes in Waveguides

History

Natural units began in 1881, when George Johnstone Stoney, noting that electric charge is quantized, derived units of length, time, and mass, now named Stoney units in his honor, by normalizing *G*, *c*, and the electron charge, *e*, to 1.[24] In 1898, Max Planck discovered that action is quantized, and published the result in a paper presented to the Prussian Academy of Sciences in May 1899.[25][26] At the end of the paper, Planck introduced, as a consequence of his discovery, the base units later named in his honor. The Planck units are based on the quantum of action, now usually known as Planck's constant. Planck called the constant *b* in his paper, though *h* is now common. Planck underlined the universality of the new unit system, writing:

> *...ihre Bedeutung für alle Zeiten und für alle, auch außerirdische und außermenschliche Kulturen notwendig behalten und welche daher als »natürliche Maßeinheiten« bezeichnet werden können...*
>
> ...These necessarily retain their meaning for all times and for all civilizations, even extraterrestrial and non-human ones, and can therefore be designated as "natural units"...

Planck considered only the units based on the universal constants G, $\hbar$, c, and k_B to arrive at natural units for length, time, mass, and temperature.[26] Planck did not adopt any electromagnetic units. However, since the non-rationalized gravitational constant, G, is set to 1, a natural extension of Planck units to a unit of electric charge is to also set the non-rationalized Coulomb constant, k_e, to 1 as well.[27] Another convention is to use the elementary charge as the basic unit of electric charge in Planck system.[28] Such system is convenient for black hole physics. The two conventions for unit charge differ by a factor of the square root of the fine-structure constant. Planck's paper also gave numerical values for the base units that were close to modern values.

Big Changes. A recently published journal article shows gravity does not act via particle mass but via electromagnetic energy circulating within particles. The article gives an expression for G based on an electron model of two quantum loops. It shows the classical dimensions of G are in error by c^4, which has a major consequence for the numerical value of the Planck scale. The article shows the radial electric field and a circumferential metric strain, the origin of gravity, are equal at the Strong Force scale within the electron thus satisfying Planck's force equality criteria. But the value of the scale changes by c^4, about 8.077 x 10^41 in the units used to measure G. This means although Planck's notion was correct the scale actually relates to the electron, not some far smaller scale. Ref: Oakley WS. Analyzing the large number problem and Newton's G via a relativistic quantum loop model of the electron. Int J Sci Rep 2015; 1(4):201-5

Torus

List of physical equations

Physical quantities that have different dimensions (such as time and length) cannot be equated even if they are numerically equal (1 second is not the same as 1 metre). In theoretical physics, however, this scruple can be set aside, by a process called nondimensionalization. Table 4 shows how the use of Planck units simplifies many fundamental equations of physics, because this gives each of the five