where α has units of radians and is shown in Figure 4.10b and Figure 4.10c. The parameter v is convenient because it allows ϕ to be expressed in a convenient form.

$$\phi = \frac{\pi}{2} v^2 \tag{4.57}$$

From the above equations it is clear that the phase difference between a direct line-of-sight path and diffracted path is a function of height and position of the obstruction, as well as the transmitter and receiver location.

In practical diffraction problems, it is advantageous to reduce all heights by a constant, so that the geometry is simplified without changing the values of the angles. This procedure is shown in Figure 4.10c.

The concept of diffraction loss as a function of the path difference around an obstruction is explained by Fresnel zones. Fresnel zones represent successive regions where secondary waves have a path length from the transmitter to receiver which are $n\lambda/2$ greater than the total path length of a line-of-sight path. Figure 4.11 demonstrates a transparent plane located between a transmitter and receiver. The concentric circles on the plane represent the loci of the origins of secondary wavelets which propagate to the receiver such that the total path length increases by $\lambda/2$ for successive circles. These circles are called Fresnel zones. The successive Fresnel zones have the effect of alternately providing constructive and destructive interference to the total received signal. The radius of the *n*th Fresnel zone circle is denoted by r_n and can be expressed in terms of n, λ, d_1, and d_2 by

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \tag{4.58}$$

This approximation is valid for $d_1, d_2 \gg r_n$.

The excess total path length traversed by a ray passing through each circle is $n\lambda/2$, where n is an integer. Thus, the path traveling through the smallest circle corresponding to $n = 1$ in Figure 4.11 will have an excess path length of $\lambda/2$ as compared to a line-of-sight path, and circles corresponding to $n = 2, 3,$ etc. will have an excess path length of λ, $3\lambda/2$, etc. The radii of the concentric circles depend on the location of the plane. The Fresnel zones of Figure 4.11 will have maximum radii if the plane is midway between the transmitter and receiver, and the radii become smaller when the plane is moved toward either the transmitter or the receiver. This effect illustrates how shadowing is sensitive to the frequency as well as the location of obstructions with relation to the transmitter or receiver.

In mobile communication systems, diffraction loss occurs from the blockage of secondary waves such that only a portion of the energy is diffracted around an obstacle. That is, an obstruction causes a blockage of energy from some of the Fresnel zones, thus allowing only some of the transmitted energy to reach the receiver. Depending on the geometry of the obstruction, the received energy will be a vector sum of the energy contributions from all unobstructed Fresnel zones.