1) Describe the free space propagation model. Derive the equation for free-space path loss

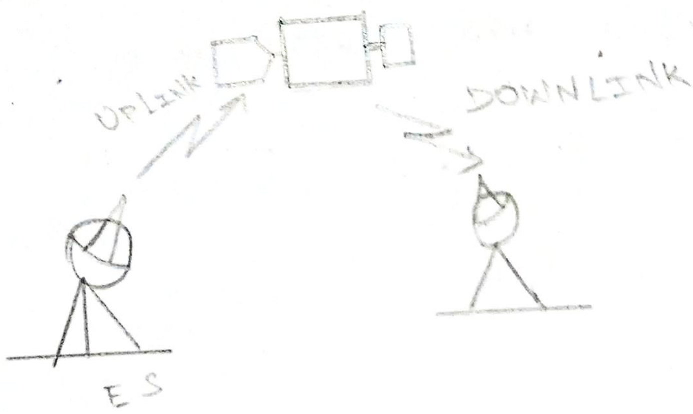
Free space Propagation :-

It is the basic model used to predict the received signal strength when the Tx and Rx have a clear line of sight path between them,

(ie) No obstacles between them

Ex:-

Satellite communication, Microwave Radio link



(2)

Analysis

Free Space Loss:

(*) consider a sphere of radius 'd'.

(*) If the Tx antenna radiates isotrophically, the power density is $\frac{P_T'}{4\pi d^2}$

(*) Then the received power is

$$P_r(d) = \frac{P_t}{4\pi d^2} \cdot A_e \quad \text{—— (1)}$$

$A_e \rightarrow$ effective area of Rx antenna

$$A_e = \frac{G_r \lambda^2}{4\pi} \quad \text{—— (2)}$$

(*) If the Tx antenna is not isotrophic, then

$$P_r(d) = P_t \cdot G_t \cdot G_r \cdot \frac{\lambda^2}{(4\pi d)^2}$$

$$P_r(d) = P_t \cdot G_t \cdot G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

The received power $P_r(d)$ as a function of the distance 'd' in free space is known as Friis law

$EIRP = P_t G_t$

Path loss (P_L) :-

→ It represents the signal attenuation in decibels

→ Path loss with gain of antenna:

$$P_L(dB) = 10 \log \left(\frac{P_t}{P_r}\right)$$

$$= 10 \log \left(\frac{\cancel{P_t} \times (4\pi d)^2 L}{\cancel{P_t}\, G_t G_r \lambda^2}\right)$$

$$P_L(dB) = -10 \log \left(\frac{G_t G_r \lambda^2}{(4\pi d)^2}\right)$$

For unity gain (i.e) $G_t = G_r = 1$

$$P_L(dB) = -10 \log \left(\frac{\lambda}{4\pi d}\right)^2$$

Franunhofer distance :-

→ The free space model is ~~valid~~

Valid only for far field or Fraunhofer region.

→ The Fraunhofer distance is given as,

$$d_f = \frac{2D^2}{\lambda}$$

where,

D → the largest linear dimension of the the antenna

Free Space Loss factor:-

$$\frac{1}{\left(\frac{\lambda}{4\pi d}\right)^2}$$

$$\left(\frac{4\pi d}{\lambda}\right)^2 \Rightarrow \left[4\pi d\left(f/c\right)\right]^2$$

↳ Attenuation in free space increases with frequency

Free Space Model:-

(*) The received power is given by the ~~Fries~~ Free space equation:

$$P_r(d) = \frac{P_t G_t G_r}{L}\left(\frac{\lambda}{4\pi d}\right)^2 \quad — (3)$$

G_t → transmitter antenna gain

G_r → Receiver antenna gain

d → TX–RX separation distance in meter

L → Loss factor

λ → wavelength in Mtz

(*) The gain of the receiver antenna is given as

$$G_r = \frac{4\pi A_e}{\lambda^2}$$

(*) For an isotrophic antenna,

The conditions:

$$d_t \gg D$$

$$d_t \ll \lambda$$

$$d_o \geq d_f$$

where,

$d_o \rightarrow$ reference distance

↳ The received power in free space at $d \geq d_o$

$$P_r(d) = P_r(d_o)\left(\frac{d_o}{d}\right)^2$$

↳ The large dynamic range of P_r is represented in dBm (or) dBW

↳ For indoor : $d_o \simeq 1m$

For outdoor : $d_o \simeq 100m$ to $1km$

2) Explain the three basic radio wave propagation mechanism : reflection, diffraction and scattering

The three Basic Propagation mechanisms

Reflection, diffraction, and scattering are the three basic Propagation such mechanism are briefly explained in this section and propagation models which describe these mechanisms are discussed subsequently in the chapter

Received power is generally the most important parameter predicted by large scale propagation models based of the physics of reflection, scattering and diffraction. Small-scale fading and multipath propagation may also be described by the physics of these three basic propagation mechanisms

(*) Reflection occurs when a propagating electromagnetic waves impinges upon an object which that has large dimensions when compared to the wave length of propagating wave. Reflection occurs from the surface of earth & buildings & walls

(*) Deflection/Diffraction occurs when the radio path between the transmitter & receiver is obstructed by a surface that has sharp irregularities

(*) Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength & where the no. of obstacles per unit volume is large

Reflection:-

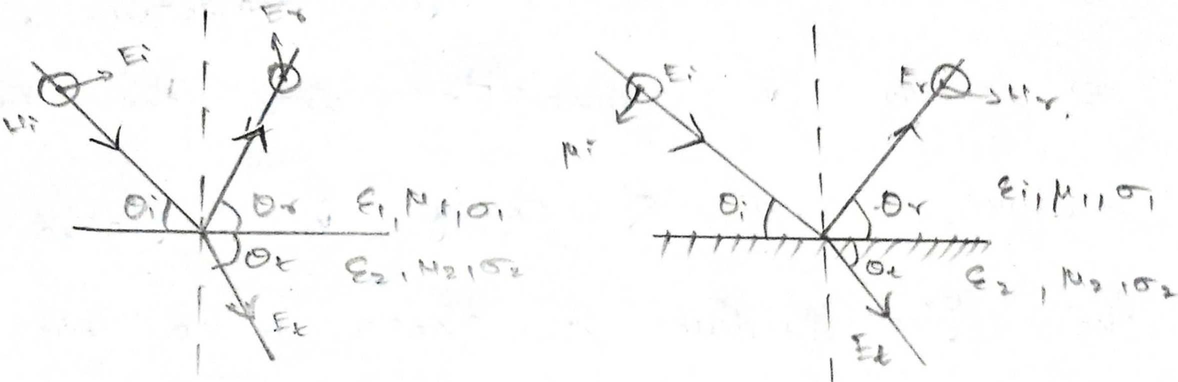
(*) When Radio wave propagating in one medium impinges upon another medium having different electrical properties the wave is partially reflected & partially transmitted

(*) If the phenomenon of plane wave is incident on a perfect dielectric, part of energy is transmitted into the second medium & part of energy is reflected back into the first medium & there is no loss of energy in absorption

(*) If the second medium of a perfect conductor, then all incident energy is reflected back to first medium without loss of energy

(*) The electric field intensity of the reflected & transmitted waves may be related to the incident wave in the medium of origin through the fresnel Reflection coefficient (Γ)

(i) The reflection coefficient is a function of material properties & generally depends on the wave polarization, angle of incidence & frequency of propagation wave



a) E-field in the plane of incidence

b) E-field normal to the plane of incidence

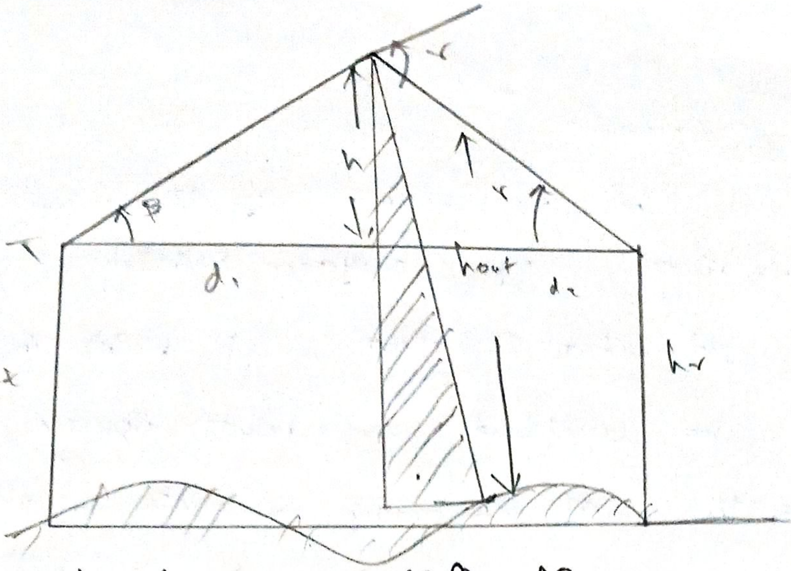
Diffraction:-

The phenomenon of diffraction is explained by Huggen's Principle

It states that all points in a wavefront can be considered as point sources for the production of secondary wavelets & that ~~beg~~ these wavelets combine to produce a new wavefront in the direction of propagation

Diffraction is caused by the field strength of a diffracted wave & the shadowed region is the vector sum of electric field components of all the secondary wavelets in the space around the obstacle

Fresnel zone Geometry:-



(a) knife edge diffraction geometry the point T Txer & R → Rxer with infinite knife edge obstruction blocking the line of sight path

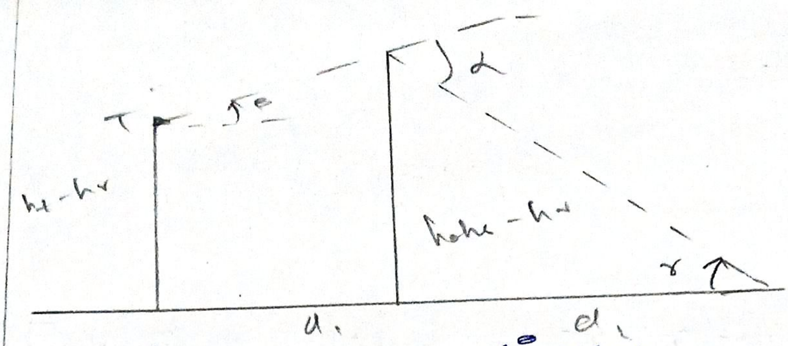
(b) Let an obstructing screen of effective height 'h' with infinite width the placed b/w them at distance 'd' from the transmitter & d_2 from the receiver

(c) Assume $h \ll d_1, d_2$

$h \gg \lambda$

(*) The difference between direct path & the diffractive path is called Excess path length (Δ). is $\Delta = \frac{h^2}{2} \frac{(d_1+d_2)}{d_1 d_2}$

(11)



from above diagram

$$\alpha \simeq \left(\frac{d_1+d_2}{d_1 d_2}\right)$$

Fresnels - kirchoff diffraction parameter 'v' is

$$v = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2d_1d_2}{\lambda(d_1+d_2)}}$$

$$v^2 = h^2 \cdot 2\left(\frac{d_1+d_2}{\lambda d_1 d_2}\right) \Rightarrow h^2 = v^2 \frac{\lambda d_1 d_2}{2(d_1+d_2)}$$

$$\phi = \pi/2 \; v^2$$

(*) 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 a path length from the transmitter to the receiver which are $n\lambda/2$ greater than the total path lengths of a line of sight path

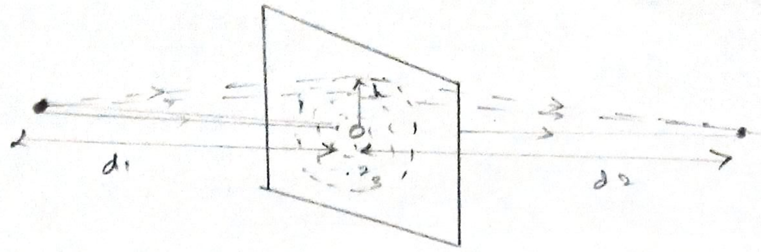


Fig concentric circles which define the boundaries of successive Fresnel zones

(*) The concentric circles on the plane represent the loci of the origin of secondary wavelets which propagate to the receiver such that the total path length increased by $\lambda/2$ for successive circles & here circles are called Fresnel zones

Radius of the n^{th} Fresnel zone circle is denoted by r_n & is given as,

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

This is valid for $d_1, d_2 >> r_n$

The excess total path length traversed by a ray passing through each circle $n\lambda/2$

(*) path travelling through smallest circle $(n=1)$ will have excess path length of $\lambda/2$ compared to LO's path

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Radius of the nth Fresnel zone circle is denoted by r_n & is given as

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

, the excess total path length traversal passing through each circle is $n\lambda/2$

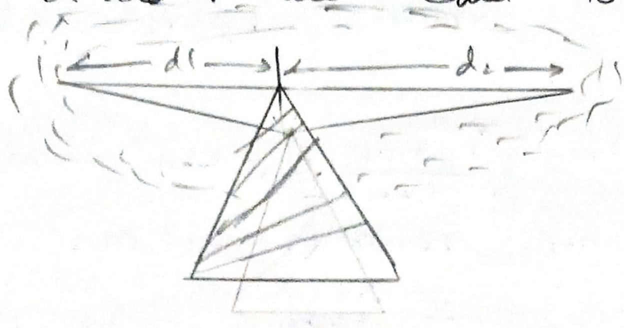
For n = 2, 3 etc have excess path length of λ, $3\lambda/2$, etc....

(c) There are three cases or cases for illustration of Fresnel zone for different knife edge diffraction scenarios

case (i) α & γ are positive, since 'h' is positive

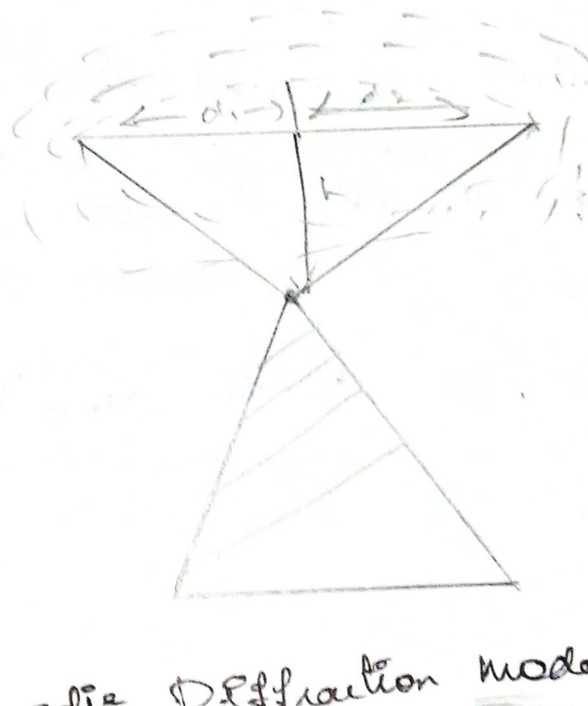
Case (ii)

α and ν are equal to zero since



Case (iii)

α, Δ, ν are negative since 'h' is negative

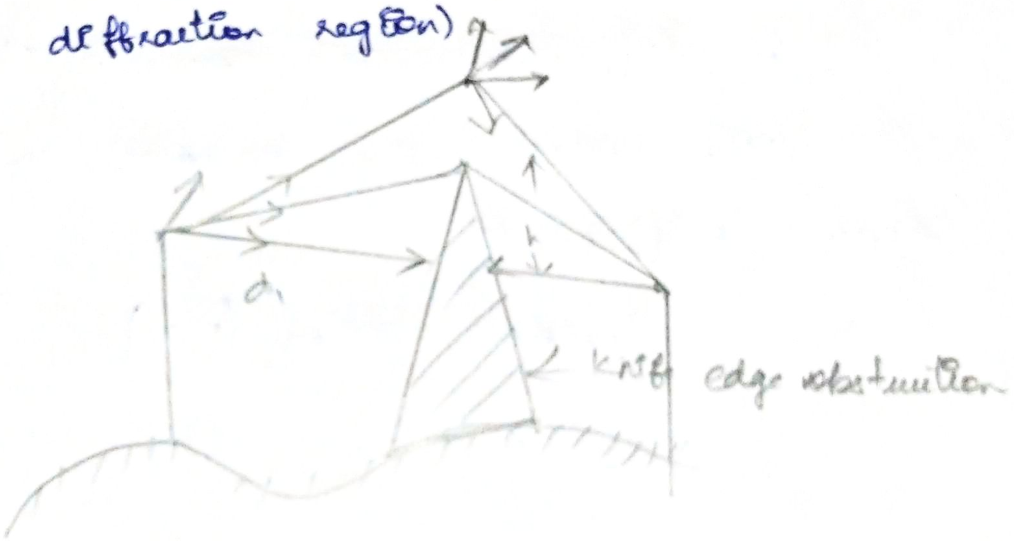


Knife edge Diffraction model :-

When shadowing is caused by a single object such as a hill or mountain, the attenuation caused by diffraction can be estimated by treating the obstruction as diffracting knife edge

This is simplest of diffraction . The diffraction loss in this case is estimated using the classical Fresnel solution for the field behind a knife edge

(*) consider a receiver at a point R located in shadowed region (also called the diffraction region)



(*) The field strength at point 'R' located in the shadowed region is the vector sum of fields due to all of the boundary Huygen's sources in the plane above knife edge

(16)

The electric field strength 'E_d' of a knife edge diffracted wave is

$$\frac{E_d}{E_0} = F(v) = \frac{(1+j)}{2} \int_v \exp(-j\pi t^2)/(2)\, dt$$

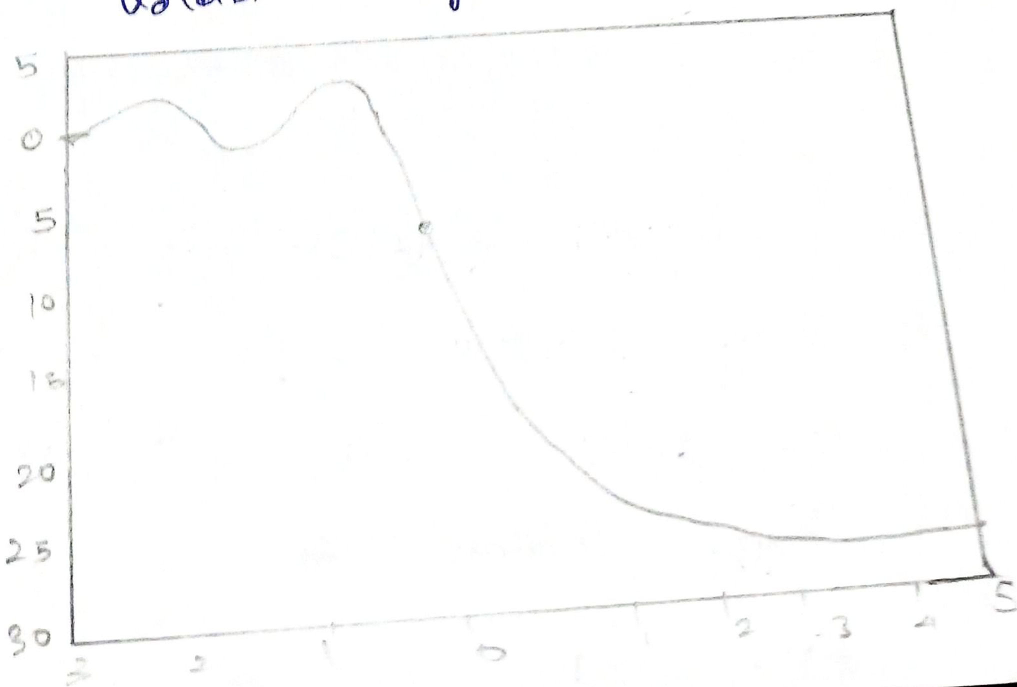
$E_0 \rightarrow$ free space field strength in the absence of both the ground & knife edge

& $F(v)$ is the complex Fresnel integral

$F(v)$ is the function of Fresnel-Kirchoff diffraction parameter 'v'

The diffraction gain due to the presence of knife edge as compared to the free space E. field is,

$$G_d(dB) = 20 \log |F(v)|$$



the solution for above equation is,

$L_d(dB) = 0 \qquad \nu \leq -1$

$L_d(dB) = 20 \log(0.5 - 0.62\nu) \qquad -1 \leq \nu \leq 0$

$L_d(dB) = 20 \log(0.5 \exp(-0.95\nu)) \qquad 0 \leq \nu \leq 1$

$L_d(dB) = 20 \log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1\nu)^2}\right)$

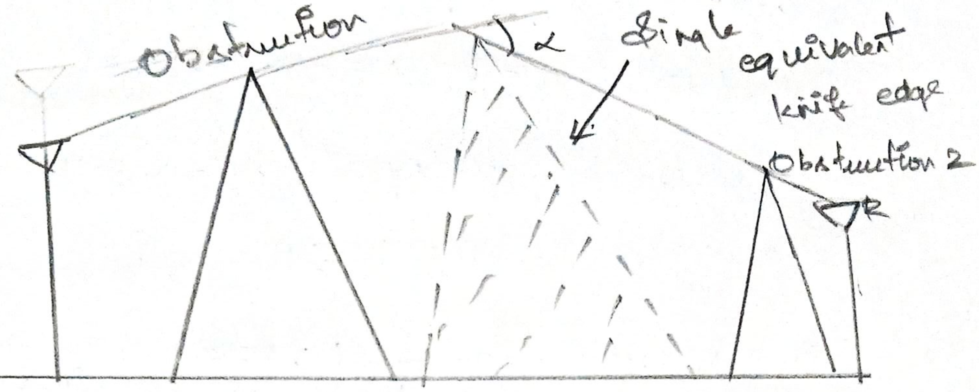
$1 \leq \nu \leq 2.4$

$L_d(dB) = 20 \log\left(\frac{0.225}{\nu}\right) \qquad \nu > 2.4$

multiple knife - edge diffraction

(*) Especially in hilly terrain, the propagation path way consists of more than one obstruction, in which case the which case the total diffraction loss due to all of the obstacles in which can the total diffraction loss due all of the obstacles must be computed

(*) Series of obstacles can be replaced by a single equivalent obstacle is that the path loss can be obtained using single knife edge diffraction method.



(*) This method provides very optimistic of the received signal strength.

(*) This method is very useful & can be applied easily for predicting diffraction loss due to two knife edge.

Scattering :-

(*) When a radio wave impinges on a rough surface, the reflected energy is spread out (diffused) in all direction due to scattering

(*) Objects such as lamp post & trees tend to scatter energy in all direction thereby providing additional radio energy at receiver

(*) Surface roughness is often tested using Rayleigh criterion which defines a critical height (h_c) of surface protuberances for a given angle of incident θ_i;

$$h_c = \frac{\lambda}{8 \sin \theta_i} \quad \text{—(1)}$$

If protuberance 'h' $< h_c$ → surface is smooth

If protuberance 'h' $> h_c$ → surface is rough

(*) Scattering loss factor 'ρ_s' is,

$$\rho_s = \exp\left[-8\left(\frac{\pi \sigma_h \sin\theta_i}{\lambda}\right)^2\right] \quad \text{—(2)}$$

σ_h → standard deviation of the surface height about the mean surface height

ρ_s → is modified by Boithias to give better agreement with measured results

$$\rho_s = \exp\left[-8\left(\frac{\pi \sigma_h \sin\theta_i}{\lambda}\right)^2\right] I_0\left[8\left(\frac{\pi \sigma_h \sin\theta_i}{\lambda}\right)^2\right] \quad \text{—(3)}$$

where I_0 Bessel function of the first kind & zero order

the reflected E-field for $h > h_c$ can be solved for rough surface using a modified reflection coefficient given as,

$$\boxed{\Gamma_{rough} = \rho_s \Gamma}$$

Radar cross Section Model:-

(*) Knowledge of the physical location of such objects can be used to accordingly predict scattered signal strength

(*) The radar cross section (RCS) of the scattering object is defined as the ratio of the power density of the receiver to the power density of the radio incident upon the frequency scattering object & has units of Square Meters

(*) The bistatic radar equation describes the propagation of a wave travelling in free space which impinges on a distant scattering object is then reradiated in the direction of the receiver

$$P_R(\mathrm{dBm}) = P_T(\mathrm{dBm}) + G_T(\mathrm{dBi}) + 20\log(\lambda) + RCS(\mathrm{dB\,m^2}) - 30\log(4\pi) - 20\log d_T - 20\log d_R$$

d_T & d_R → distance from the scattering object to the transmitter & receiver respectively

(*) RCS is useful for predicting receiver power which scatter off large object such as buildings which are for both transmitter and receiver

(*) For medium & large size buildings located 5-10 km away, RCS values were found to be in range of 14.1 to 55.7 dBm^2