1 | Groundwave

When transmitting from one radio to another the signal travel as electromagnetic waves, these waves can reach the receiver taking multiple paths. It could be a direct path from transmitter to receiver, or a reflected wave of a surface such as the ground. This worksheet will focus on the paths close to the ground. The ground acts both as a reflector and also as an absorber [Bullington, 1947]. This means that a received wave can be contributed from three main factors. In 1947 Burlington wrote that *"The principal effect of plane earth on the propagation of radio waves is indicated by the following equation"*[Bullington, 1947]. The surface part comes from the grounds absorption of the electromagnetic wave, when the energy enters the ground it sets up ground currents. These currents are a representation of the imperfect reflection.

$$E = E_0 \left[\underbrace{1}_{direct} + \underbrace{Re^{j\Delta}}_{reflected} + \underbrace{(1-R)Ae^{j\Delta}}_{surface} \right] \tag{1.1}$$

Where:

E	is the recieved field intensity	$\left[\frac{V}{m}\right]$
E_0	is the recieved field intensity in free space	$\left[\frac{V}{m}\right]$
R	is the reflection coefficient of the ground	[1]
Δ	is the phase difference between direct and reflected wave	[rad]
A	is the surface-wave attenuation factor	[1]

The phase difference Δ, is the difference in phase resulting only from the difference in length between the direct wave and the reflected wave, L, which can be found using geometry. The phase difference can be found as:

$$\Delta = 2\pi \frac{L}{\lambda} \tag{1.2}$$

Where:

L	is the difference in length between the direct wave and the reflected wave	[m]
λ	is wavelenght	[m]

For a plane earth case this is L is found as:

$$L = \sqrt{(h_t + h_r)^2 + d^2} - d \tag{1.3}$$

Where:

d	is the distance between the transmitter and receiver	[m]
h_t	is the height of the transmitter	[m]
h_r	is the height of the receiver	[m]

For cases where the $d > 5(h_t + h_r)$ this can be approximated as [Bullington, 1947]:

$$L = \frac{2h_t h_r}{d} \tag{1.4}$$

$$\Delta = 4\pi \frac{h_t h_r}{d\lambda} \tag{1.5}$$

The reflection coeficient R is dependent on the incoming angle of the signal, θ, as well as the electromagnetic properties of the ground, ϵ and σ. The relation can be written as[Bullington, 1947]:

$$R = \frac{\sin(\theta) - z}{\sin(\theta) + z} \tag{1.6}$$

Where:

z	$\frac{\sqrt{\epsilon_0 - \cos^2(\theta)}}{\epsilon_0}$ for vertical polerization	[1]
z	$\sqrt{\epsilon_0 - \cos^2(\theta)}$ for horizontal polerization	[1]
ϵ_0	$\epsilon - j60\sigma\lambda$	[1]
ϵ	is the dielectric constant of the ground relative to unity in free space	[1]
σ	is the conductivity of the ground in mhos per meter	$\left[\frac{mhos}{m}\right]$
θ	is reflection angle	[rad]

By looking at this equation it can be seen that as θ goes towards 0, R goes towards -1. Which also implies that for sufficiently low receiver and transmitter, the direct and reflected wave is completely out of phase since $Re^{j\Delta} = -1$. This leaves only the surface wave part of the equation.

The surface wave attenuation factor can be approximated as[Bullington, 1947]

$$A \approx \frac{-1}{1 + j\frac{2\pi d}{\lambda}\left(\sin(\theta) + z\right)^2} \tag{1.7}$$

This approximation holds for $A < 0.1$, however for A approaching unity the phase approaches 180 degree [Bullington, 1947].

When θ approaches zero only the surface wave component remain and it is thus sufficient to look at the magnitude of it [Chong and Kim, 2013]

$$|(1-R)A| \approx \left|2\frac{-1}{1+j\frac{2\pi d}{\lambda}\left(\sin(\theta)+z\right)^2}\right| \tag{1.8}$$

$$|(1-R)A| \approx \frac{2}{\frac{2\pi d}{\lambda}z^2} \tag{1.9}$$

By introducing h_0, the minimum effective antenna height, as:

$$h_0 = \left|\frac{\lambda}{2\pi z}\right| \tag{1.10}$$

Where:

h_0	is the minimum effective antenna height	[m]

By utilizing this Equation 1.9, can be written as:

$$|(1-R)A| \approx \frac{4\pi h_0^2}{\lambda d} \tag{1.11}$$

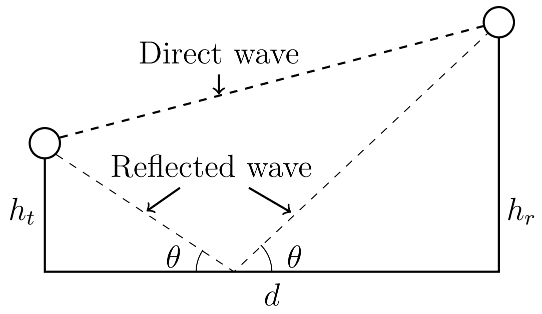
The received power can then be found using[Chong and Kim, 2013]

$$P_r = P_0\left(\frac{E}{E_0}\right)^2 \tag{1.12}$$

$$P_r = P_t G_r G_t \frac{\lambda^2}{(4\pi)^2 d^2}\left(\frac{E}{E_0}\right)^2 \tag{1.13}$$

Where:

P_r	is the received power at the receiver antenna	[W]
P_0	is the predicted power by the free space model (see free space model worksheet)	[W]
P_t	is the transmitted power from the transmitter	[W]
G_r	is the gain of the receiver antenna	[1]
G_t	is the gain of the transmitter antenna	[1]



Figur 1.1: Illustration

Litteratur

Bullington, K. (1947). Radio Propagation at Frequencies Above 30 Megacycles. *PROCEEDINGS OF THE I.R.E.* årg. 35, hft. 10, 10-1947, s. 1122–1136.

Chong, P. K. and Kim, D. (2013). Surface-Level Path Loss Modelling for Sensor Networks in Flat and Irregular Terrain. *ACM Transactions on Sensor Networks.* Vol. 9, No. 2, Article 15.