EC597 – Wireless Communications Electronics
SU2000 - DRV
Class Notes – Session 13

Friis Transmission Equation

Transmission of signals from the transmitter to the receiver through intervening space is described quantitatively by the well-known Friis equation. The equation is developed in the following manner. Consider a transmitter radiating power P_T w isotropically in all directions. At a distance R from the transmitter, this power is spread uniformly over a sphere of radius R resulting in a power density given as $S = \frac{P_T}{4\pi R^2}$ w/m^2. When a directional transmitting antenna with gain G_T is used to focus the power in specified directions, the power density is given by $S = \frac{P_T G_T}{4\pi R^2}$. The amount of the radiated power intercepted by the receiver antenna is expressed in terms of its effective area, A_{eff}, as $P_R = \frac{P_T G_T A_{eff}}{4\pi R^2}$. Using the antenna gain-area relationship, $G = \frac{4\pi A}{\lambda^2}$, leads to an expression for received power as $P_R = \frac{P_T G_T G_T}{\left(\frac{4\pi R}{\lambda}\right)^2} = \frac{EIRPG_T}{\left(\frac{4\pi R}{\lambda}\right)^2}$.

Commonly, the denominator is defined as the space loss or path loss, $L_p = \left(\frac{4\pi R}{\lambda}\right)^2$. L_P is not an ohmic loss, rather it represents the fact that at larger radii, the radiated power is spread over a larger area thus reducing the power density. Various modifications to this equation can be made for special purposes, but all are based upon this basic form.

Link Budget

The performance of a communication system depends upon the power reaching the receiver, but it also depends upon the noise present in the receiver as well. For a receiver with an effective temperature T_{eff}, an antenna temperature of T_a, and a bandwidth of B has a total noise power (referred to the input) of $N = kT_{eff}B$. System performance is governed by the ratio of the received signal power to noise power prior to the detection process. This figure of merit is often called the carrier to noise ratio or CNR and is expressed as $CNR = \frac{C}{N} = \frac{P_T G_T G_R}{L_p k T_{eff} B} = \frac{EIRPG_R}{L_p k T_{eff} B}$ where the all components are assumed to be terminated in matched loads. This is known as the link budget of a communication channel. It expresses the system performance independent of the modulation method. The output message signal to noise ratio (SNR) is proportional to the CNR, but depends upon the modulation method and its associated detection gain. For example, the detection gain of DSB is given as $G_{DET-DSB}=1$ whereas $G_{DET-FM}=3\beta^2/2$. Minimum system performance is usually measured in post-detection SNR since the final message power to noise power at the output of the system governs how well the message is perceived by the user. It is rather interesting that SNR≈40 to 50 dB is the minimum for acceptable reception for audio or video reception. On the other hand, audio CDs have an SNR on the order of –90 dB.

Digital system performance can be calculated from the link budget as well with a few basic considerations. The energy contained in one symbol interval T_S is given by $E_S=CT_S=C/R_S$ where R_S is the symbol rate in symbols/second. The noise power density is expressed as the noise power divided by the noise bandwidth at the demodulator input as $N_o=N/B$ in w/Hz. Combining these results we have $\frac{E_S}{N_o} = \frac{C}{N}\frac{B}{R_S} = \frac{C}{N}BT_S$.

Most practical filters are designed so that $BT_S \approx 1$ which results in $\frac{E_S}{N_o} \approx \frac{C}{N}$. This form can be used to predict BER, the usual specification of digital system performance.

The link budget developed above is in simplified form since it is developed for the transmitter and receiver isolated in space. Terrestrial communications depends upon the effects of the lossy earth, the ionosphere, fading, topographical features, man-made structures, interference, etc. The basic form of the link budget equation is easily modified to include these effects. They are described in many communications handbooks or references.

System design

The details for design of a communication system are now complete. The effects of each component are included in calculating the parameters in the link budget. Gain, loss, noise temperature, bandwidth, etc. are calculated as described in earlier class notes. These results are then applied to the link budget equation to obtain the overall system performance.

RF/Microwave Instrumentation

RF and microwave measurements require specialized instrumentation. These include spectrums analyzer, network analyzers, power meters, noise-figure meters, swept-sources, frequency counters, BER meters, and TDRs. Due to the limits of time we will examine only spectrum and vector network analyzers in detail.

Vector Network Analyzers

See ClassNotes13_vna

Spectrum Analyzers

See ClassNotes13_sa