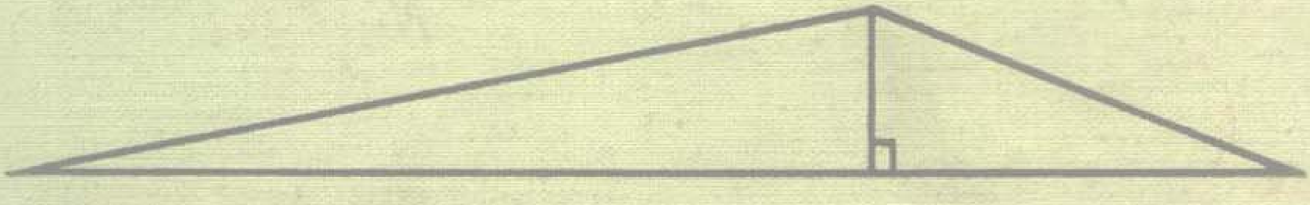
Receiving Systems Design



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PREFACE

This book is the result of many comments which have expressed a desire for a text on receiving systems design. Most of the readers have been exposed to the basics involved but have never put it all together. This text is intended to lead the reader through typical cases from which variations can be made to suit a particular need. For those who may desire to refresh themselves in the basics, a review is presented for reference.

The organization of this book is arranged to address the objective of receiving systems design, with supporting explanations in the following chapters.

INTRODUCTION

This book is intended to assist the reader in the design of receiving systems of four fundamental types:

- Down converter
- Up converter
- Hybrid up and down converter
- Wadley up converter

The text consists of five parts presented in the following sequence:

- A basic overview of signal characteristics (Chapter 1)
- The superheterodyne (Chapter 4)
- Components (Chapter 5)
- Specialized receiving systems (Chapter 6)
- Design examples (Chapter 7)

Interspersed throughout are computer programs written in the BASIC language, to assist the designer in system performance prediction.

The designer should accumulate a library of available components and their characteristics for ready reference. Generally it is most expeditious to procure components rather than undergo design and development efforts of these items, unless the designer has this capability available. This is recommended for initial modeling, later moving to in-house designs if cost effective.

A final chapter includes examples and the sequence of computations and considerations leading to the final design. It is almost always a necessity to revise the structure, as unforseen design faults are found through subsequent performance analysis.

Experience will provide the designer with an insight into what can be done. Low noise and high third order intercept performance, almost always specified, are not simultaneously achievable. A design is usually a compromise of these characteristics.

CONTENTS

1

AN OVERVIEW OF SIGNAL CHARACTERISTICS

This section is concerned with the reception of the signal from a distant emitter. Considered are the prediction of the signal strength and the attenuation due to free space path loss. The Fresnel zones are defined for link calculation and the subject of fade margin is addressed. With these basic considerations the link performance can be predicted.

1.1 RECEIVER INPUT POWER PREDICTIONS

To determine the necessary receiver noise figure and sensitivity if it has not been previously specified, it becomes necessary to estimate the signal strength at the receiving antenna. Having determined this, the receiver and antenna requirements can be determined. While this is readily done for line of sight links, it becomes less defined for ionospheric reflection, troposcatter, knife edge diffraction systems, *et cetera,* and will not be discussed here. Most modern links are line of sight limited because of operation at UHF, VHF, and microwave frequencies, which penetrate the ionosphere and are not, therefore, reflected back to earth as HF signals are.

To make this calculation the signal strength at the receiving antenna is

$$P_r = P_t + A_t - \textit{path loss} \tag{1-1}$$

where

P_r is the power received at the receiving antenna
P_t is the transmitter power
A_t is the transmitting antenna gain in the receiving direction
Path loss is discussed in section (1.2).

The $P_t + A_t$ term is the effective radiated power in the direction of the receiving antenna.

Receiver sensitivity or P_r *(min)* will have been determined from considerations of S/N, C/N, E_b/N_o, *et cetera,* attainable noise figure, and the receiving antenna gain requirements A_r.

A_r becomes

$$A_r = P_{r\,(min)} - P_r \text{ (dB notation)} \tag{1-2}$$

Example: Find the required receiving antenna gain when given:

Path loss = 170 dB
P_t = 100 watts, 50 dBm
A_t = 10 dB
$P_{r(min)}$ = −100 dBm

then the effective radiated power is:

$$\begin{aligned} ERP &= P_t + A_t \\ &= 50 + 10 = 60 \text{ dBm} \end{aligned} \tag{1-3}$$

and

$$\begin{aligned} P_r &= ERP - Path\ loss \\ &= 60 \text{ dBm} - 170 \text{ dB} = -110 \text{ dBm} \\ A_r &= -100 \text{ dBm} - (-110 \text{ dBm}) = 10 \text{ dBm} \end{aligned} \tag{1-4}$$

The receiving antenna gain must be 10 dB, minimum.

These equations can be manipulated to determine any one parameter knowing the others.

For a discussion of path loss, see section 1.2.

1.2 FREE SPACE PATH LOSS

Electromagnetic emission from a point source radiates energy equally in all directions. At any distance d away from the source, this energy is distributed evenly over a spherical area whose radius is d and its center is the source. It follows that if the transmitted power is P_t, the power per unit area at a distance d is:

$$\frac{P_t}{4\pi d^2} \tag{1-5}$$

The power received by a receiver with an antenna whose effective area is A is:

$$P_r = \frac{P_t}{4\pi d^2} A \tag{1-6}$$

Since isotropic antennas are the reference standard upon which antennas are usually compared, it is convenient to utilize this as the receiving antenna. The effective area of the isotropic antenna is

$$A = \frac{\lambda^2}{4\pi} \tag{1-7}$$

where

λ is the wavelength, $\lambda = \dfrac{\textit{velocity of propagation}}{\textit{frequency}}$

Substituting into (1-6) we have

$$P_r = \frac{P_t\,(\lambda^2/4\pi)}{4\pi d^2} \qquad (1\text{-}8)$$

$$= \frac{P_t\,\lambda^2}{4^2\,\pi^2\,\mathrm{d}^2} = \frac{P_t\,\lambda^2}{157.9\,d^2}$$

The path loss in dB is

$$L_p = 10 \log \frac{P_t}{P_r} = 10 \log \left(\frac{157.9\,d^2}{\lambda^2}\right) \qquad (1\text{-}9)$$

If d is in miles, and λ is in centimeters, then equation (1-9) becomes

$$L_p = 10 \log \left(\frac{157.9\,d^2}{\lambda^2}\;\frac{1}{(6.214 \cdot 10^{-6})^2}\right)$$

$$= 10 \log \left(4.089 \cdot 10^{12}\;\frac{d^2}{\lambda^2}\right) \qquad (1\text{-}10)$$

In dB notation,

$$L_p = 126.12\ \mathrm{dB} + 20 \log d - 20 \log \lambda \qquad (1\text{-}11)$$

where

d is in miles

λ is in centimeters

Other forms of this basic equation may be obtained by substituting frequency in GHz for λ.

Then

$$L_p = 92.45 + 20 \log f + 20 \log d \qquad (1\text{-}12)$$

where

d is in kilometers

f is frequency, in GHz

and

$$L_p = 96.58 + 20 \log f + 20 \log d \qquad (1\text{-}13)$$

where

d is in statute miles

f is in GHz

Note that all of the path loss equations assume isotropic receiving antennas. Where the transmitting or receiving antenna has gain, this must be accounted for as a reduction of path loss.

Equation (1-13) is shown in graphical form in Fig. (1-1), for reference purpose.

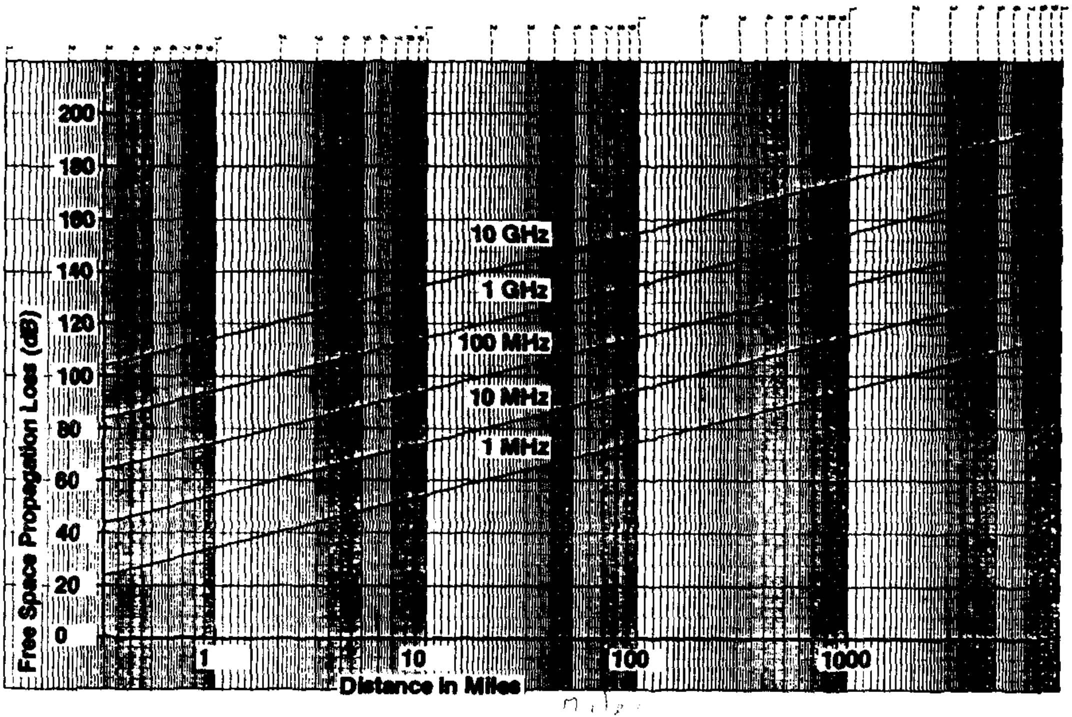

Fig. 1-1. Free space propagation loss

The reader is cautioned in the use of these equations for link calculations. These are free space equations with no intervening obstructions or signal reflections, resulting in multipath situations. If by the use of elevated antennas with moderate gain a free space situation can be approached, then these equations are valid.

For frequencies greater than 8 GHz the environmental effects on the signal must be accounted for. Reference [1] treats this subject in detail.

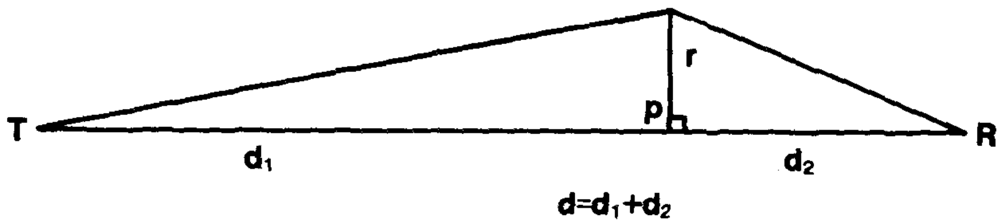

Fig. 1-2. Physical relationship between transmitter *T* and receiver *R* where *r* is the radius of the first Fresnel zone.

1.3 FRESNEL ZONES

Fresnel zones describe the phase behavior of a signal originating at a transmitter T and appearing at a distant receiving site R. With the aid of Fig. (1-2), T and R are connected by a line $n\lambda$ long describing the shortest distance between them. A plane perpendicular to this line is constructed at p and a circle is drawn on this plane containing all points where the path length has increased by $(1/2)\lambda$ to $(n+1/2)\lambda$. This is the first Fresnel zone which contains nearly 25% of the signal power within its boundary. (This is the most important zone.) Similarly, other circles may be drawn for path length increases of multiples of $(1/2)\lambda$. These are successively known as the second, third, fourth, *et cetera*, zones for path length increases of λ, 1.5λ, and 2λ, respectively. All odd multiples of $(1/2)\lambda$ are in phase at R, while even multiples, which are in phase with each other, are out of phase with the odd multiples at R. The signal contributions of each zone are nearly equal, diminishing very slightly as the zone numbers become large. A successive summation of the signal contributions of each zone (i.e., 1, 1+2, 1+2+3, 1+2+3....n) would show a cyclic behavior until, with a sufficiently large n, the cyclic amplitude diminishes and the signal at R becomes equal to the free space value.

The first zone is the most important zone and it should be kept clear of obstructions. The radius of this zone at any point along the axis may be found from

$$r = 13.16\left(\lambda\,\frac{d_1 d_2}{d}\right)^{\frac{1}{2}} \tag{1-14}$$

where

r is the radius of the first zone (feet)
λ is the wavelength (cm)
d_1 is the distance to point p from the transmitter (miles)
d_2 is the distance to point p from the receiver (miles)
d is the straight line distance between transmitter and receiver (miles)

In other units, where d is in miles and F is in MHz:

$$r = 2280\,(d_1 d_2/dF)^{\frac{1}{2}} \tag{1-15}$$

The value of r maximizes when point p is midway between T and R, at which time r may be found from:

$$r = 1140\,(d/F)^{\frac{1}{2}} \tag{1-16}$$

Reflection from the earth will vary in magnitude as a function of the reflection coefficient. Where the angle of incidence is small, this coefficient approaches unity. The incidence and reflection angles are equal. There is a phase reversal at the point of reflection for all polarizations. The resulting signal intensity profile for various clearances is shown in Table 1-1. Shown are the cases of reflection from highly reflective, relatively smooth ground and water, and are labeled plane earth and smooth sphere diffraction. The knife edge diffraction case is applicable to fairly smooth vegetated terrain without atmospheric disturbances. In plane earth theory, 6 dB signal enhancement is possible at clearances equal to odd integral multiples of the Fresnel radius.

Table 1-1.
Radio Wave Propagation as Affected by Path Clearance (dB) [2]

Clearance / First Fresnel Zone Radius	Knife Edge Diffraction	Smooth Sphere	Plane Earth
-3	-26	>-70	>-70
-2.5	-24	>-70	>-70
-2	-22	-70	>-70
-1.5	-19	-59	>-70
-1	-17	-45	>-70
- .5	-12	-12	>-70
0	0±1	-30	-70
.5	│	0	0
1.0	│	+6	+6
1.5	│	*	*
2.0	│	*	*
2.5	│	*	*

1.4 FADE MARGIN

A link is subject to degradation of the signal because of physical changes in the transmission medium, geometry, or both. An allowance for such changes must be made to guarantee the communications reliability of the link. This allowance is established in dB and is called the fade margin. Link reliability is generally expressed in percent values such as 99.9%, which allow an outage of 0.1%.

Multipath fading is a major cause of outages, and is particularly severe in mobile installations. The mechanism is one of reflection or attenuation of the signal from: buildings, water, trees, *et cetera*. The summation of all signals arriving via different paths at the receiving antenna causes enhancement or reduction of the signal phases. These variations are largely random and are called Rayleigh fading because of their distribution. Fig. (1-3) relates link reliability to relative signal strength and is a theoretical maximum. Using this