CUSTOMER SUPPORT

RF BASICS MODULE

Prepared by: Customer Support.
WaveRider Communications Inc.

Contents

1. Training

1.1 Introduction

The following information is provided for the use of WaveRider's authorized partners. This module is part of a series of Customer Support modules designed to summarize the most important and applicable technology today as pertaining to WaveRider Communications Inc. product line.

1.2 Radio Frequency (RF) Basics – *An Introduction to Wireless Systems*

This section provides a general introduction to the concepts and issues to be considered when designing spread spectrum wireless systems.

Spectrum Allocation

Frequency Spectrum is regulated and allocated for specific purposes in the USA by the FCC, and in Canada by Industry Canada. Typically, these policies have such far-reaching ramifications that a consensus is normally reached on a 'Global' basis. This activity is presided over by the International Telecommunications Union (ITU). Countries that are members of the ITU generally follow the ITU spectrum allocation. The telecommunications regulatory body in each country can provide spectrum information.

Commercial unlicensed Spread Spectrum systems typically use the ISM bands worldwide. These are located as shown below:

902 to 928 MHz

2400 to 2483.5 MHz*

5725 to 5850 MHz

** Microwave Ovens located here*

Authorized channel bandwidth is 1MHz, and channel spacing is 25kHz or -20dB bandwidth, whichever is greater.

FCC, Industry Canada

As it relates specifically to the NCL135, operation and use is regulated in the U.S. by the FCC as follows:

FCC Part 15, Class B - Unlicensed operation from 2400 to 2483.5 MHz

In Canada, the equivalent specification is determined by Industry Canada, as shown below:

RSS139 - *Licensed* operation from 2400 to 2483.5 MHz

RSS210 - *Unlicensed* operation from 2450 to 2483.5 MHz.

In part for reasons of safety, the transmitter power output level in the ISM band is limited to 1W (+30dBm) maximum. For similar reasons, and also to minimize interference, Effective Isotropic Radiated Power (EIRP), or power radiated by the associated antenna system, is limited to 4 W (+36dBm) maximum.

Spectral Efficiency and Modulation Schemes

Given a specific area of RF spectrum authorized for use, the next challenge is to maximize its utilization. This raises the obvious question: *what are the most efficient methods, and what factors determine spectral efficiency?*

Spectral Efficiency refers to spectrum utilization as measured in Bits/sec/Hz. For a given fixed allocation of spectrum, Shannon's Law determines the absolute limit. In real terms, however, the modulation method used will largely dictate the data rate obtained.

Some modulation schemes commonly used in data systems are FSK (including BFSK, and QFSK), PSK (including QPSK), and QAM (of various levels). The unit of *information* is the symbol, and the different schemes use different numbers of bits to define each symbol. For a given symbol rate, the greater the number of bits-per-symbol, the higher the data rate. Since an increase in speed normally introduces an increase in error rate, error-correcting schemes (overhead) are often included in order to produce a net gain in data throughput.

The general rule is that to obtain higher data rates, higher-order modulation schemes must be employed. One price paid for this increased throughput is an increase in operating threshold level. In real terms, the trade-off is data rate vs. energy-per-bit, and thus range.

Spread Spectrum Systems: DSSS and FHSS

In stark contrast to the above, a spread spectrum system's transmitted signal is 'spread' over a *much wider* bandwidth than that required by the information transmitted. Two popular means of implementing such systems are Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS).

Both DSSS and FHSS are inherently difficult to intercept - providing increased security.

DSSS

Direct Sequence Spread Spectrum techniques

FHSS

The typical system topology comprises one *Master* and one or more *Station* (slave) units. Each Master / Station(s) combination is programmed to follow, in a pseudo-random sequence, a set of channels called the 'Hopset'. Each Station unit in the same Domain follows the same Hopset.

FCC / IC Regulations state that for FHSS:

> *A transceiver may dwell on any given frequency in the Hopset for no more than 400mSec in any 30Sec period. Authorized channel Bandwidth is 1MHz, and channel spacing is 25kHz, or -20dB bandwidth, whichever is greater.*

The Proxim Transceiver

At the heart of the NCL135 is the Proxim Transceiver. Its output level is nominally +18dBm *(+18dBm = 65 mWatt).* When deployed in a system, transmitter output is boosted by system Antenna gain and reduced by transmission line and connector losses.

Effective Isotropic Radiated Power (EIRP) is given by:

EIRP (dBm) = Tx Output (dBm) + Antenna Gain (dBi) - Transmission Cable and Connector Losses (dB)

Proxim FHSS Transceiver uses a proprietary *Cheetah Protocol*, and offers two possible modulation schemes:

QFSK (4FSK) - *normal mode*: - peak performance, but sacrifices range

BFSK - greater range, but sacrifices speed

The transceiver may be set to Auto, QFSK, or BFSK mode

In default mode (Auto), packet transmission is attempted *3 times* at QFSK without success before switching to BFSK mode.

Free-Space Path Loss

Free-Space Loss is incurred by the signal by virtue of the tendency of an electromagnetic wave to propagate and therefore disperse energy in all directions outward from its source. In what is known as the *far-field*[1], this loss is quite predictable, and given by:

$$FSL\ (dB) = 32.45 + 20Log_{10}F(MHz) + 20Log_{10}D(km)$$

This equation is one of the bases of link budget calculations. Free-space loss represents the single greatest source of loss in the system.

The '6dB Rule'

Close inspection of the free-space path loss equation, yields a relationship that is useful in dealing with link budget issues. Each 6dB *increase* in EIRP equates to a *doubling* of range. Conversely, a 6dB *reduction* in system losses (either by way of transmission line loss, either on receive or transmitter end) translates into a *doubling* of range.

Radio Signal Transmission Components

Transmission over the earth may be broken down into Reflection, Refraction and Diffraction components.

Reflection

Radio waves will be reflected from the earth's surface and other objects. Since the received signal is a combination of all paths, these signals will combine to provide a signal, which is different from the direct ray, or line-of-sight signal. The reflected signal strength will vary in amplitude by the absorption coefficient of the reflecting object at that frequency.

The phase of the signal will vary with respect to the direct signal by the increase in distance travelled as well as the phase change from the reflecting surface.

[1] *$d_F > 2D/l$, where D = the aperture of the antenna, or its largest dimension. d_F = far-field distance, and l is the wavelength of the signal propagated. In the far-field, radial lines from the signal source can be assumed to be parallel.*

Thus, the resulting (composite) signal at the receiver could be either in phase, or out of phase, causing either an *increase* or *decrease* in resultant signal at the receiver.

The reflecting object will act as a partial reflector[2] and a partial absorber of the radio signal. The attenuation factor of the reflecting object is proportional to the conductivity of the ground, and the frequency of transmission is inversely affected by the incident angle of reflection, and the distance from the transmitting and receiving antenna.

Refraction

The dielectric constant of the earth's atmosphere decreases gradually with increasing altitude. As the dielectric constant decreases, the transmission speed increases. This leads to a phenomenon of bending or refraction of the radio waves back toward the earth. The effect of this is the same as if the radio waves continued to travel in a straight line, but over an earth where the modified radius is:

$$\frac{r}{r_0} = k_r \approx \left(1 + \frac{r\partial m}{\partial h}\right)^{-1}$$

Where, r = the true radius of the earth, and

μ = Refractive index of air

r_0 » 6370km

h = height above the earth's surface

The *rate of change of the refractive index per metre* of height results in an effective earth's radius of 4/3 the actual radius.

Radio Horizon

From the above,

Assuming that K = 4/3 (for <u>smooth</u> earth), for an antenna height of ***h*** metres, the radio horizon is given by:

$$d = 2.9\sqrt{2h}$$

where, ***h*** = transmitter antenna height (m)

So, for example, for an antenna height of **24m** (79ft.), the Radio horizon is **20km**.

[2] *Note that a <u>perfect conductor</u> cannot absorb electromagnetic energy, and so must reflect all energy. As a result, upon reflection, the E-Field in Horizontally polarised signals will be revered in direction. The E-Field in Vertically polarised signals remains unchanged in direction. Consequently, when the direct or LOS signal is Horizontally polarised, reflected signals are more destructive to the LOS signal. The actual situation will vary between total cancellation in the case of a perfect conductor (non-existent) and attenuation depending on the nature of the reflecting surface.*

If we consider the case of transmitter and receiver antennas, the maximum radio path distance between antennas (assuming smooth earth) is given by:

$$d_{km} = 2.9\left(\sqrt{2h_T} + \sqrt{2h_R}\right)$$

where, $\boldsymbol{h_T}$ = transmitter antenna height (m)
where, $\boldsymbol{h_R}$ = receiver antenna height (m)

If we assume *flat* earth, the path length becomes the *Optical* Horizon, or Line-of-Sight distance:

$$d_{km} = 2.6\left(\sqrt{2h_T} + \sqrt{2h_R}\right)$$

Thus, for the example of antenna heights of **24m**, the Radio Horizon is **39km,** and the Optical Horizon is **34km**. Note that this assumes <u>*smooth*</u> earth. Therefore, local (natural and man-made) obstructions, and foliage may further reduce the actual path length.

<u>Diffraction and Diffraction Loss</u>

Diffraction refers to the phenomenon of bending radio waves around objects. It occurs when the wavefront encounters an obstacle that is *large compared to the wavelength* of the signal. The magnitude of the loss caused by an interfering object will increase with frequency and distance from the signal source.

Note: The wavelength at 2.4GHz is approximately 10cm

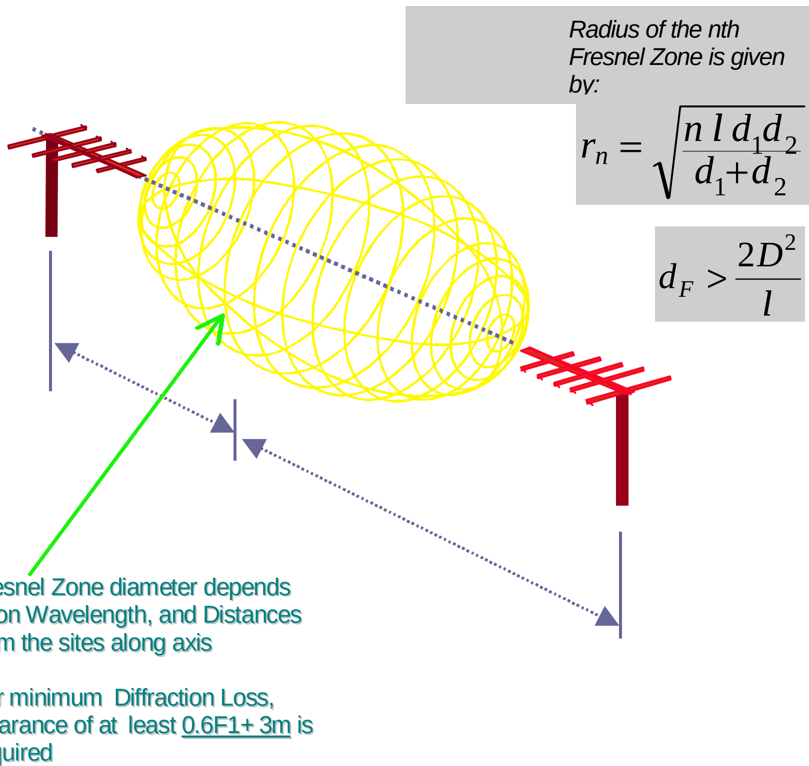
<u>Below about 1000MHz</u>, there is diffraction or bending from an obstacle with increasing attenuation as a function of obstacle obstruction.

<u>Above 1GHz</u>, as the obstruction increases, the attenuation *increases even more rapidly*, such that the path may become <u>unusable</u>.

The magnitude of the obstruction loss is *dependent on the area of the beam obstructed, and the type of obstruction, in relation to the total energy transmitted*

Fresnel Zones

Fresnel Zone theory attempts to quantify Diffraction effects.



Line-of-Sight

Optical Line-of–Sight (LOS) refers to the ability to see one site from another. *Radio LOS* refers to the ability of the receiver to 'see' the transmitted signal at the target site, and is determined by several different factors.

Although Radio LOS is in principle determined by obstructions, diffraction loss and refraction, for the purposes of Spread Spectrum system design, LOS is defined solely by Fresnel Zone clearance.

The Path Profile

The Path Profile is a *profile view* of a given point-to-point link. Its primary function is to indicate the existence or otherwise of required Fresnel Zone clearance. Antenna heights (AGL) are indicated as well as topographic details of the terrain (including known foliage conditions) between the sites. In microwave system design, this is normally done using computer path analysis programs and the requisite terrain database.

The path profile analysis may also be done manually, using graph paper and the appropriate topographic map. In this case, the terrain profile is manually transferred to the graph paper, and Fresnel Zone analysis conducted based on the resulting profile. To complete the model, any known man-made obstructions are added as required.

Link Budget Calculations

The Link Budget calculation is fundamental to microwave path design. It allows the designer to scrutinize the feasibility of the link from a signal-level perspective. As the name implies, the signal energy is 'budgeted' according to the characteristics (loss or gain) of the various components (e.g., antennas, transmission lines, connectors, amplifiers, etc.) in the system.

Refer to the module on the Link Path Analysis Tool for further details of this procedure.

Receiver Threshold Level

Rx Threshold Level is nominal (design) level below which performance is not specified nor operation desired.

For the NCL135, the threshold level is specified as -80dBm

Fade Margin

Fade Margin on a given link is defined as the degree to which the *Receive Signal Level* (dBm) exceeds the stated *Receiver Threshold Level* (dBm). Composite Fade Margin is an aggregate of the following influences that affect the receiver operating threshold level:

1. **DFM**. Dispersive Fade Margin (dB) is defined by the radio manufacturer, and is determined by the type of modulation, effectiveness of any equalization in the receive path, and the multipath signal's delay time. DFM characterizes the radio's robustness to dispersive (spectrum-distorting) fades.

2. **EIFM**. External Interference Fade Margin (dB) is receiver threshold degradation due to interference from a from external systems. In the absence of AIFM, EIFM simply becomes IFM.

3. **AIFM**. Adjacent-Channel Interference Fade Margin (dB) accounts for receiver threshold degradation due to interference from adjacent channel transmitters in one's own system.

These four fade margins are power added to derive the Composite Fade Margin, CFM as follows:

$$CFM = 10\log(10^{-TFM/10} + 10^{-DFM/10} + 10^{-EIFM/10} + 10^{-AIFM/10})$$

It will be seen that the longer the link, the more critical the above factors become. For path lengths of 5km or less, *a minimum 3dB* Fade Margin is recommended.

Availability

Closely related to the Composite Fade Margin is the concept of *Link Availability*. Availability may be defined as the time expressed in percentage, for which the received signal level is above the stated target value. Thus, Availability A(%), is given by:

$$A(\%) = \left[1 - \frac{T}{100}\right] \times 100$$

$$T = (rT_0 \times 10^{-(CFM/10)}) / I_0$$

Where, outage time in seconds due to Multipath Fading = *T*

r = Fade occurrence factor
T_0 = (t/50)(8x10^6) = length of fade season
t = average annual temperature in degrees *Fahrenheit*

$$r = c\left(\frac{f}{4}\right)\left(\frac{D_{km}}{1.6}\right)^3 \times 10^{-5}$$

Where, c = climate-terrain factor, and
D_{km} = Path length in km

So, the above expression may be used to modify the Fade Margin such that it accounts for Multipath effects*. Note that the 'Fade Occurrence factor' is proportional to the path length to the third power!*

Sources of Interference

Interference may be caused by several possible sources:

- In-band signals originating from other systems
- Reflections, multipath
- Receiver front-end overload, produced by adjacent transmitters such as MDS systems, Radar etc.

The nature of Frequency Hopping Spread Spectrum systems is such that interference would tend to degrade throughput, rather than cause the cessation of link operation. Even in such instances, the inherent immunity to interference provides that extra margin of safety.

1.3 Antenna Fundamentals – *Choosing the right Antenna*

In many ways, the Antenna and its associated Transmission Line, are two of the most critical elements in the wireless system. These two elements are significant determinants of the system throughput and performance of the system over time.

The Antenna - how it works

The antenna is a *transducer*, which converts radio frequency electrical energy fed to it (via the transmission line) to an electromagnetic wave propagated into space. Assuming that the operating frequency in both cases is the same, *this process is reciprocal in nature - the antenna will perform identically in Transmit or Receive mode*. This is important to recognize, since the NCL135 is based on a transceiver (transmitter and receiver) unit. The same Antenna and Transmission Line path is used for both transmit and receive functions.

Antenna Theory

The nature of the Transmission Line is such that for most efficient power transfer, a proper Impedance Match is essential for maximum power transfer. Ideally, both the transceiver end and the antenna must terminate the line with what is known as the transmission line's *Characteristic Impedance*[3]. When this is achieved, all the power delivered by the transceiver is accepted by the transmission line, and similarly all the power delivered by the transmission line is accepted by the antenna. In other words, at either end of the transmission line, there is *no reflected power*. Reflections on a transmission line cause signal degradation. In the world of data systems, this can be related to inter-symbol interference, or ISI. This limits the maximum usable data rate.

In reality, there will always be some level of reflected power in a given transmission line, but at reasonable cost the losses can be reduced to acceptable levels.

Note that connector characteristics also affect the matching of transceiver to line, antenna to line, and line to line.

Thus, the antenna must also function as a matching load for Transmitter (or matching Source for Receiver).

VSWR and Return Loss

Voltage Standing Wave Ratio, or **VSWR**, is a measure of the degree to which a perfect match exists. Thus, the *lower* the VSWR, the better the match, and the more efficient the power transfer. A practical maximum VSWR is 1.5:1. Obtaining values very much below this is proportionately more expensive, and is subject to the 'law of diminishing returns'.

Note that VSWR is relatively easy to measure, and may be measured at any convenient point along the line – usually at connector interfaces. Measuring the VSWR at the transceiver output port, 'looking' towards the antenna, provides a *composite* reading. This reading is in fact determined by the distributed VSWR's of the various components, e.g., jumper (between transceiver output port and main transmission line), connectors, main transmission line, and antenna system.

Return Loss (RL) is related to VSWR by the following expressions:

$$RL_{dB} = 20\log(1/r),$$

[3] *Note that the Characteristic Impedance of the transmission lines used in RF systems is normally 50 Ohms.*

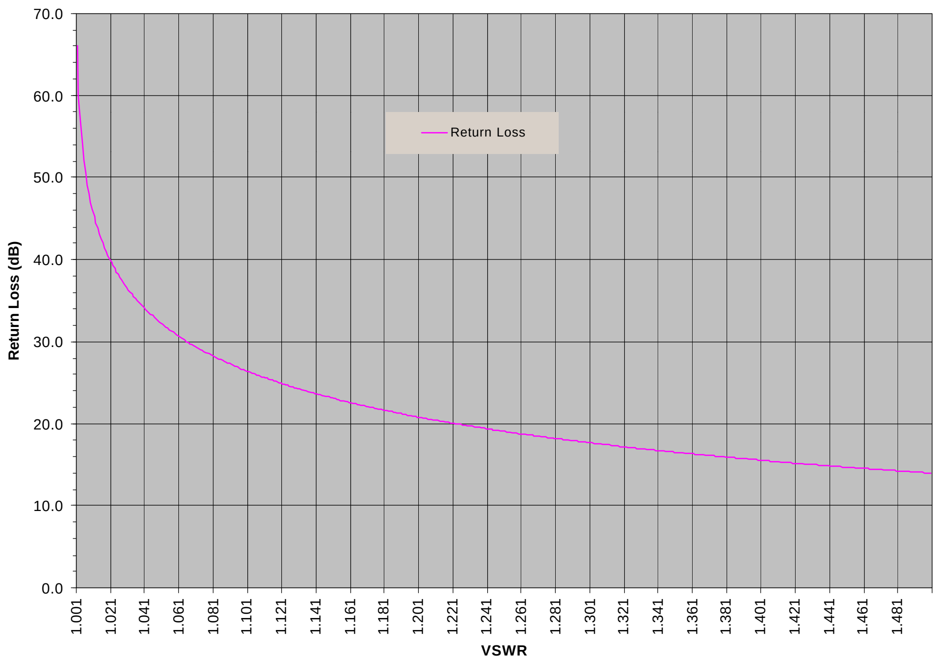
where ρ is the *reflection coefficient*, and

$$r = \frac{VSWR - 1}{VSWR + 1}$$

Thus,

$$RL_{dB} = 20 \log \left[\frac{VSWR + 1}{VSWR - 1} \right]$$

Return Loss vs. VSWR



Example: A transmission line / antenna composite Return Loss figure of 26.4dB is equivalent to a VSWR of 1.1:1. A VSWR of 1.5:1 is equivalent to a Return Loss of 13.9dB.

As VSWR decreases, Return Loss becomes a more sensitive measure of transmission line performance than VSWR. Thus, a VSWR change of 1.1 to 1.5 is equivalent to a Return Loss change of 26.4 – 13.9, or approximately 13dB.

Radiation patterns

Radiation patterns describe the distribution in space of electromagnetic energy generated by a given antenna. The patterns are normally presented as polar plots (relative energy level vs. angular position) in the E-Plane, and H-Plane - in other words, in the same plane as the E-Field and H-Field respectively.

A simplified version, called a Radiation Pattern Envelope (RPE) is often used for design purposes. In this case the pattern is deliberately 'linearized', and the normal (sometimes wide) fluctuations in the field removed.

Radiation patterns (or the RPE version) are used to design and evaluate system performance as it relates to transmission (EIRP) in any given direction, or reception (RSL) from any given direction, including interference.

Gain

Antenna Gain is normally specified in **dBi** (relative to the ideal *isotropic antenna*) or **dBd** (relative to a *half-wave dipole*), and is measured along the axis of greatest energy level.

Power rating

The Power rating of a given antenna is related to the amount of power that the unit is likely to have to dissipate.

Spread Spectrum system transmitter output power is regulated, and will never legally exceed 1 Watt (+30dBm). Consequently, antenna power rating will normally not be a significant factor.

Beamwidth

Antenna beamwidth is measured in terms of *angular* distance in degrees between the ± 3dB points either side of the main beam on the radiation pattern.

As antenna gain increases, the beamwidth decreases. This is most easily understood if we imagine that the energy emitted by the antenna is *never actually increased* (notwithstanding the use of the term 'gain'), but only *re-directed*. Thus, the apparent energy increase provided by directional antennas is obtained at the expense of energy radiated in other directions.

Directional antenna patterns appear in the form of pencil-thin beams no more than a few degrees wide, to Cardioid patterns (both wide and narrow), to specialized types such as the 'peanut'.

Polarization

Polarization of an antenna, or electromagnetic wave, is determined by the orientation of the related Electric (E) Field[4]. Polarisation may be Horizontal, Vertical, or Elliptical. If the E Field is vertical, the Polarisation is vertical. Similarly, if the E Field is horizontal, the Polarisation is horizontal. In the case of elliptical polarisation, the E and H fields rotate, and the wave may be described as Right-Hand Circularly Polarised (RHCP) or Left-Hand Circularly Polarised (LHCP).

Influence of nearby objects

Depending on their nature, nearby objects may affect the antenna radiation pattern. For example, vertically polarised omni-directionally antennas, when side-mounted on metallic towers are subject to severe vertical pattern distortion. The vertically polarised signal 'sees' more of an obstruction in the vertical tower. The only solution here is to use a horizontally polarised antenna.

The converse is also true, in that horizontally polarised antenna radiation patterns are more affected by horizontal metallic structures. Antenna polarisation should therefore be chosen after considering these effects.

Environmental effects on performance

[4] *Recall that an electromagnetic wave consists of an E-Field and an H-Field, propagating in space at 90 degrees to each other. The antenna is used to generate such a wave.*

Antenna radiation patterns are affected to varying degrees by environmental effects, depending on the type of antenna.

Radomes

A Radome is a radio-frequency transparent cover used to protect the Antenna from such things as wind load, snow and ice, or dust build-up that would otherwise cause excessive mechanical stress on the tower structure and undesirable radiation pattern distortion. Add-on radomes are most often seen on parabolic antennas. Yagis are normally factory-sealed in a permanent housing.

Although designed to be RF-transparent, there is inevitably some signal loss, and as such should be accounted for in the link budget design process. For sealed Yagi antennas, the loss is already taken into consideration in the published specification.

Antenna types

There are many different types of antenna, and each is designed with specific purposes in mind. For the spread spectrum systems, the type of antenna(s) used will largely be determined by the coverage area requirements.

Wireless system coverage requirements may be divided broadly into *Point-to-Point* and *Area* (or Point-to-Multipoint) Coverage. For point-to-point systems, directional types such as the Yagi or Parabolic antenna are the most common. These see limited utility in point-to-multipoint systems, depending upon the geographic distribution of the various sites. In general, for point-to-multipoint systems, broader beamwidth antenna types such as Cardioid or omni-directional antennas are required. Here, it is useful to remember that in general, the *higher the gain*, the *narrower the beamwidth*.

Omni-directional Antennas

Vertical pattern Nulls

One of the major drawbacks with using Omni-directional antennas is the existence of vertical pattern nulls. These nulls increase both in number and depth as antenna gain increases. The outcome of this situation is that the radiation pattern and ultimately the coverage in 'close-in' areas are potentially extremely uneven.

Selecting the right Antenna

Antenna selection is governed primarily by the following factors:

- Frequency of operation
- Gain (EIRP considerations)
- Radiation Pattern
  - What type of Coverage is required? Directional (point-to-point, or point-to-multipoint), or Omni-directional (360°) coverage
  - Are there any Interference considerations?
- Polarisation required
  - Horizontal, Vertical, Elliptical
- Mechanical considerations – type of connector, physical mount
- VSWR, Return Loss, Frequency response characteristics

- Environmental considerations
    - Will the antenna be exposed to strong winds, rain, snow and ice, salt spray, etc? Is a Radome required?
- Power rating
    - How much power must the antenna handle?