WILKERSON INSTRUMENT CO., INC.
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sensoRAD™

Wireless Signal Conditioning

Engineering Manual

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System Description and Requirements

A wireless data gathering system consists, as a minimum, of:

1. Analog instruments monitoring the processes of interest
2. Devices providing switch contacts or discrete digital outputs to be monitored
3. Radio devices transmitting and receiving data to and from the monitoring location
4. Coaxial cables and antennae associated with the radio system
5. Instruments monitoring the analog signals and switch status from the receiver output

The RF transmitter, antenna, and coaxial cable make up the transmitter portion of the wireless system.

The RF receiver, antenna and coaxial cable make up the receiver portion of the wireless system.

System Parameters

The Wilkerson Instrument Company's Wireless Peer to Peer and Polling system can send analog and switch status data up to 20 miles. To achieve this range, the transmitter antenna and the receiver antenna must be visible to each other (line of sight) and have freedom from reflective objects near the line of sight in an area known as the Fresnel Zone (see Appendix C).

Shorter ranges can be achieved with obstructions in the path. Systems have been successfully implemented with signals passing through multiple building walls and vertically through multiple building floors and through forests.

Wilkerson Instrument Company has several demonstration systems that can be used to test an application without commitment.

The distance between the transmitter antenna and the receiver antenna has a large impact on received signal strength. The height of the transmit and receive antennas above the earth, and other objects, is also part of the system configuration due to reflections of RF energy off of these surfaces. This reflected RF energy arrives at the receiving antenna out of phase with the direct path signal and may add or subtract from the direct signal, based on the phase shift between the two. The clear space required around the direct line of sight is the Fresnel Zone (See Appendix C).

Rain, fog, and snow also have a small attenuating effect on the RF signal strength.

The Peer-to-Peer and Polling Wireless Systems can be supplied with 900 MHz or 2.4 GHz transmitters and receivers.

The 900 MHz range is less attenuated by atmospheric conditions and signal loss in the coaxial cabling system. Therefore longer ranges can be obtained using the 900 MHz frequency devices.

The 2.4 GHz units are more suitable for short range work because they will be less susceptible to other RF signals from a greater distance. Signal loss is greater in the coaxial cabling system and from transmission through space.

dBm - Definition

This unit, as used in the discussion of wireless products, refers to decibels referenced to 1 milliwatt of rms power. In this manual, it is assumed that all antennae and coaxial cables have an impedance of 50 ohms resistive. Therefore the dBm unit references 1 mW across a 50 ohm load.

The decibel is defined as dB = 10 log P1/P2 - where P1 and P2 represent 2 power levels
The dBm term references P1 to 1 mW, therefore P2 = 1 mW
If P1 = 2 mW then dB = 10 log 2/1 which is 3 dB
(dB has no engineering units since it is proportional to the ratio of 2 numbers with the same unit)

Examples:

If P1 = 1 mW then P1/P2 = 1.	The log of 1 = 0, therefore 10 log P1/P2 = 0 dBm
If P1 = 10 mW then P1/P2 = 10.	The log of 10 = 1, therefore 10 log P1/P2 = 10 dBm
If P1 = 100 mW then P1/P2 = 100.	The log of 100 = 2, therefore 10 log P1/P2 = 20 dBm
If P1 = 0.1 mW then P1/P2 = 0.1.	The log of 0.1 = -1, therefore 10 log P1/P2 = -10 dBm
If P1 = 0.01 mW then P1/P2 = 0.01.	The log of 0.01 = -2, therefore 10 log P1/P2 = -20 dBm

These levels in dBm and dB are used to specify and calculate the performance of the coaxial cable, antenna, and fittings used in the wireless system. Determining the practical range of a given system is a matter of adding and subtracting the gain in dB of all the components and insuring the received signal is greater than the minimum required by the receiver for good performance.

The dBi term used with antennae specifies the antenna gain in relation to an isotropic source which would radiate a perfect spherical pattern from a point source. All antenna gain is derived by modifying the shape of the radiated pattern such that more radiated energy is transmitted in a narrow direction. An antenna receiving a signal is perfectly reciprocal to a transmitting antenna and therefore the gain is the same whether receiving or transmitting.

Calculating Range

(Practical Earth Method)

Best performance is achieved under true line of sight conditions. True line of sight implies a clear optical path between the transmitting and receiving antennas. In addition there must be no objects within a given distance of the line of sight axis. Because the signal from the transmitting antenna spreads in an elliptical pattern, reflective objects near the line of sight axis reflect the spreading signal back toward the receiving antenna. The reflected signal arrives at the receiving antenna later than the line of sight axis signal and reduces the overall signal seen by the receiving antenna. This area of reflective interference is known as the Fresnel zone.

Line of sight is not necessary for excellent performance in short range systems. Successful systems can be implemented with radiation passing through building walls, floors, and vegetation.

The supports for the antennae should provide a clear optical path from antenna to antenna. Horizontal objects below and vertical objects to the side of the antennae should be out of the Fresnel zone to prevent signal loss by reflection from these objects.

The diameter of the fresnel zone is a function of the frequency and the distance between the antennas. For reference here is a table to use as a guideline:

Fresnel Zone Table

	Frequency			
	900 MHz		2.4 GHz	
Distance between antennas	Fresnel zone diameter	Freespace loss (dB)	Fresnel zone diameter	Freespace loss (dB)
1000 ft (300 m)	16 ft (7 m)	81	11 ft (5.4 m)	90
1 Mile (1.6 km)	32 ft (12 m)	96	21 ft (8.4 m)	104
5 Miles (8 km)	68 ft (23 m)	110	43 ft (15.2 m)	118
10 Miles (16 km)	95 ft (31 m)	116	59 ft (20 m)	124
20 Miles (32 km)	138 ft (42 m)	122	87 ft (27 m)	130
40 Miles (64 km)	192 ft (59 m)	128	118 ft (36 m)	136

Objects that absorb RF energy, such as trees, simply attenuate the signal arriving at the receiving antenna.

Topographical map programs for computers are available that allow a profile to be viewed for a straight line path between two points. This tool is extremely valuable for viewing land contours for a proposed long path. An online tool is available at “http://nationalmap.gov”.

Do The Math

The formula for calculating power arriving at the receiver is:

$$P_R = P_T + G_T + G_R + G_C + G_H - P_L \qquad \text{(Eq 1)}$$

Where:
P_R = Power at receiver - dBm
P_T = Transmitter output power - dBm
G_T = Transmitter antenna gain - dBi
G_R = Receiver antenna gain - dBi
G_C = Coaxial cable and fittings loss - dB
G_H = Antennae height gain = $-(7 - 6\log(H))$ (Eq 2)
Where:
H = Antennae height in feet (meters x 3.28)
P_L = Path Loss = $32.45 + (20\log(F) + 20\log(D)$ (Eq 3)
Where:
F = Frequency in MHz
D = Distance between antennae in Kilometers (miles x 1.609)

Typical Coaxial Cable Loss Chart

Cable Type	dB Loss/100Ft at 900 MHz	dB Loss/100Ft at 2.4GHz
RG58/U	15.8	24.8
RG174/U	27.9	43
LMR195	11.1	18.6
LMR400	3.9	6.6
LMR600	2.5	4.3

See Appendix A - 1 for coaxial cable details.

$$G_C = \frac{\text{Cable Length}}{100} \times -(\text{dB from chart})$$

Typical Antenna Selection Chart

Type	Gain	Connector	Mechanical Details
Whip	1.8dBi	SMA Rev Pol Socket	Appendix A- 2
Omni	6dBi	Type N Socket	Appendix A- 3
Yagi	8dBi	Type N Socket	Appendix A- 4
Yagi	14dBi	Type N Socket	Appendix A- 5
Parabolic	18dBi	Type N Socket	Appendix A- 6

Antenna gain G_T and G_R = Gain (from chart for selected antenna)

The RF Transmitters used in Wilkerson Instrument Company products have a 100mW output which is 20dBm (P_T). The RF Receivers have a threshold sensitivity of -110dBm (9600 Baud rate).

Using the above tables, record the values for G_C, G_T and G_R, calculate G_H and then do the math per Eq 1. If the power at the receiver input is greater than minimum required, the system will have adequate signal to work. If the signal at the receiver is marginal, efforts should be made to increase the received signal level.

All attempts should be made to achieve a 20 dB margin of signal strength, therefore the (P_R) in the equation should be equal to or greater than -110 dBm + 20 dB = -90 dBm.

The variables that can be adjusted to raise the received signal level are, antenna gain, coaxial cable type and antenna height/position.

A formula for calculating required combined antenna height is: H = (D/8.2)^2

Where:
H = Combined antennae height in meters (feet / 3.28)
D = Distance between antennae in Kilometers (miles x 1.609)

NOTE: This formula assumes flat terrain between the antennae. The actual antennae height must be the calculated value above the highest elevation between the antennae.

Example: A system is set up as follows; 7 miles between antennae, combined antennae height is 40 feet (20 feet each antenna), using an 8 dBi yagi antenna connected with 50 feet of LMR400 cable at each end.

P_T	=	20	dBm	RF Transmitter Output
G_T	=	8	dBi	Antenna (yagi)
G_R	=	8	dBi	Antenna (yagi)
G_C	=	-3.9	dB	100 Feet LMR400 Cable
G_H	=	0.8	dB	Antenna 1 Height
G_H	=	0.8	dB	Antenna 2 Height
P_L	=	-112.7	dB	Space Loss [32.45 + 20log(914MHz)] + [20log(7mi X 1.609)]
				= 91.67dB + 21.03dB = 112.7dB
Results		-79	dBm	

The RF Receiver requires -110dBm (P_R) absolute minimum at its input. This example provides a safety margin of 110 - 79 = 31dBm, an excellent safety margin of signal strength at the receiver. Safety margins of 10 to 20dBm should be the desired goal for a system.

A simple test to insure an adequate safety margin is to connect an SMA connector style 20dB attenuator, in series, between the receiver antenna coaxial cable fitting and the incoming antenna cable to provide 20dB of attenuation to the received signal. If the system is made to work with this attenuator in place, removing the attenuator will guarantee a minimum safety margin of 20dB.

A variable attenuator can also be used to determine signal level margins. Place the attenuator in the receiver antenna input and attenuate the signal until the system fails. The amount of attenuation required is the safety margin in dB when the attenuator is removed.

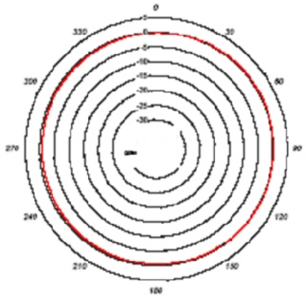
Antennas

The antenna connected to the receiver in a wireless system is the sensor that provides a signal to the receiving system. The antenna connected to the transmitter is the load that radiates the RF signal into space. Radio receivers are designed to work on extremely low signal levels and because of this, careful attention is given to antenna design and cable connections. Source and load impedances are carefully matched to the receiver input and transmitter output impedances to achieve maximum power transfer. The most common impedance used in 900 MHz systems is 50 ohms. The impedance across the antenna terminals is 50 ohms at the operating frequency. The transmitter is designed to drive a 50 ohm load and the receiver is designed to be driven from a 50 ohm source impedance.

The reference antenna used to state gain of an antenna is the isotropic source which theoretically radiates energy in a perfect sphere and has a gain of 0 dBi. All antennas achieve gain by modifying the radiation pattern to concentrate radiation in a directive pattern.

Whip Antenna

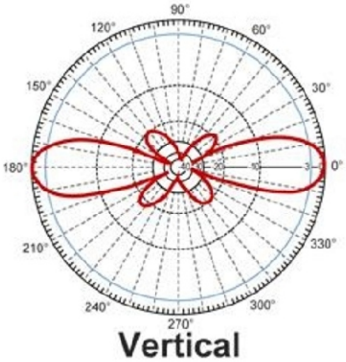
This vertical mount antenna is designed for short range work indoors. It has a gain of 1.8 dBi and a radiation pattern shaped like a horizontal donut.



7” Whip Antenna
1.8 dBi Gain

Omni Directional Vertical

This vertical antenna also has a radiation pattern shaped like a horizontal donut, but has a gain of 6 dBi and is designed for outdoor use. It is useful for a master antenna in a polling system where the control transmitter and receiver must send and receive to several slave units dispersed over a broad azimuth angle.



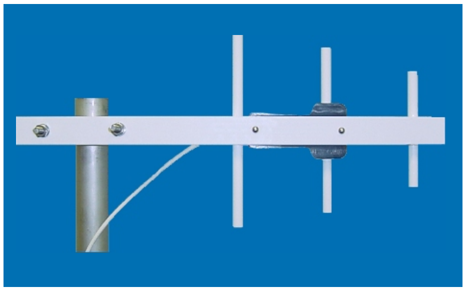
24” Omnidirectional Antenna
6 dBi Gain

Yagi Antenna

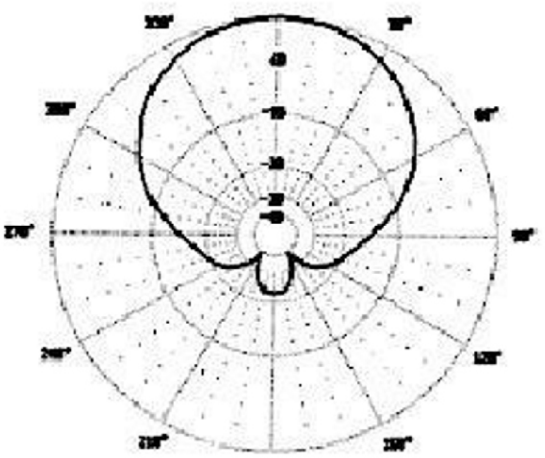
Yagi antennas achieve more gain than verticals by concentrating radiation in a single direction. Their reduced gain from the back end helps keep other signals from interfering with normal operation. The front to back ratio is an important characteristic of a yagi antenna.

A yagi antenna can be operated with the elements mounted vertically or horizontally. The most common use for industrial wireless is vertical. The transmitting and receiving antenna must both have the same element polarization for satisfactory operation. A large loss in signal is experienced when the elements are crossed polarized.

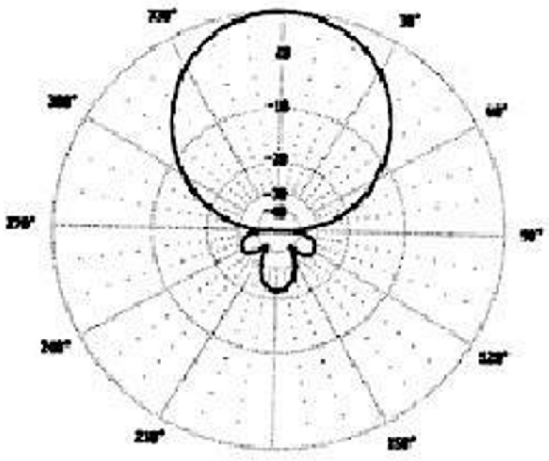
When a vertical omnidirectional antenna is used on the control end of a polling system, a yagi can be used on each slave unit for maximum gain and reduction in interference due to the front to back ratio gain reduction.



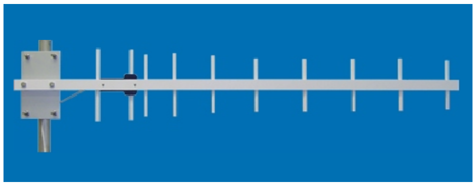
15” Yagi
8 dBi Gain



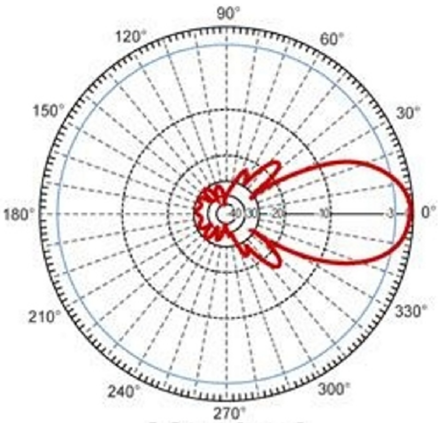
Horizontal Radiation Pattern



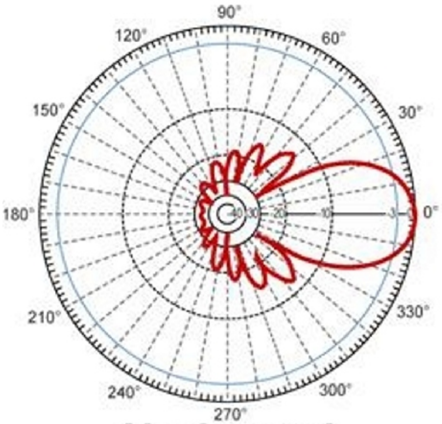
Vertical Radiation Pattern



43” Yagi
14 dBi Gain



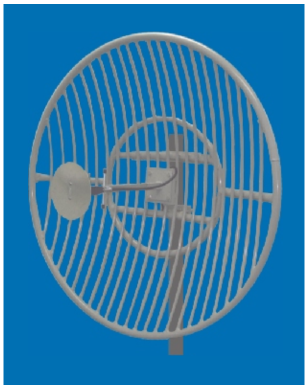
Vertical



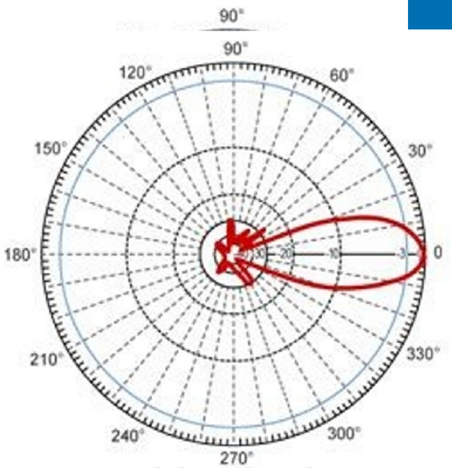
Horizontal

Parabolic Antenna

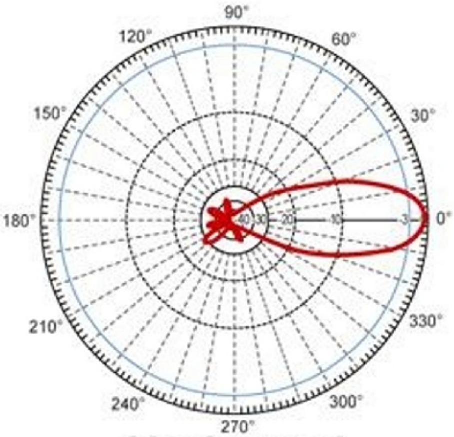
The Parabolic Antenna can only receive signals from the front. It is the antenna of choice for long range work or in areas of potentially high interference.



47.5” Parabolic
18 dBi Gain



Vertical



Horizontal

Appendix A-1

Coaxial Cable Chart

Cable Designation	Strands/ Cond. Dia.	Dielectric	Jacket / O.D. In.	Wt Lb/Ft	Impedance	Temp. Range
RG-58/U	1/.033 BC	PE	PVC/.193	.025	51.5	-40/+80C
RG-174/U	7/.0063 CCS	PE	PVC/.110	.007	50.0	-40/+75C
LMR195	1/0.037 BC	FPE	PE/.195	.021	50.0	-20/+60C
			PVC/.195	.021	50.0	-40/+85C
LMR400	1/0.108 BC	FPE	PE/.405	.068	50.0	-40/+85C
			FR-PVC/.405	.068	50.0	-20/+60C
LMR600	1/0.176 BC	FPE	PE/.590	.131	50.0	-40/+85C
			FR-PVC/.590	.131	50.0	-20/+60C

Appendix A-2

1.8 dBi Gain Whip Antenna Specifications

Overall Length: 7.0”
Whip Material: Wire (Black)
Base Material: Polyacetal (Black)
Connector Material: Brass with Nickel Plating
Operating Temperature: -20 / +65 Degrees C.

Frequency: 902 / 928 MHz
Impedance: 50 Ohms Nominal
VSWR: <2.0:1
Radiation: Omni
Polarization / Wave: Vertical / ½ wave

Appendix A-3

6 dBi Gain Omnidirectional Antenna Specifications

Dimensions: 24” L x .5” Diameter
Material: White Fiberglass Radome
Mounting: 2 3/8” dia. Mast max.
Wind Rating: >150 MPH
Mounting Kit: Supplied with HD Aluminum Bracket and SS U-Bolts

Frequency: 902 / 928 MHz
Impedance: 50 Ohms
VSWR: <2.0:1
Radiation: Omni
Polarization Vertical
Connector: Antenna supplied with N Female Connector

Appendix A-4

8 dBi Gain Yagi Antenna Specifications

Dimensions: 25” Length
Material: UV Polymer Coated Aluminum
Mounting: 2 3/8” dia. Mast max.
Wind Rating: >150 MPH
Mounting Kit: Supplied with SS U-Bolts

Frequency: 902 / 928 MHz
Impedance: 50 Ohms
VSWR: <1.5:1
Radiation: Directional
Polarization: Vertical or Horizontal
Connector: Antenna supplied with 12” pigtail with N Female Connector

Appendix A-5

14 dBi Gain Yagi Antenna Specifications

Dimensions: 43” Length
Material: UV Polymer Coated Aluminum
Mounting: 2 3/8” dia. Mast max.
Wind Rating: >150 MPH
Mounting Kit: Supplied with solid 1/4” aluminum mounting plate and two SS U-Bolts

Frequency: 902 / 928 MHz
Impedance: 50 Ohms
VSWR: <1.5:1
Radiation: Directional
Polarization: Vertical or Horizontal
Connector: Antenna supplied with 12” pigtail with N Female Connector

Appendix A-6

18 dBi Gain Parabolic Antenna Specifications

Dimensions: 47.2” Diameter
Material: Galvanized Steel Powder Coated Grid
Mounting: 2 3/8” dia. Mast max.
Wind Rating: 134 MPH
Mounting Kit: Supplied with HD 30 degree tilt and swivel mast kit.

Frequency: 902 / 928 MHz
Impedance: 50 Ohms
VSWR: <1.5:1
Radiation: Directional
Polarization: Vertical
Connector: Antenna supplied with 18” pigtail with N Female Connector

Appendix B

Frequency-Hopping Spread Spectrum

spread spectrum

Spread spectrum is a form of wireless communications in which the frequency of the transmitted signal is deliberately varied. This results in a much greater bandwidth than the signal would have if its frequency were not varied.

A conventional wireless signal has a frequency, usually specified in megahertz (MHz) or gigahertz (GHz), that does not change with time (except for small, rapid fluctuations that occur as a result of modulation). When you listen to a signal at 103.1 MHz on an FM stereo receiver, for example, the signal stays at 103.1 MHz. It does not go up to 105.1 MHz or down to 99.1 MHz. The digits on the radio's frequency dial stay the same at all times. The frequency of a conventional wireless signal is kept as constant as the state of the art will permit, so the bandwidth can be kept within certain limits, and so the signal can be easily located by someone who wants to retrieve the information.

There are at least two problems with conventional wireless communications that can occur under certain circumstances. First, a signal whose frequency is constant is subject to catastrophic interference. This occurs when another signal is transmitted on, or very near, the frequency of the desired signal. Catastrophic interference can be accidental (as in amateur-radio communications) or it can be deliberate (as in wartime). Second, a constant-frequency signal is easy to intercept, and is therefore not well suited to applications in which information must be kept confidential between the source (transmitting party) and destination (receiving party).

To minimize troubles that can arise from the above mentioned vulnerabilities of conventional communications circuits, the frequency of the transmitted signal can be deliberately varied over a comparatively large segment of the electromagnetic radiation spectrum. This variation is done according to a specific, but complicated mathematical function. In order to intercept the signal, a receiver must be tuned to frequencies that vary precisely according to this function. The receiver must "know" the frequency-versus-time function employed by the transmitter, and must also "know" the starting-time point at which the function begins. If someone wants to jam a spread-spectrum signal, that person must have a transmitter that "knows" the function and its starting-time point. The spread-spectrum function must be kept out of the hands of unauthorized people or entities.

Most spread-spectrum signals use a digital scheme called frequency hopping. The transmitter frequency changes abruptly, many times each second. Between "hops," the transmitter frequency is stable. The length of time that the transmitter remains on a given frequency between "hops" is known as the dwell time. A few spread-spectrum circuits employ continuous frequency variation, which is an analog scheme.

frequency-hopping spread spectrum

Frequency hopping is one of two basic modulation techniques used in spread spectrum signal transmission. It is the repeated switching of frequencies during radio transmission, often to minimize the effectiveness of "electronic warfare" - that is, the unauthorized interception or jamming of telecommunications. It also is known as frequency- hopping code division multiple access (FH-CDMA).
Spread spectrum modulation techniques have become more common in recent years. Spread spectrum enables a signal to be transmitted across a frequency band that is much wider than the minimum bandwidth required by the information signal. The transmitter "spreads" the energy, originally concentrated in narrowband, across a number of frequency band channels on a wider electromagnetic spectrum. Benefits include improved privacy, decreased narrowband interference, and increased signal capacity.

In an FH-CDMA system, a transmitter "hops" between available frequencies according to a specified algorithm, which can be either random or preplanned. The transmitter operates in synchronization with a receiver, which remains tuned to the same center frequency as the transmitter. A short burst of data is transmitted on a narrowband. Then, the transmitter tunes to another frequency and transmits again. The receiver thus is capable of hopping its frequency over a given bandwidth several times a second, transmitting on one frequency for a certain period of time, then hopping to another frequency and transmitting again. Frequency hopping requires a much wider bandwidth than is needed to transmit the same information using only one carrier frequency.

The spread spectrum approach that is an alternative to FH-CDMA is direct sequence code division multiple access (DS-CDMA), which chops the data into small pieces and spreads them across the frequency domain. FH-CDMA devices use less power and are generally cheaper, but the performance of DS-CDMA systems is usually better and more reliable. The biggest advantage of frequency hopping lies in the coexistence of several access points in the same area, something not possible with direct sequence.

Certain rules govern how frequency-hopping devices are used. In North America, the Industrial, Scientific, and Medial (ISM) waveband is divided into 75 hopping channels, with power transmission not to exceed 1 watt on each channel. These restrictions ensure that a single device does not consume too much bandwidth or linger too long on a single frequency.

The Federal Communications Commission (Fcc) has amended rules to allow frequency hopping spread spectrum systems in the unregulated 2.4 GHz band. The rule change is designed to allow wider bandwidths, thus enabling Internet devices to operate at higher speeds and fostering development of wireless LANs and wireless cable modems.

Movie star Hedy Lamarr is generally credited as co-originator of the idea of spread spectrum transmission. She and her pianist were issued a patent for the technique during World War II. They discovered the technique using a player piano to control the frequency hops, and envisioned it as a way to provide secure communications during wartime. The pair never made any money off the invention and their patent eventually expired. Sylvania introduced a similar concept in the 1950s and coined the term "spread spectrum."

sensoRAD™ Warranty Statement

The DR9011 / DR9021 carries a limited 3 year from date of shipment warranty. In the event of a failure due to defective material or workmanship, the unit will be repaired or replaced at no charge. Repairs will take place at the Wilkerson Instrument Company Inc. factory. In no event shall Wilkerson Instrument Company Inc's. responsibility exceed the original purchase price of the covered product.

The product covered by this warranty is warranted to perform to it's original specifications as published by Wilkerson Instrument Company Inc.. There is no warranty of merchantability or fitness for a particular purpose. This warranty excludes liability for any consequential damage that may accompany or follow a covered defect occurrence or failure. The warranty further excludes damage from improper use, abuse, or operation contrary to instructions provided by the manufacturer.