Tutorial on Basic Link Budget Analysis

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Abstract

Advances in the state-of-the-art have made wireless technology a more compelling solution for many consumer applications. This poses a problem to many practicing engineers and technology managers who are unfamiliar with the relevant concepts and terminology. To add to the confusion, FCC regulations require the use of Spread Spectrum techniques for most applications in the unlicensed bands.

This paper is intended to provide the basic concepts necessary to perform a top level analysis of a wireless link. In addition, other terms and concepts are briefly described with should help in understanding some of the system design issues, including a brief description of Spread Spectrum techniques. Two examples are given which demonstrate the influence of range, data rate, and modulation technique on the radio requirements.

Introduction

There has been a great deal of interest of late in the application of wireless technology in industrial, commercial, and even consumer environments. Several vendors, including Intersil, offer products which comply with FCC regulations for unlicensed operation at 2.4GHz. These regulations permit radiated RF power of up to 1W when spread spectrum modulation techniques are used. There are many applications for which the complexities imposed by the use of spread spectrum radios are more than offset by the interference rejection properties and higher RF power permitted by FCC regulations.

Successful design of high speed wireless data links involves many factors and is well beyond the scope of this application note. However, a top-level link budget analysis is a fairly straightforward exercise. It is the first step an engineer will take in order to determine the feasibility of any given system. A link budget calculation is also an excellent means for anyone to begin to understand the various factors which must be traded off to realize a given cost and level of reliability for a communications link.

This application note describes a method for performing a basic link budget analysis. This discussion is followed by two simple examples. One example involves a short range wireless link capable of 40kbits/s (kbps), which might be suitable to provide a laptop computer with wireless access to a nearby dial-up modem. The second example involves a high speed (2Mbps), longer range link designed for Wireless USB in a home environment. These examples will demonstrate the effects of range, data rate, and modulation method on system requirements.

PRISM® Overview

PRISM is a 2.4GHz Wireless Local Area Network (WLAN) chip set designed to meet the direct sequence spread spectrum physical layer (radio) specifications of the IEEE802.11 WLAN standard. PRISM uses Differential Phase Shift Keying (DPSK) as the modulation scheme. The PRISM radio architecture provides half duplex wireless RF communications for packet data rate of 2Mbps. PRISM provides 70mW of RF power at the antenna, which enables continuous data connectivity at up to 400 feet indoors and 1000 feet outdoors. For more details, see Intersil Application Note AN9624 PRISM DSSS PC Card Wireless LAN Description.

Communications Basics

When evaluating a wireless link, the three most important questions to be answered are:

1. How much radio frequency (RF) power is available?
2. How much bandwidth is available?
3. What is the required reliability (as defined by Bit Error Rate, or BER)?

In general, RF power and bandwidth effectively place an upper bound on the capacity of a communications link. The upper limit in terms of data rate is given by Shannon's Channel Capacity Theorem:

$$C = B * \log_2 (1 + S/N) \quad \text{(EQ.1)}$$

where:

C = channel capacity (bits/s)

B = channel bandwidth (Hz)

S = signal strength (watts)

N = noise power (watts)

Note that this equation means that for an ideal system, the bit error rate (BER) will approach zero if the data transmission rate is below the channel capacity. In the "real world", the degree to which a practical system can approach this limit is dependent on modulation technique and receiver noise.

Channel Noise

For all communications systems, channel noise is intimately tied to bandwidth. All objects which have heat emit RF energy in the form of random (Gaussian) noise. The amount of radiation emitted can be calculated by:

$$N = kTB \quad \text{(EQ.2)}$$

where:

N = noise power (watts)

k = Boltzman's constant (1.38×10^{-23} J/K)

T = system temperature, usually assumed to be 290K

B = channel bandwidth (Hz)

This is the lowest possible noise level for a system with a given physical temperature. For most applications, temperature is typically assumed to be room temperature (290K). Equations 1 and 2 demonstrate that RF power and bandwidth can be traded off to achieve a given performance level (as defined by BER).

Range and Path Loss

Another key consideration is the issue of range. As radio waves propagate in free space, power falls off as the square of range. For a doubling of range, power reaching a receiver antenna is reduced by a factor of four. This effect is due to the spreading of the radio waves as they propagate, and can be calculated by:

$$L = 20 \log_{10} (4\pi D / \lambda) \quad \text{(EQ.3)}$$

where:

D = the distance between receiver and transmitter

λ = free space wavelength = c/f

c = speed of light (3×10^8 m/s)

f = frequency (Hz)

Equation 3 above describes line-of-sight, or free space propagation. Because of building obstructions such as walls and ceilings, propagation losses indoors can be significantly higher. This occurs because of a combination of attenuation by walls and ceilings, and blockage due to equipment, furniture, and even people. For example, a “2 x 4” wood stud wall with sheetrock on both sides results in about 6dB loss per wall. Experience has shown that line-of-sight propagation holds only for about the first 20 feet. Beyond 20 feet, propagation losses indoors increase at up to 30dB per 100 feet (see Figure 1) in dense office environments. This is a good “rule-of-thumb”, in that it is conservative (it overstates path loss in most cases). Actual propagation losses may vary significantly depending on building construction and layout.

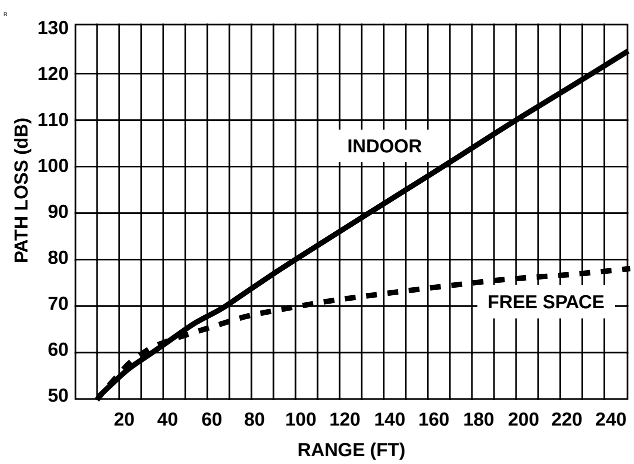

FIGURE 1. ESTIMATED INDOOR PROPAGATION LOSSES AT 2.4GHz

Multipath and Fade Margin

Multipath occurs when waves emitted by the transmitter travel along a different path and interfere destructively with waves travelling on a direct line-of-sight path. This is sometimes referred to as signal fading. This phenomenon occurs because waves travelling along different paths may be completely out of phase when they reach the antenna, thereby canceling each other.

Since signal cancellation is almost never complete, one method of overcoming this problem is to transmit more power. In an indoor environment, multipath is almost always present and tends to be dynamic (constantly varying). Severe fading due to multipath can result in a signal reduction of more than 30dB. It is therefore essential to provide adequate link margin to overcome this loss when designing a wireless system. Failure to do so will adversely affect reliability.

The amount of extra RF power radiated to overcome this phenomenon is referred to as fade margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule-of-thumb is 20dB to 30dB.

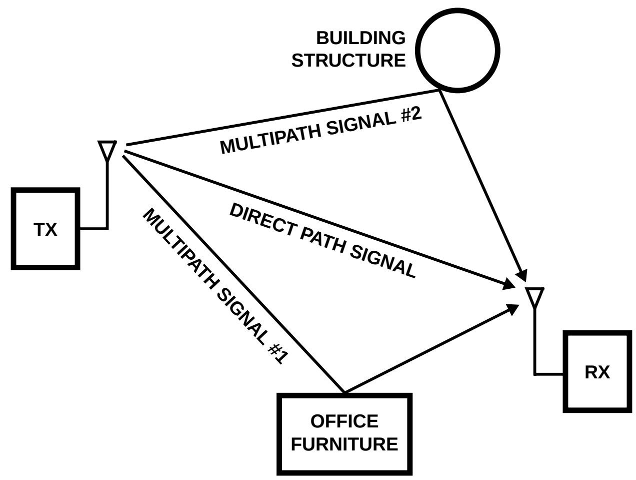

FIGURE 2. MULTIPATH

One method of mitigating the effects of multipath is antenna diversity. Since the cancellation of radio waves is geometry dependent, use of two (or more) antennas separated by at least half of a wavelength can drastically mitigate this problem. On acquisition of a signal, the receiver checks each antenna and simply selects the antenna with the best signal quality. This reduces, but does not eliminate, the required link margin that would otherwise be needed for a system which does not employ diversity. The downside is this approach requires more antennas and a more complicated receiver design.

Another method of dealing with the multipath problem is via the use of an adaptive channel equalizer. Adaptive equalization can be used with or without antenna diversity.

After the signal is received and digitized, it is fed through a series of adaptive delay stages which are summed together via feedback loops. This technique is particularly effective in slowly changing environments such as transmission over telephone lines, but is more difficult to implement in rapidly changing environments like factory floors, offices and homes where transmitters and receivers are moving in relation to each other. The main drawback is the impact on system cost and complexity. Adaptive equalizers can be expensive to implement for broadband data links.

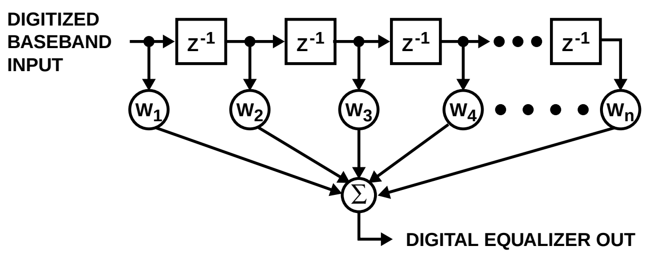

FIGURE 3. ADAPTIVE EQUALIZER

Spread spectrum systems are fairly robust in the presence of multipath. Direct Sequence Spread Spectrum (DSSS) systems will reject reflected signals which are significantly delayed relative to the direct path or strongest signal. This is the same property which allows multiple users to share the same bandwidth in Code Diversity Multiple Access (CDMA) systems. Frequency Hopping Spread Systems (FHSS) also exhibit some degree of immunity to multipath. Because a FHSS transmitter is continuously changing frequencies, it will always hop to some frequencies which experience little or no multipath loss. In a severe fading environment, throughput of an FHSS system will be reduced, but it is unlikely that the link will be lost completely. The performance of DSSS systems in the presence of multipath is described further in a separate section below.

Modulation Technique

Modulation technique is a key consideration. This is the method by which the analog or digital information is converted to signals at RF frequencies suitable for transmission. Selection of modulation method determines system bandwidth, power efficiency, sensitivity, and complexity. Most of us are familiar with Amplitude Modulation (AM) and Frequency Modulation (FM) because of their widespread use in commercial radio. Phase Modulation is another important technique. It is used in applications such as Global Position System (GPS) receivers and some cellular telephone networks.

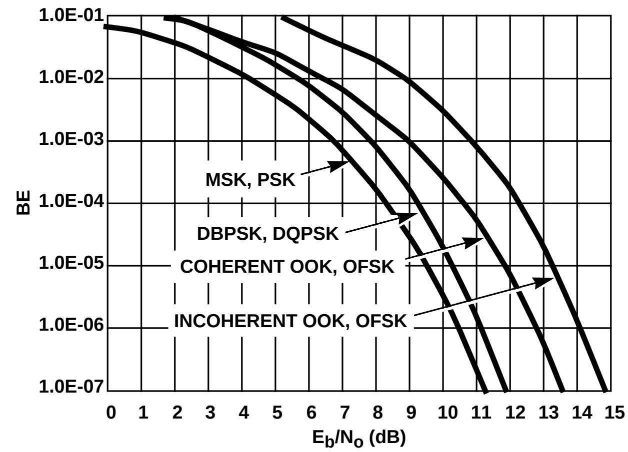

FIGURE 4. PROBABILITY OF BIT ERROR FOR COMMON MODULATION METHODS

For the purposes of link budget analysis, the most important aspect of a given modulation technique is the Signal-to-Noise Ratio (SNR) necessary for a receiver to achieve a specified level of reliability in terms of BER. A graph of E_b/N_o vs BER is shown in Figure 4. E_b/N_o is a measure of the required energy per bit relative to the noise power. Note that E_b/N_o is independent of the system data rate. In order to convert from E_b/N_o to SNR, the data rate and system bandwidth must be taken into account as shown below:

$$SNR = (E_b/N_o) * (R/B_T) \quad \text{(EQ.4)}$$

where:

E_b = Energy required per bit of information

N_o = thermal noise in 1Hz of bandwidth

R = system data rate

B_T = system bandwidth

TABLE 1. TYPICAL BANDWIDTHS FOR VARIOUS DIGITAL MODULATION METHODS

MODULATION METHOD	TYPICAL BANDWIDTH (NULL-TO-NULL)
QPSK, DQPSK	1.0 x Bit Rate
MSK	1.5 x Bit Rate
BPSK, DBPSK, OFSK	2.0 x Bit Rate

Spread Spectrum Radios

The term “spread spectrum” simply means that the energy radiated by the transmitter is spread out over a wider amount of the RF spectrum than would otherwise be used. By spreading out the energy, it is far less likely that two users sharing the same spectrum will interfere with each other. This is an important consideration in an unlicensed band, which why the regulatory authorities imposed spread spectrum requirements on radios which transmit over -1dBm (about 0.75mW) in the following bands:

TABLE 2. WORLD WIDE UNLICENSED FREQUENCY ALLOCATION RF POWER LIMITS

BAND	FCC REGS (US)	ETSI (EUROPE)	MPT (JAPAN)
902 - 928MHz	<1000mW	N/A	N/A
2400 - 2483.4MHz	<1000mW	<100mW	N/A
2471 - 2497MHz	N/A	N/A	<10mW/MHz
5725 - 5875MHz	<1000mW	<100mW	N/A

In the U.S., these bands are collectively designated as Industry, Science, and Medicine (ISM) bands. Operation in these bands with approved devices does not require an FCC license. By waiving licensing requirements, these bands have been made generally accessible to virtually anyone. This is mainly why the ISM bands are so important for commercial and consumer applications.

As mentioned above, radios employing spread spectrum methods are allowed to radiated up to 1.0W (30dBm) of RF energy, as compared to less than 1mW for non-spread radios. There are two common types of spread spectrum systems. The easiest to understand is Frequency Hopped Spread Spectrum (FHSS). In this method, the carrier frequency hops from channel to channel in some pre-arranged sequence. The receiver is programmed to hop in sequence with the transmitter. If one channel is jammed, the data is simply retransmitted when the transmitter hops to a clear channel. The major drawback to FHSS is limited data rate. In the 2.4GHz band, FCC regulations require that the maximum occupied bandwidth for any single channel is 1MHz. This effectively limits the data rate through this type of system to about 1Mbps.

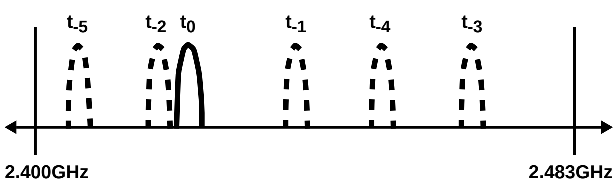

FIGURE 5. FHSS SPECTRUM UTILIZATION

By contrast, Direct Sequence Spread Spectrum (DSSS) systems in the ISM bands provide much higher data rates. DSSS systems do not jump from frequency to frequency. Instead, the transmitter actually spreads the energy out over a wider portion of the RF spectrum. This can be accomplished by combining the data stream with a much higher rate Pseudo Random Numerical (PRN) sequence via an XOR function. The result is a digital stream at the same rate as the PRN. When the RF carrier is modulated by the higher speed digital stream, the result is a spreading of the RF energy.

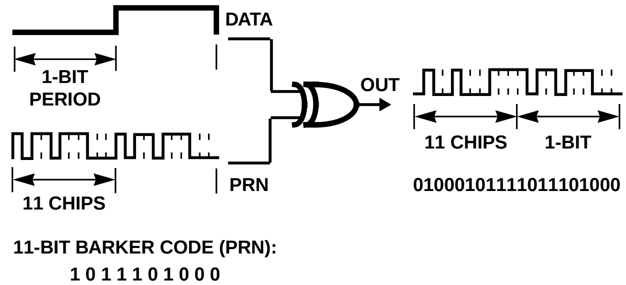

FIGURE 6. COMBINING PRN SEQUENCE AND DATA

The individual 1's and 0's that make up the PRN are called "chips". They are distinct from the "bits" in the data stream because chips are predetermined by the PRN sequence and hence, contain no information. The ratio of the chip rate (C) to the data rate (R) is called processing gain. In the PRISM radio, this ratio is selectable. It can be set to 11, 13, 15, or 16 chips/bit. The IEEE 802.11 Standard specifies an 11 chip PN sequence (Barker code), which will be used for this example.

$$\text{Processing Gain} = 10\log10(C/R) = 10.4\text{dB} \quad \text{(EQ.5)}$$

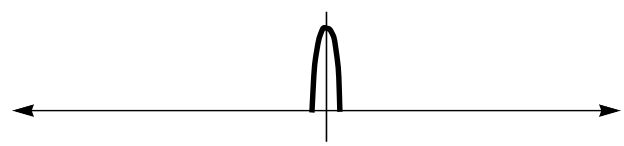

FIGURE 7A. TRANSMITTER BASEBAND SIGNAL BEFORE SPREADING

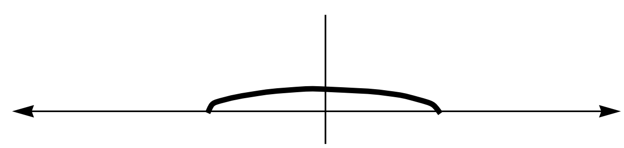

FIGURE 7B. TRANSMITTER BASEBAND SIGNAL AFTER SPREADING

At the receiver, the pseudo random code is used to "de-spread" the received data. In the PRISM chip set, this is accomplished by means of a matched filter at baseband. It is during this process that the matched filter rejects unwanted interference because it is uncorrelated with the PRN. By careful selection of the PRN sequence, the matched filter provides an additional benefit. It can reject multipath signals which are delayed relative to the main signal by more than one chip period, or about 44ns. In this manner, it provides some of the benefits of the adaptive equalizer shown in Figure 3, though its operation and implementation are much simpler.

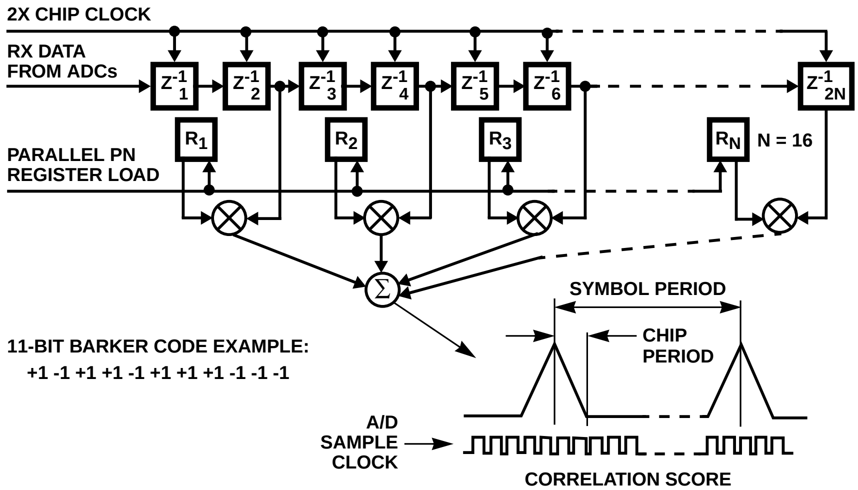

FIGURE 8. MATCHED FILTER CORRELATOR

If viewed on a spectrum analyzer, the de-spreading process would cause the received spectrum to decrease in width by a factor of 11:1, while at the same time causing the peak in the spectrum to increase in amplitude by the same amount. This is why this effect is called processing gain.

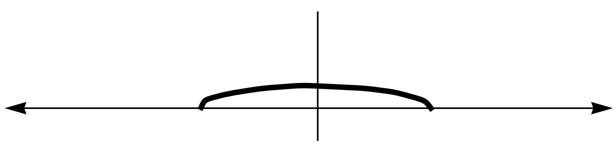

FIGURE 9A. RECEIVER BASEBAND SIGNAL BEFORE MATCHED FILTER CORRELATOR

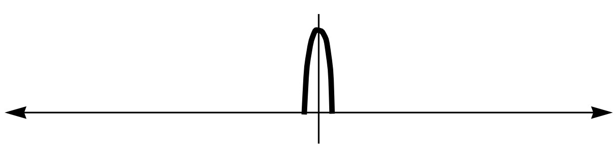

FIGURE 9B. RECEIVER BASEBAND SIGNAL AFTER MATCHED FILTER CORRELATOR

Example 1: Wireless Link to Dial-Up Modem

As an example, consider a data link intended to provide a wireless link between a laptop computer and a dial-up modem in a home environment as shown in Figure 10. In order to support a throughput of 28.8kbps, the link should be designed for about 40kbps. The additional data rate is needed to accommodate framing, overhead, checksums which may be required for the wireless link.

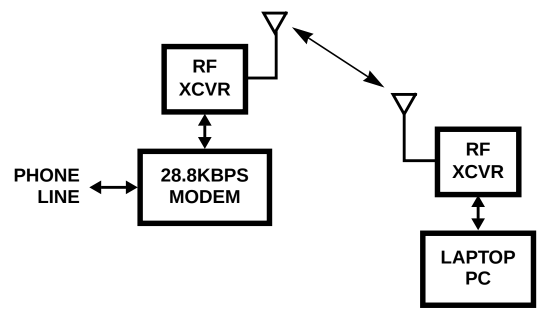

FIGURE 10. EXAMPLE 1: WIRELESS LINK TO MODEM

Example 1: Requirements

Required data rate = 40kbps
(28.8kbps plus framing, overhead, and checksum)

Range =5 meters
Desired BER $=10^{-6}$

Example 1: FCC and ETSI Regulations

For unlicensed systems not employing spread spectrum techniques, RF power is limited to -1.25dBm, or about 0.75mW. For details on RF power limitations, refer to FCC Regulations 15.247 and 15.249. If spreading is employed, RF power can be increased to 1W (U.S. operations). For Europe, ETSI regulations (ETSI 300, 328) limit RF power for spread spectrum radios to 20dBm, or 100mW. Spreading is therefore attractive because it allows for transmission of up to 1000 times more RF power.

Example 1: So, Should Spread Spectrum Techniques Be Used In This Case?

Spread spectrum offers some interference rejection properties, but it also entails higher complexity. Therefore, the application should first be evaluated to determine if it can be reliably serviced by a low power, non-spread spectrum radio. If not, then spread spectrum high power radios should be considered.

Example 1: Frequency Selection

There are several bands available for unlicensed operation (see Table 2). As described previously, in the Multipath and Fade Margin section, the higher the frequency, the higher the propagation loss. Therefore, a lower frequency is better in terms of propagation loss. It is generally less expensive to build radios at lower frequencies. Other considerations include available bandwidth and regulatory limitations. The available bands are 900MHz, 2.4GHz, and 5.725GHz. The easy choice is 900MHz, but this band is getting crowded with things like cordless phones. For such a short link, 900MHz is still a good choice.

Example 1: Modulation Technique

There are lots of choices here. The Intersil PRISM radio chip set uses Phase Shift Keying (PSK) modulation, but some of the motivating factors behind this choice are not applicable in this instance. A simpler method is Frequency Shift Keying (FSK). FSK is actually a form of Frequency Modulation (FM), which has been around for a long time. With FSK, two separate frequencies are chosen, one frequency representing a logical “zero”, the other representing logical “one”. Data is transmitted by switching between the two frequencies.

A good choice of modulation would therefore be FSK. The separation of two frequencies relative to the bit rate is called modulation index (h).

h = frequency separation / bit rate

= Δf / R

A modulation index of 1 (h = 1) is a good choice for a low cost application, unless there are restrictions on bandwidth. When h = 1, the frequencies are said to be orthogonal. This form of modulation is called Orthogonal FSK, or OFSK. Choosing h = 1 results in a simple but fairly robust receiver design. In this case, the frequencies would be separated by 40kHz.

Example 1: System Bandwidth and Noise Floor

In general, the modulation technique dictates the required system bandwidth (or visa versa, depending on design constraints). For FSK modulation and h = 1, the bandwidth is typically about 2 times the data rate (see Table 1), or 80kHz. We therefore can compute the noise power:

N = kTB (EQ.6)

= 1.38×10^{-23} J/K x 290K x 80,000 s^{-1}

= 2.4×10^{-13}mW

= -126dBm

This figure represents a theoretical noise floor for an ideal receiver. A real receiver noise floor will always be higher, due to noise and losses in the receiver itself. Noise Figure (NF) is a measure of the amount of noise added by the receiver itself. A typical number for a low cost receiver would be about 15dB. This number must be added to the thermal noise to determine the receiver noise floor:

Receiver Noise Floor = -126dBm + 15dB (EQ.7)

= -111dBm

Example 1: Receiver Sensitivity

The first step in performing the link budget is determining the required signal strength at the receiver input. This is referred to as receiver sensitivity (P_{rx}). As described previously, this is a function of the Modulation Technique and the desired BER. A graph of E_b/N_o vs BER is shown in Figure 2. For the case at hand, the modulation technique is OFSK. For 10^{-6} BER:

E_b/N_o = 14.2dB = 26.3 (EQ.8)

SNR = $(E_b/N_o) * (R/B_T)$ (EQ.9)

= 26.3 * (40kbps / 80kHz)

= 11dB

Prx = Receiver Noise Floor + SNR (EQ. 10)

= -111dBm + 11dB

= -100dBm

Example 1: Link Calculation

Propagation loss (L_{fs}) can be computed as:

L_{fs} = 20 x $\log_{10}$(4 * pi * D/lambda) (EQ. 11)

= 20 x $\log_{10}$(4 * pi * 5 meters/0.33 meters)

= 46dB

Note: lambda is the free space wavelength at the carrier frequency

λ = c/f

= 3 x 108ms-1/900MHz

= 0.33 meters

Finally, some assumption must be made about transmit and receive antenna gain values. For a simple dipole antenna, an assumption of 0dB gain is reasonable. This number will be taken for the gain of both the transmit antenna gain (G_{tx})and receive antenna gain (G_{rx}). Now, the required transmitter power (P_{tx}) can be computed:

$P_{tx} = P_{rx} - G_{tx} - G_{rx} + L_{fs}$ + Fade Margin (EQ. 12)

= -100dBm - 0dB - 0dB + 46dB + 30dB

= -24dBm

Example 1: Conclusions

This exercise shows that the wireless modem link can be reliably served by an OFSK radio operating at 900MHz using as little as -24dBm transmit power. FCC regulations permit transmission of up to -1.25dBm in the unlicensed bands without requiring spread spectrum modulation. However, as mentioned above, the 900MHz band is becoming crowded. This is particularly true for consumer application due to the proliferation of cordless telephones. If this is considered a major problem, the above analysis can easily be re-evaluated assuming a carrier frequency in other unlicensed bands such as 2.4GHz, or even 5GHz.

In addition to the analysis of the radio link itself, there are other considerations beyond those mentioned here. These include the suitability of the modem protocol to packet mode transmission, synchronization of data rates, etc. The foregoing discussion focused on the link analysis and is by no means exhaustive. It is intended to illustrate top level trades involving data rate, range, and choice of modulation.

Example 2: Wireless USB - An Ideal Application for PRISM

Having shown that PRISM is not the optimal choice for a short-haul, low bit rate wireless link such as the wireless modem described above, a more suitable application will now be explored. Universal Serial Bus (USB) is rapidly replacing the serial port on personal computers. USB provides high speed flexible interconnectivity between a PC and its peripherals. Despite its flexibility, USB has a range limitation of 5 meters.

USB has two modes of signaling. The full speed signaling rate is 12Mbps, while the low rate is 1.5Mbps. The low speed rate is designed to support devices such as mice and keyboards. However, a radio capable of providing 1.5Mbps throughput could be used in a wireless hub application, though it could not support the full hi-speed rate of 12Mbps. A wireless hub could support bulk transfers, and possibly isochronous applications such as wireless audio and MPEG1 video if rate buffering were available at the transmit side of the link.

In this example, a wireless digital link capable of 1.5Mbps throughput at up to 100 feet indoors is desired. As in the previous example, a somewhat higher data rate will be required in order to accommodate framing, overhead, and checksum for the wireless link. Typically, throughput is about 70% to 75% of peak data rate. Therefore, the required data rate for the wireless link is roughly 2Mbps.

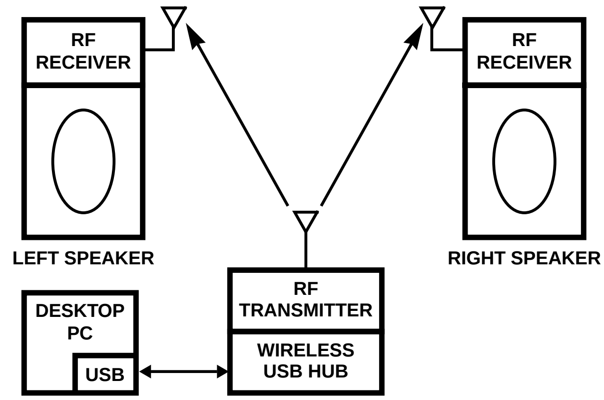

FIGURE 11. WIRELESS USB LINK

Example 2: Requirements

Data Rate = 2Mbps (1.408Mbps + framing, overhead, checksum)

Range = 30 meters indoors (100 feet)

Desired BER = 10^{-6}

Example 2: Should I Use a Spread Spectrum Radio?

In the previous example, spreading was not required. However, there are a couple of major differences with this example. The data rate is much higher and the range is a farther. Therefore, due to FCC restrictions on transmitted power for non-spread spectrum transmitters in the unlicensed bands, the non-spread OFSK radio described in Example 1 above will not be capable of meeting this far more stringent application. By contrast, Intersil's PRISM radio was designed specifically for such demanding applications. It employs spread spectrum techniques and can radiate up to 1W of RF power according to FCC regulations (FCC 15.247).

Example 2: Frequency Selection

As described previously, there are several bands allocated for unlicensed operation. There is spectrum at 902-928MHz. However, this band is getting pretty crowded. Another consideration is the limited bandwidth. There is only 26MHz in this band. A better choice would be the 2.400 - 2.483GHz. There is less radio traffic in this band (although there is potential interference from microwave ovens), and the total available bandwidth is 83MHz. In addition, this frequency band is approved for unlicensed operation in the U.S., Europe, and Japan.

Example 2: Modulation Technique

PRISM utilizes Differential Binary Phase Shift Keyed (DBPSK) modulation to transmit data at up to 1Mbps, and Differential Quadrature Phase Shift Keyed (DQPSK) modulation to transmit data up to 2Mbps. The main advantage of DQPSK is spectral efficiency. The null-to-null bandwidth for a DQPSK radio is about the same as the data rate (R).

Example 2: System Bandwidth and Noise Floor

For 2Mbps, the occupied bandwidth of a PRISM transmitter would be 22MHz due to spreading. Due to the 11:1 ratio between the chip rate (C) and the data rate (R), the radio is transmitting 22Mcps. This results in an occupied bandwidth of 22MHz (see Figure 7). However, after the de-spreading at the receiver, the bandwidth at baseband would be restored to 2MHz (see Figure 8). It is important to note that although PRISM is a spread spectrum radio, the noise floor is computed using the de-spread bandwidth:

$$\text{Noise} = kTB \quad \text{(EQ. 13)}$$

$$= 1.38 \times 10^{-23}\ \text{J/K} \times 290\text{K} \times 2{,}000{,}000\ \text{s}^{-1}$$

$$= 4 \times 10^{-12}\text{mW}$$

$$= -113\text{dBm}$$

PRISM has a receiver noise figure of 7dB. The receiver noise floor is then:

$$\text{Rx Noise Floor} = -111\text{dBm} + 7\text{dB} \quad \text{(EQ. 14)}$$

$$= -104\text{dBm}$$

From Figure 1, the free space path loss at 100 feet for indoor propagation may be determined. This value is 80dB. DQPSK is an efficient modulation technique. The required E_b/N_o to achieve a 10^{-6} BER is 11dB. The required signal-to-noise ratio (SNR) and receiver sensitivity (Prx) can now be determined:

$$E_b/N_o = 11\text{dB} = 12.7 \quad \text{(EQ. 15)}$$

$$\text{SNR} = (E_b/N_o) * (R/BT) \quad \text{(EQ. 16)}$$

$$= 12.7 * (2\text{Mbps} / 2.0\text{MHz})$$

$$= 11\text{dB}$$

$$P_{rx} = \text{Receiver Noise Floor} + \text{SNR} \quad \text{(EQ. 17)}$$

$$= -104\text{dBm} + 11\text{dB}$$

$$= -93\text{dBm}$$

One of the characteristics of Direct Sequence Spread Spectrum (DSSS) radios such as PRISM is reduction in the effects of multipath. If the indirect signal is delayed by more than a chip period, it will appear to the receiver as uncorrelated random noise, and will not cancel the direct signal. Therefore, an allocation of 30dB is an even more conservative assumption for fade margin. Transmit and receive antenna gain are unchanged from the previous example (0dB). Using this data, the link budget may now be recalculated:

$$P_{tx} = P_{rx} - G_{tx} - G_{rx} + L_{fs} + \text{Fade Margin} \quad \text{(EQ. 18)}$$

$$= -93\text{dBm} - 0\text{dB} - 0\text{dB} + 80\text{dB} + 30\text{dB}$$

$$= 17\text{dBm}$$

FCC regulations permit DSSS systems to transmit up to 1W (or 30dBm). The PRISM Radio chip set provides +18dBm radiated power, which is ideal for this application. In addition, the DSSS waveform provides an additional 10dB of rejection of potential jammers, such as microwave ovens, arc welders, and other industrial machinery.

Example 2: Conclusions

PRISM is an ideal solution for high bit rate (up to 2Mbps) mobile data transmission. In addition to its robust waveform, it features IEEE 802.11 compliant operation. It has a Carrier Sense Multiple Access collision avoidance feature which allows multiple users to share the same RF channel. The programmable synthesizer allows for the collocation of several channels to accommodate even more users. The highly integrated chip set provides a complete Antenna-to-Bits solution.

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For Intersil documents available on the internet, see web site www.intersil.com/
Intersil AnswerFAX (321) 724-7800.

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