Introduction
Radio, to many people, is a black box mystery. The challenges in design may be many and the learning curve can be high, and it is probably better left to other people. This misconception is heard many times over; but, in reality, given the high levels of integration from RFIC vendors, the task is surprisingly simple.

Initially many designers concern themselves with the complications surrounding the issue of regional regulation since the regulations tend to differ throughout the world. Understanding and addressing the different regional regulations however is mostly a function of research since in each region there is usually a government agency responsible for publishing documents to explain the rules associated with 'intentional' transmitters.

Example:
USA; the Federal Communications Commission (FCC) publishes their requirements for unlicensed radio transmission in FCC Title 47 part 15.

The greater mystery in radio exists in that radio link quality depends on so many external factors; each variable interacting with each other to create complex scenarios, which are often difficult to interpret. Understanding the basic concepts however often simplifies the comprehension of day to day differences in radio link qualities. Once an understanding of these basics is achieved, many of these issues can be resolved by a low cost, and easy to implement technique called antenna diversity.

Environmental Considerations
The primary environmental factors that can influence the consistent robustness of a radio link are phenomena called multipath/fading and antenna polarization/diversity. These phenomena can be either constructive or deconstructive to the quality of the radio link depending on many given circumstances. It is the infinite number of conceivable circumstances that cause difficulties when trying to understand the specific environmental conditions acting upon a radio link at any one time and the resultant link quality that is achieved.
Antenna Polarization / Diversity
The phenomenon known as antenna polarization is due to the directional properties of any given antenna. While the effects of antenna polarization may be interpreted as a reduction in the quality of some radio links, some radio designers often make use of this property to tune an antenna to their needs by restricting transmission or reception to signals on a limited number of vectors. This is done as antennas do not radiate equally in all directions and making use of this property can mask a system from other sources of RF noise.

Using simplistic terminology, antennas are either considered Omni-directional or directional. Omni-directional antennas hypothetically transmit and receive equally in all directions. Directional antennas transmit or receive along a limited number of vectors.

Creating highly robust links start with understanding the application.

Example: If a link is to be achieved where signals will only come from a certain direction, then a highly directional antenna is extremely beneficial.

- A receiver fitted with a directional antenna will receive signals from a transmitter that is positioned within a vector of good line-of-sight to the directional properties of the antenna. Other transmitters that are positioned outside of the directional vectors may be masked from the receiver.
- A transmitter fitted with a directional antenna will radiate most of its energy in a predefined direction rather than distributing its energy in all directions and reducing its range capabilities.

To simplify the task of comprehending antenna profiles, antenna vendors provide antenna radiation plots. Antenna radiation plots can come in different formats such as the ‘E’ plane plot and the ‘polar’ plot.

The ‘E’ plane plot provides a great deal of information but the directionality, or pattern shape, is usually not as clear as from a polar plot. The polar plot is designed to resemble a compass, making it easier to comprehend antenna gain in any given direction.
Figure 1 – Example Radiation Plots

In the antenna plots engineers can see a high level 2-dimensional representation of how an antenna performs in its intended plane, however antennas do tend to change characteristics about their other axis also but often the 3-dimensional data is not provided as it drastically increases the complexity of the diagrams.
The whip antenna is considered typically as an Omni-directional antenna with a very simple 3-dimensional profile.

![3-dimensional profile of a whip antenna](image1)

![2-dimensional polar ‘slice’ plot](image2)

*Figure 2 – Radiation fields surrounding a simple whip antenna*

In close proximity, whip antennas tend to provide good coverage on a level plane but due to their 3-dimensional profile they tend to provide poor performance directly above or below them. This can be better understood when the antenna is placed into a two floor indoor environment.

![Figure 3 – Effects of Antenna directionality](image3)
Often due to the reflections of RF signals off walls and other interior objects the effects of the antenna polarization may not be observed, however other effects may be observed that may be constructive or deconstructive to an RF signal. This effect is called multipath/fading.

**Multipath/Fading**

Fading is the phenomena often observed when small movements by either a transmitter or a receiver can lead to large differences in link quality. This happens as an antenna moves in and out of the peaks of a signal.

![Figure 4 – Fading effects on an antenna](image)

Multipath expands on this concept. As radio waves are transmitted, they may not be received by the receiver through one path, rather the signal may come from multiple paths through reflections off other objects such as walls and trees – multipath. The signals received from each of these sources are likely to arrive at slightly different time intervals meaning slight phase shifts may occur. When these signals combine they may result in a form of cancellation – fading.
Figure 5 – Direct and Indirect RF pathways

Figure 6 – Worst case RF fading effect from phase shifts caused by multipath
Using a worst case scenario it can be demonstrated that should two signals arrive at a receiver exactly 180 degrees out of phase then the receiver will not see any data – this would be 100% signal fading. In most cases it would be very unusual for a receiver to receive two signals with exactly 180 degrees of phase shift, but it is likely that some phase shift will have occurred when multipath environments are present. Under these conditions some signal fading will occur.

**Antenna Diversity**

Antenna diversity is a technique that is often used to recover signal integrity. Antennas in a product that implements antenna diversity usually have their antenna mounted at 90 degrees to one another such that the effects of polarization/directionality do not reduce the quality of the potential radio link.

*Figure 7 – Combating directionality through the use of multiple antennas*
In addition to mounting antennas at 90 degrees to one another, antennas in a product that implements antenna diversity have their antennas mounted at a distance of at least ¼ wavelength apart, this ensures that at least one antenna is in a peak of the waveform.

![Figure 8 - Combating RF fading with multiple antennas](image)

While antenna diversity is useful at recovering signal integrity and retaining link budget from the effects of the environment, many designers opt not to use it as the trade offs can be considered quite high in their applications. In most cases the trade off comes from the increased MCU overhead as the MCU has to remain awake for longer periods of time to evaluate the antenna signals. The increased MCU activity usually leads to a greater specification and a more costly MCU, the MCU also has extended ‘on-times’ that result in shorter battery lives. In other cases the extra space used to implement a two antenna solution or the additional code expertise required restricts the engineers to a single antenna design.

Coding an antenna diversity system adds a substantial coding burden onto a design. Many antenna diversity systems are optimized to operate in a synchronized manner. The MCU on the receiver maintains a timer that allows the receiver to know when to start receiving data. Under these circumstances, the MCU can immediately start evaluating the signal on both antennas. To evaluate the signal, the MCU would switch between each antenna and evaluate the RSSI levels. In other implementations where the receiver does not use a timer, the radio has to detect the start
of a packet since preambles can be misinterpreted as noise (or vice versa). Unfortunately, strong noise on a given antenna can result in the start of packets being missed.

Longer preambles are often used to provide the MCU and its antenna diversity algorithm time to detect and evaluate the signal on each antenna ensuring that a true preamble is found, but shorter preambles are preferred as they reduce MCU on-time and in turn reduce MCU current consumption in both the transmit and receive sides of a radio link. Engineers often try to find a compromise by tuning their antenna diversity algorithm to reduce preamble lengths, but do so at the risk of causing other radio related issues since preamble sequences are usually optimized to provide fast bit clock recovery.

While implementing antenna diversity into a system appears to be very beneficial to the robustness of an RF link, the task itself appears daunting, but a family of radio ICs called

**Figure 9 – Reviewing RSSI levels to qualify antenna selection**
EZRadioPRO™ from Silicon Labs addresses the coding and MCU on-time issues by integrating the antenna diversity algorithm and control into the RFIC itself.

EZRadioPRO doesn’t rely on the transmitter/receiver synchronization method, which allows for an EZRadioPRO implementation to save power at both ends of the RF link, and also overcomes the missed packet problem by periodically switching antennas whenever a received signal is below the signal quality threshold (SQ). The signal quality threshold is based upon receiver sensitivity or a valid signal threshold, and the antenna selection is based on this valid signal indication. Once a receiver selects an antenna, the receiver remains with the antenna for the remainder of the packet.

![State diagram of antenna diversity algorithm according to the first embodiment](image)

To ensure that the antenna switches frequently enough to catch a packet on one of the antennas, a timer is started every time the algorithm enters the ‘measure SQ’ function.

\[
\text{Minimum Switching Time} = \frac{T_{PL}}{N}
\]

Where:

- \(T_{PL}\) is the maximum allowable time in the part of a given signal that can be used to select the antenna (*e.g. the preamble of a packet*)

- \(N\) is the number of antennas employed by the diversity receiver.
During the ‘Measure SQ’ function the Signal Quality (SQ) is measured and if the SQ is below the Signal Quality threshold or the timer times out then the antennas are switched and the ‘Measure SQ’ state restarts. Alternatively if the measured SQ is above the SQ threshold the receiver stays with the selected antenna and the remainder of the packet is received.

While the antenna was selected due to the valid signal indication, the quality may be less than optimal because one or more of the measurements on the antenna(s) may have been taken in noise prior to the packet arrival.

When a valid signal quality indicator is generated for the first time, the EZRadioPRO antenna diversity algorithm checks the other antennas for a higher signal quality indication before selecting the antenna with the highest signal quality.

As previously described; in a radio system it is advantageous to battery life to ensure preambles are as short as possible without compromising fast clock bit recovery.

In order to meet these goals, EZRadioPRO uses a preamble quality detector to determine signal quality. When the preamble detector indicates an invalid preamble or a time out, then the next
antenna is selected and the receiver will try again to find a valid preamble. If a valid preamble is found, then the RSSI value is stored and the receiver switches antennas to store the RSSI on the other antenna(s). The antenna with the strongest RSSI is selected. Since RSSI measurements are relatively fast, time is saved and preambles can be shorter.

To ensure a false preamble detection doesn’t occur, the reconfirms the presence of a preamble once final antenna selection has taken place. If a preamble is not detected, then the diversity algorithm starts from the beginning. If the preamble is detected successfully, then the antenna selected in the previous step will be used for the remainder of the packet.
EZRadioPRO antenna diversity state diagram

EZRadioPRO offers a best-in-class, low-cost and extremely robust ISM radio link that designers can rely on. Devices are available as transmitters, receivers and transceivers, all register and footprint compatible in the 20-pin 4x4 QFN package.

REFERENCES
