

## INTRODUCTION

For those of you with previous RF experience or a good grasp of RF basics, skip this tutorial. Its simplicity will probably insult your intelligence. For those of you delving into the fearsome world of RF for the first time, however, read it fully and with care. When you finish you will have a clearer understanding of how signals are transmitted and received in an RF environment, and perhaps a newfound admiration for the unseen world of wireless intelligence that swirls around us.

This application note goes to great lengths to remove the mysteries of RF. Please don't mistake the ease with which you may grasp these basic principals for the effort required to actually execute an RF design. *Nooo, noooo, kiddies*, don't try this at home. At least not if your job's on the line. The science of RF is unlike any other area of discipline in electronics. Proficient RF design requires sophisticated test equipment, years of experience, lots of money, and a big smile from Above. Fortunately, while actual RF design is quite difficult, understanding basic RF concepts is amazingly straightforward.

## WHAT IS RADIO FREQUENCY?

Radio Frequency (RF) does not refer just to radio broadcasting but rather encompasses all of the electromagnetic spectrum. RF energy is classified according to frequency. The range of frequencies is called the *Radio Spectrum*. While there is no precise beginning or end to frequencies making up the RF spectrum, Figure 1 shows the generally accepted ranges and class designations.

## HOW IS THE RF HARNESSSED?

In order for a signal to be transmitted wireless, it is necessary for the signal to be conveyed into free space then recovered and restored to its original form. Two devices are used to accomplish this task: the transmitter and the receiver.

## The Transmitter

The function of a transmitter is to take an analog or digital signal and, through an antenna, deliver it into free space. A simple transmitter is illustrated below.

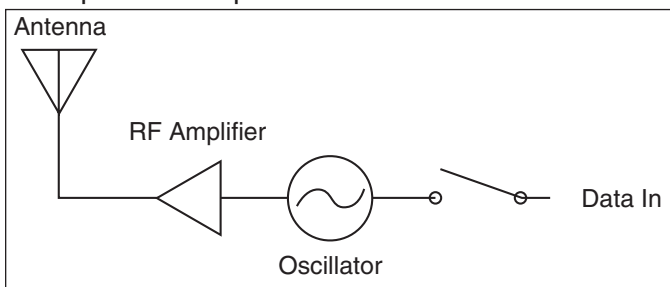


Figure 2: A Simple RF Transmitter

You will notice the transmitter has three primary components: a frequency source (the oscillator), a gain stage (the amplifier) and a free space coupler (the antenna). The oscillator generates the frequency at which the transmitter will operate. This frequency is called the *Fundamental*. In order for the fundamental frequency to be transmitted effectively through the resistance of free space, it is necessary for the signal to be amplified. This is the purpose of the gain stage.

Once the oscillator's frequency has been amplified, it must transition from being a frequency contained within conductors (called transmission lines) into free space. This is the function of the antenna. The transmitting antenna allows the RF energy to be efficiently radiated from the output stage into free space. It is, in essence, a bridge between a guided wave and free space.

## WHAT IS MODULATION?

Now that you have a basic understanding of how a signal finds itself delivered into free space, you may be wondering how any useful information could be represented by that signal. The answer is *Modulation*. Modulation is the process whereby a carrier medium is impressed with content. The

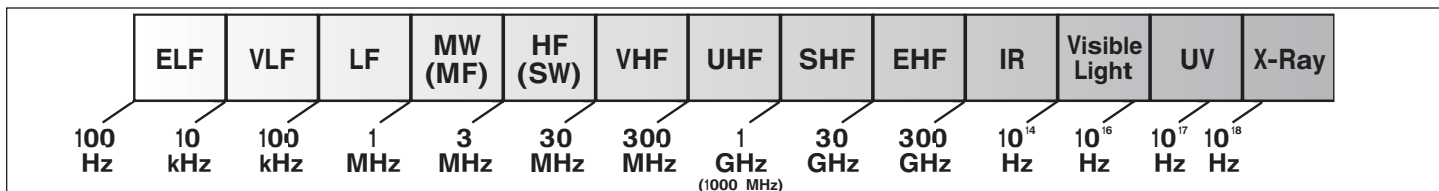


Figure 1: The Electromagnetic Spectrum

frequency to be controlled is called the *Carrier*. A carrier is like a moving truck. Just as you might place the contents of your house on the truck, so the information you wish to transmit is loaded onto a carrier. That signal, which has been impressed onto the carrier for “transportation”, is called the *Program* or *Control Signal*. In the case of digital data transmission, a carrier frequency is modulated with a control signal consisting of binary data.

While there are many modulation methods, let us consider the simplest and earliest form of modulation, Morse Code. Looking at Figure 3 you can see that by turning on and off the carrier to represent the intelligent content of a message, the operator of the telegraph key is serving as the modulation source. Interestingly, this basic form of modulation is still one of the most popular, though today it is known as On-Off Keying (OOK) or Carrier-Present Carrier-Absent (CPCA). By replacing the telegraph key with a microprocessor, a serial transmission link is formed. If you would like to learn more about modulation techniques, you may wish to review Linx Application Note #00130.

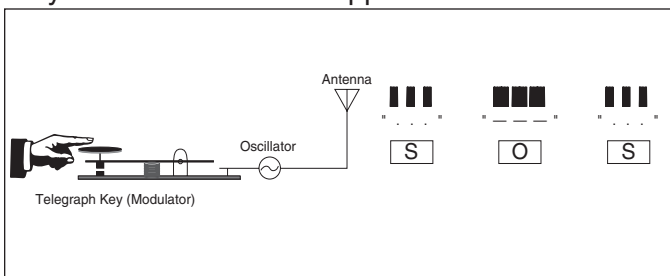


Figure 3: A Telegraph

### The Receiver

The purpose of a receiver is to receive the modulated carrier, remove it, and recover the original program signal. This process is called *Demodulation*.

Figure 4 illustrates a single-conversion superhet AM receiver. While receiver topologies vary widely all involve several stages to affect the reception and recovery process. First, the receiving antenna intercepts the electromagnetic waves radiated from the transmitting antenna. When these waves impinge upon the receiving antenna, they induce a small voltage in it. This voltage causes a weak current to flow, which contains the same frequency as the original current in the transmitting antenna. That current is amplified to a more useable level and then fed into a device called a mixer. The mixer takes this incoming signal and combines it with an

on-board frequency source called a local oscillator. This converts the signal to a new lower frequency called the *Intermediate Frequency* or IF for short. The detector then strips out the IF frequency and leaves present only the original information.

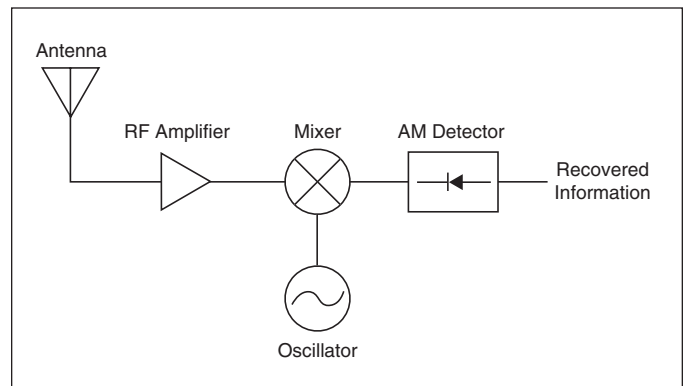


Figure 4: Simple Superhet Receiver

By now you should have a basic, but clear, understanding of how information signals are transmitted and received. With that as a foundation, you are now ready to consider the steps involved in putting RF to work for you.

## UNDERSTANDING AND RESPECTING LEGAL ISSUES

Many designers have steered away from integrating RF out of concern over the complexity of these legal issues. Some view the oversight of radio frequencies by the FCC as yet another example of unnecessary government intervention into the lives of private citizens. While the FCC has made many polices and rulings that are unnecessarily limiting and sometimes border on the absurd, consider an example of life without them.

After days of research, you choose the optimum frequency for your company’s new product, the Loafmaster 2000. You then select a power level appropriate for your range and power consumption requirements. Months later, after many nights of effort you proudly bring the Loafmaster to market. Happily, it garners awards and rave reviews. Three months later, a company in a different industry who knows nothing of your product introduces the Slamometer XL. While this product operates on the same frequency as yours, it was designed with completely different objectives in mind. To achieve those objectives the Slamometer needs to continuously output 500 watts of power across a 500 MHz bandwidth. From all over the country your

once-pleased customers call demanding an explanation for the sporadic operation of their Loafmasters. Much to the anger of the Slamometer manufacturing company your solution is to retrofit all units with a 1,000 watt gain stage powered by a car battery in a backpack.

Undeniably, there are steps that can be taken to streamline the certification process but regulation of the RF Spectrum worldwide is essential. Playing by the regulatory rules helps to ensure that the crowded RF spectrum is used efficiently, and it gives all RF products the best chance of functioning without conflict. To learn more about these considerations you will want to read Linx application notes #00140, #00125, #00126, and obtain copies of the governing regulations for the countries in which you intend your product to operate.

### **CHOOSE A FREQUENCY OF OPERATION**

To go somewhere you choose a road on which to travel. So, too, must you select a frequency on which your information signal will travel. This is a difficult task as there are many diverse issues involved. Here are a number of the most critical to consider.

#### ***Propagation Characteristics***

The transfer of energy through space is called *Propagation*. In general, radio wave propagation is divided into three broad categories: (1) Ground Wave propagation, where the signal travels through or along the earth's surface; (2) Line-of-Sight, where the wave travels almost like a beam of light in a straight line and thus requires that the

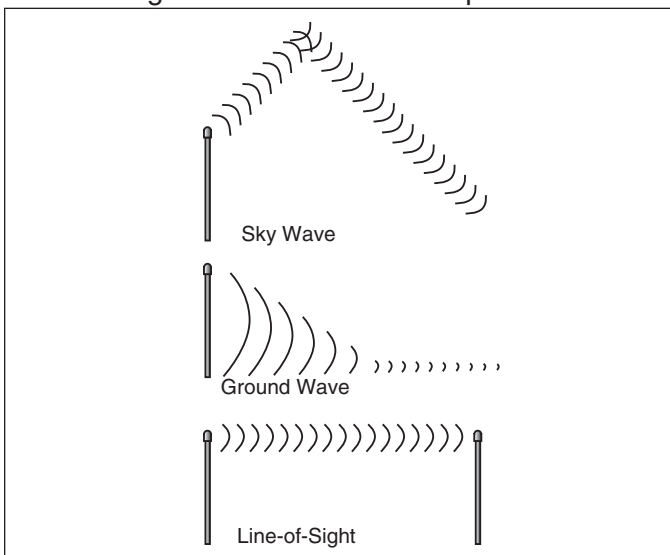


Figure 5: Propagation Categories

transmitter and receiver be within sighting distance of each other; (3) Sky Wave propagation, where the signal travels primarily through the air via reflections from the ionosphere.

It is important to consider the physical environment in which the device will operate in order to determine if the frequency you have chosen possesses useable propagation characteristics. For example, transmission through walls would be highly attenuated and poorly served by frequencies in the microwave region, while effective transmission through water might require selection of a frequency in the VLF range.

#### ***Required Bandwidth***

The amount of information that can be transferred depends on the carrier frequency and available bandwidth. The carrier frequency must be many times the required bandwidth, thus, applications such as video and data links, which require wide bandwidths, utilize frequencies well into the microwave range. In general, the bandwidth should be as narrow as possible to accommodate the required information content. This yields the best immunity to noise and allows the highest possible system sensitivity.

#### ***Power Consumption***

In battery-powered applications, power consumption is generally a critical issue. Surprisingly, the relationship between frequency and power consumption is often overlooked. Since propagation efficiency is reduced as frequency climbs, higher frequencies require more power to achieve range.

#### ***Potential Interference***

The final component of frequency selection is to understand what potential interference sources your device will be up against in the real world. Interference is the presence of unwanted noise or signals that increases the difficulty of reception. You may find that many frequencies suited to your application have a high level of interference present because of their broad popularity.

Interference can be divided into three primary categories: natural noise, man-made noise, and man-made signals. Natural noise originates in space and the earth's atmosphere. It tends to be greater at low frequencies. Man-made noise is caused by unintentional RF radiation from man-

made devices, such as motors, switching power supplies and microwaves. Man-made signals are intentional RF emissions such as radio, television, cellular, etc.

Immunity to noise depends on bandwidth and the frequency accuracy of the transmitter. The more accurate a signal's frequency and the narrower a signal's bandwidth, the narrower the receiver's front-end filter can be. This increases the ratio between the signal and noise and greatly reduces

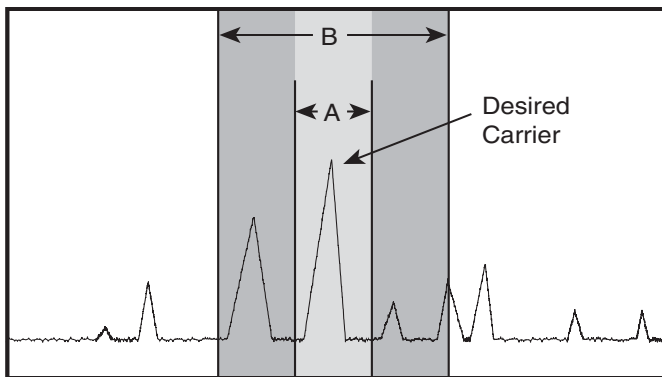


Figure 6: Desired Bandwidth

the potential for off-frequency interference. Figure 6 illustrates how a receiver with a narrow front end bandpass opening (A) has a much better chance of receiving the incoming signal than receiver (B) with its wide front end bandpass opening.

### **DEVELOP RF REQUIREMENT SPECIFICATIONS**

This specification is simply a list of characteristics you feel are important. It will act as a roadmap during your consideration of the various RF solutions that are available. You will want to list particulars, such as preferred operational voltages, power consumption requirements, data rates, range requirements and frequency choices.

### **EXPLORE RF OPTIONS**

Armed with a basic understanding of RF and your individual needs, you can now consider your RF options more intelligently. Your initial decision will be whether to use a custom discrete design or a pre-made RF module. The table in the next column details some of the advantages of each.

In order to fairly compare the cost of a discrete vs. modular design, be sure to bear in mind the part placement, tuning and testing costs incurred in the production phase of a discrete design.

## **Modular RF Product**

### **Advantages**

- Minimal time to market
- Low cost of evaluation
- Easy regulatory compliance
- Stable, consistent performance
- No production tuning or testing required
- Reduced size and part count
- Single part placement lowers production cost
- Comparable cost to a discrete design

### **Disadvantages**

- Performance may not exactly match requirements
- Single vendor availability
- No control over production life
- Custom modifications available only in high quantities

## **Discrete RF Design**

### **Advantages**

- Complete control over performance specifications
- Control over manufacturing process and design changes
- Performance compromises can be tailored to cost requirements
- Parts may be available from multiple vendors

### **Disadvantages**

- High design cost
- Lengthy time to market
- Increased production testing
- Higher board material cost
- Difficult parts procurement
- Significant equipment investment

## **CHOOSE AN ANTENNA**

The antenna choice is critical in determining the overall performance and legality of a system. There are many issues related to understanding and selecting an antenna, which are covered in Linx application note #00500. It should be noted here, however, that as frequency increases antenna length is reduced. In some applications a large antenna element is unsuitable for size or cosmetic reasons. This requires the designer to use a high operational frequency or create a unique antenna solution.

**CERTIFY THE PRODUCT**

Once your product is in its finished form, exactly as it will be produced, it should be sent to one of the many testing laboratories authorized to conduct FCC Part 15 compliance testing. The testing used to take up to three weeks with another 60 to 90 days for the FCC filing and ID number to be issued. The FCC now allows the test lab to issue the ID numbers on behalf of the FCC, which has greatly shortened the certification process. The testing and certification process now takes about a week and generally costs about \$5,000. After the product has been tested and found to be compliant, the test laboratory will submit the documentation to the FCC on your behalf and issue an ID number.

**PUTTING IT ALL TOGETHER**

From this application note you have, hopefully, learned a bit more about the basics of RF and the steps involved in putting it to work for you. You may also have gained an additional measure of respect for the fine balance of considerations that any RF product represents. At Linx the science of RF is our business. We attempt to make its application as straightforward as possible so that you can concentrate on profitably bringing your product to market. If you have questions that were not covered in this application note or you would like help in achieving an optimum wireless solution please feel free to contact a Linx application engineer at [info@linxtechnologies.com](mailto:info@linxtechnologies.com) or (800) 736-6677.