

Application Note AN-00100

RF 101 Information for the RF Challenged

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 principles 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.

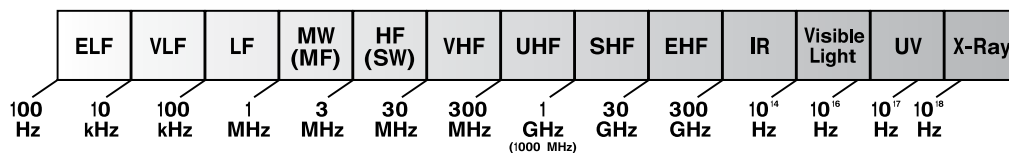


Figure 1: The Electromagnetic Spectrum

How Is RF Harnessed?

In order for a signal to be transmitted wirelessly, 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 in Figure 2.

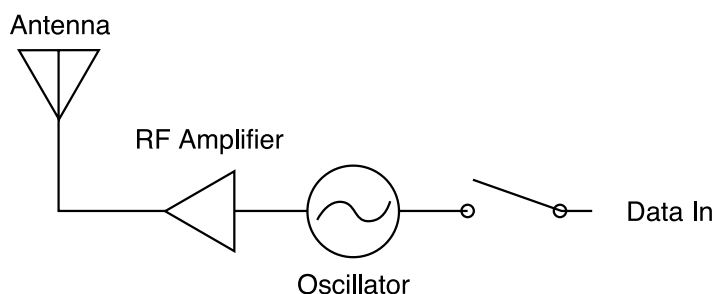


Figure 2: A Simple RF Transmitter

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 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 AN-00130.

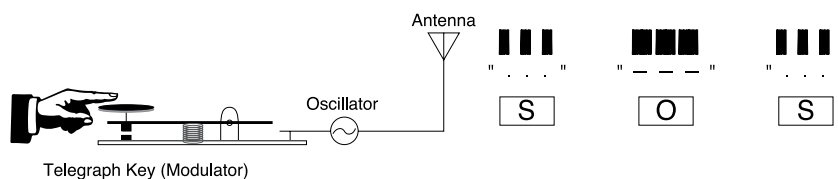


Figure 3: A Telegraph

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 usable level and then fed into a device called a mixer. The mixer takes this incoming signal and combines it with an onboard 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.

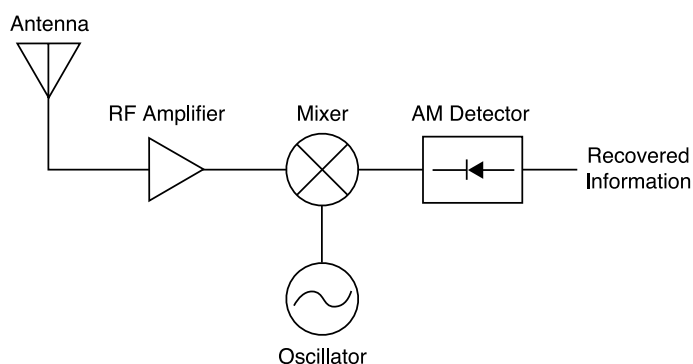


Figure 4: A Simple Superhet Receiver

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 policies 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 500MHz 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 AN-00140, AN-00125, AN-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 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.

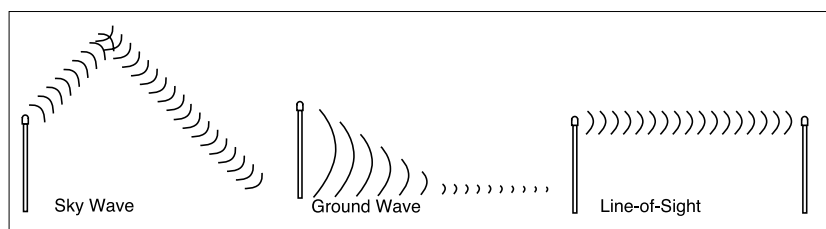


Figure 5: Propagation Categories

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 usable 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 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 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.

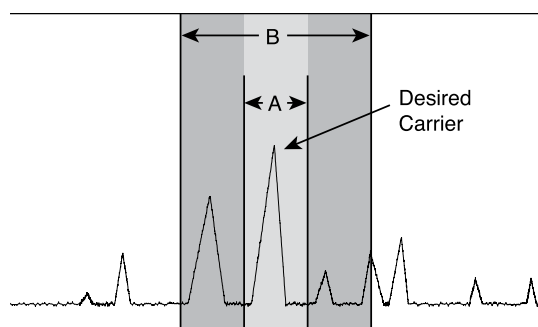


Figure 6: Desired Bandwidth

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 discreet design or a pre-made RF module. Figure 7 details some of the advantages of each.

Modular RF Product	Discreet RF Design
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 Signal part placement lowers production cost Comparable cost to a discreet design Disadvantages Performance may not exactly match requirements Single vendor availability No control over production life Custom modifications available only in high quantities	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

Figure 7: Advantages and Disadvantages to Modular RF Products and Discreet RF Design

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.

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 AN-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 or +1 800 736 6677 (+1 541 471 6265 if outside the United States).

TE TECHNICAL SUPPORT CENTER

USA:	+1 (800) 522-6752
Canada:	+1 (905) 475-6222
Mexico:	+52 (0) 55-1106-0800
Latin/S. America:	+54 (0) 11-4733-2200
Germany:	+49 (0) 6251-133-1999
UK:	+44 (0) 800-267666
France:	+33 (0) 1-3420-8686
Netherlands:	+31 (0) 73-6246-999
China:	+86 (0) 400-820-6015

te.com

TE Connectivity, TE, TE connectivity (logo), Linx and Linx Technologies are trademarks owned or licensed by the TE Connectivity Ltd. family of companies. All other logos, products and/or company names referred to herein might be trademarks of their respective owners.

The information given herein, including drawings, illustrations and schematics which are intended for illustration purposes only, is believed to be reliable. However, TE Connectivity makes no warranties as to its accuracy or completeness and disclaims any liability in connection with its use. TE Connectivity's obligations shall only be as set forth in TE Connectivity's Standard Terms and Conditions of Sale for this product and in no case will TE Connectivity be liable for any incidental, indirect or consequential damages arising out of the sale, resale, use or misuse of the product. Users of TE Connectivity products should make their own evaluation to determine the suitability of each such product for the specific application.

TE Connectivity warrants to the original end user customer of its products that its products are free from defects in material and workmanship. Subject to conditions and limitations TE Connectivity will, at its option, either repair or replace any part of its products that prove defective because of improper workmanship or materials. This limited warranty is in force for the useful lifetime of the original end product into which the TE Connectivity product is installed. Useful lifetime of the original end product may vary but is not warranted to exceed one (1) year from the original date of the end product purchase.

©2023 TE Connectivity. All Rights Reserved.

08/23 Original