# The Low Power AM Broadcasters Handbook

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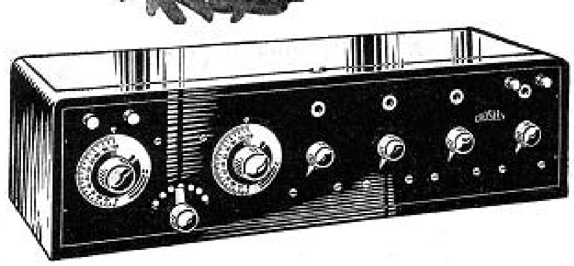


# 1 – Introduction

Low Power AM (LPAM) is one of the most undocumented and underutilized concepts I have ever seen in my work with radio. When it comes to Low Power FM (LPFM), information is abundant, and there are hundreds of people doing work on schematics and actively engaging in broadcasting. For LPAM however, there is almost no access to practical circuits and antenna design data, despite being the oldest broadcast band in the country.

In my own initial research into the idea of creating an LPAM station, I encountered many engineers that were convinced it was not feasible without a large amount of investment, and that if you were able to make it work at all, it would have poor range. While some of their concerns were valid, their arguments have proved to be too pessimistic. LPAM is more work than broadcasting on some parts of the radio spectrum (notably the high frequency areas), but it is very feasible. Even with compromising antenna systems, LPAM has comparable range to LPFM for the same amount of power.

| **Comparison of Low Power Broadcasting** | |
|---|---|
| **LPAM** | **LPFM** |
| Good range | Poor range |
| More open frequencies | Less open frequencies |
| Signals prone to noisy interference | Transmitter can interfere with TVs |
| Easy to build transmitters | Careful construction required |
| Good in mountainous terrain | Line-of-sight works best |
| Larger, more complex antennas | Small, easy antennas |
| Low fidelity audio, 3-10kHz mono | High fidelity audio, 15kHz stereo |
| Broadcast approx. 1/4-1 mile legally* | Legal range only a few hundred feet |

The major boost to LPAM in recent years has actually not been technical, but legal. Note the last row on the table above. You can broadcast approximately that far, legally, without licenses and expensive bureaucratic frog jumping at the FCC. That number can be jumped by improving your antenna or transmitter in different ways (better and higher antennas, more efficient transmitters) and can drop under poor broadcasting conditions, but either way you can get much farther distance than with LPFM. There are also exceptions with LPAM, particularly with carrier current (powerline injection) and college campus

*For general over-air (Part-15) broadcasting.

exceptions. These unlicensed exceptions are currently not available with LPFM.

First, a clarification regarding my use of “AM Broadcasting”. When I say that, I am not being entirely correct with my wording. AM does not actually mean the “AM broadcast band”, AM simply means “Amplitude Modulation”, which is the type of modulation used for the band. AM does not mean the actual band, and AM as a form of audio transmission is used in many parts of the radio spectrum. The band is actually called the Mediumwave band, and it indicates the frequencies that the band encompasses, which are 540-1710kHz.

I should probably explain the chosen binding method. Instead of the traditional method of printing perfect-bound soft cover, I have opted for a looseleaf book system. There are have numerous reasons for this:

1) Despite the old age of AM broadcasting itself, LPAM is in a somewhat pioneering stage that is open to new information. I wanted to make the book modifiable, in case new and better data becomes available (as it often did during the writing of the book). I have set up an update service for the book, which entitles purchasers to receive new updates and segments to the book. With a binder, you can get a new section in the mail, and simply add it to the book. As I write this, there is already new information available regarding a drastic increase in helically-wound antenna efficiency, and useful information on mounting antennas and equipment sustainability. With the update service, I can write about these things when more information becomes available and send free updates directly to you, eliminating the need for multiple editions while providing you with the latest information on LPAM broadcasting without having to get a completely new book.

2) Binders are more engineering-friendly. You can slide in useful notes and data. They stay open without a hassle, and the pages don't flip when unattended. If a page breaks out for some reason, tape can be used to replace it.
3) I have a family relative that produces binders, which gave me more control over printing and cost.

LPAM broadcasting can be a fun, engaging, and rewarding experience. But it should be noted that it is not a one-day project. The antennas in particular require a fair amount of construction, space, and planning. But if the reader is willing to do some hands on work, LPAM can be a very effective way to get on the air, create a community presence, and learn how to build working radio equipment from scratch!

I want to give acknowledgment to the now defunct Medium Wave Alliance website and its author Crash Knorr. Without his site, this book would have probably never been written. For a while, it was *the* source for LPAM broadcasting information.

I also want to thank Jonathan Smick, who has been the ask-all radio expert when writing this. Without his help, several of the things here would be absent.

I also want to thank anybody that has given advice and helped with the work over the last few years. That includes the engineers that helped me with technical questions, my friends who helped get me into the university EE libraries, and the writers that have put together the RF design books and technical papers I have used as references.

I especially want to thank the Pavek Museum of Broadcasting for allowing me access to their large collection of radio books, and for providing endless amounts of selfless help and vintage pictures. If you support the history of radio, please consider becoming a sponsor of the museum. If anything, just go to see their working spark-gap transmitter! They can be found on the internet at http://www.pavekmuseum.org.

On the political site, I also want to thank the people that have lobbied for low power broadcasting services, most importantly Don Schellhardt and the Amherst Alliance.

This is the first edition of the book, and as such I expect there will be errors. If any problems with the book are found, please report them to me. I will give credit to all who contribute fixes.

This book is the result of almost two years of digging through piles of engineering books, doing my own tests and schematic designs, and general advice from people actually working with low power and high power AM broadcasting. I hope you will find the information within to be useful.

*"Nothing but playthings!
I tell you, I won't stand for it!"*

# 2 – Preparation

When starting a broadcast station, a considerable amount of planning must be done. There are many variables, such as where to broadcast, what kind of equipment is necessary, and what kind of tools might be needed to put everything together. This chapter serves as an introduction to the technical planning needed before any equipment is purchased or built.

## Finding a Frequency

It's very important of course to find an open frequency to broadcast on. The Mediumwave band is spaced in 10kHz intervals, such as 1010kHz, 1020kHz, and so on. Most receivers can tune between 530kHz and 1710kHz, though some older models cannot tune the 1600-1710kHz portion (for tinkerers: It's not very difficult to modify old radios to tune the upper band, you simply need to take away some turns from the tuning coil).

It's not only important to find out which frequencies are open during the day, but also during the night. Mediumwave has a special property to it that, at night, makes radio signals bounce off the ionosphere. The result of this is that radio stations can interfere with each other, even from several hundred miles away. This phenomenon is known as skywave. For some people (especially long distance listeners), it's beneficial. But for local broadcasters, it's nothing but parasitic interference that can turn the radio dial into a mess at night.

Fortunately for LPAM stations, it is difficult to produce skywave interference using vertical antennas. The groups that are causing most of the skywave interference are the commercial broadcasters with transmitters well above 200W, such as the 50kW powerhouses. Unfortunately for LPAM stations however, they are susceptible to nighttime interference by these higher-powered stations. The best frequency for avoiding this type of interference must be found.

The first quick test to find an open frequency is to tune (not autoseek) through the AM dial during the day, and mark the channels that don't appear to have any signal (strong or weak) coming to them. At least one open frequency should be found, otherwise the ones with the weakest incoming audio should be chosen. Another alternative step to this process is to go to the Radio Locator web site (http://www.radio-locator.com) and search for the AM broadcast stations in your area. Type in your zip code and do a “search by mileage” for about 300 miles. Then from that list, write down the frequencies that are the farthest away (or not existent on the list) and try using them. It is best to choose a broadcast frequency that is as far away as possible from the nearest local broadcast station. Interfering with neighboring stations is one frequent way broadcasters get into trouble, illegal or otherwise.

Once a good list of potential frequencies is found, the same frequencies should be listened to at night from a good outdoor radio (such as a car radio). This test is hardly scientific, because skywave interference can change rapidly, but it should give a ballpark analysis of how much skywave signal is coming in. If the skywave signal is relatively strong, a different frequency should be considered.

What are the best frequencies for avoiding skywave interference? Typically, the very bottom end of the broadcast band and the upper 1600-1710kHz tend to be best. From these, I would recommend the upper band for over-air (antenna) broadcasting. Not only is it free from most skywave interference, but it is also higher frequency which (for reasons explained later) makes LPAM antennas more efficient. Most LPAM broadcasters operate at the higher end of the band.

Once a suitable frequency is found, the equipment can be considered.

## Audio Equipment

A guide to selecting and configuring station equipment is provided in the next chapter.

## Transmitter

The transmitter is what actually creates the radio signal, amplifies it to a useful power level, mixes your audio into it, and then sends it to the antenna or transmission line (coax cable). When choosing a transmitter, two things are mainly considered: the amount of power the transmitter can deliver, and the method of tuning.

For power, there are two main categories in LPAM broadcasting: “Part-15”, and higher powered.

Part-15 is a section of the Code of Federal Regulations that describes all of the transmission details and limits for radio equipment. The FCC does allow people to broadcast on the AM band without a license, but only with severe restrictions that hinder the distance the signal can travel. Part-15 transmitters are specifically designed to conform to these restrictions. Signals from these transmitters can only travel about 1/4-1 mile at best, varying with environmental differences and antenna effectiveness. Transmitters are limited to 100mW (milliwatts) output, and antennas (including the coax line if one is used) are restricted to 3 meters (10 feet) in length.

“Everything else” is anything that is more powerful than Part-15, such as a 1, 10, or 100 watt transmitter. These transmitters, coupled with good antennas, can go 1-15+ miles. Unless you have a license from the FCC, it is illegal to broadcast at these power levels and you can get into trouble for it.

This is just a basic introduction to the rules and regulations associated with LPAM broadcasting. Consult the Legal chapter for further information.

Transmitters also vary by the type of oscillator they use: Crystal, LC variable, or PLL. The oscillator is the part of the transmitter that generates the frequency to be broadcast on.

**Crystal Oscillators** use a fixed crystal to generate the frequency. They are the most stable, simple, and reliable of the methods, but they also require a crystal for each frequency, making it time consuming (and possibly expensive) to change frequencies. Also, crystal manufacturers are sometimes hard to find (though a few sources have been included in the back of the book).

**LC Variable Oscillators** use an inductor and a capacitor to generate the frequency. They are extremely handy because they require no special components. But they drift in frequency with heat or loading changes, which makes them very unreliable for broadcasting. It's possible to make a relatively stable LC Variable Oscillator, but most serious broadcast transmitters don't use them.

**PLL Oscillators** are a digital compromise between crystal and LC oscillators. They can be changed to different frequencies easily while maintaining good stability (if designed properly). Their main drawback is a large increase in circuit complexity and components, but they are becoming the oscillator choice for most LPAM transmitters.

Another thing to look for in a transmitter is other perks, such as a built in audio limiter/compressor. Things like this can save you time and money by having much of the audio processing equipment on board and pre-calibrated for the transmitter's audio characteristics. Transmitters with embedded antenna tuners and lowpass filters can also be handy and time saving.

LPAM transmitters are easy to build for radio standards. Because the frequencies associated with AM broadcasting are so low, cheaper components and looser construction can be used than with higher frequency transmitters. If you are interested in trying to assemble your own transmitter, a few plans have been included in the Schematics chapter.

It should be noted now that you can't run your transmitter without a load. A load is something for the output of the transmitter to go into. If you turn the transmitter on without a load, the output energy will build up in the final amplifier of the transmitter, which can eventually cause it to overheat and break down. You either need to attach it to a tuned antenna or a Dummy Load. A Dummy Load is, literally, a resistor. The resistor looks like an antenna to the transmitter, except it converts the energy leaving the transmitter into heat energy instead of electromagnetic energy. In order to work, the resistance should be the same as the impedance of the transmitter output, so for a 50 ohms output, 50 ohms of resistance should be used. The resistor(s) should be rated to handle at least twice the transmitter output power, and can be put in series or parallel to change resistance or power capacity. You can also buy pre-built dummy loads from numerous HAM radio companies.

## Coax Cable (the transmission line)

This is the piece that can be used to connect the transmitter to a remote antenna. Television coax cannot be used to accomplish this! Television uses 75 ohm (Ω) coax, whereas radio transmitters require 50Ω coax to work properly.

50Ω cable can be acquired from Radio Shack or any local HAM store. It usually costs about $30 for 50 feet. Most transmitters use the SO-239 style connector, but BNC style connectors are sometimes used. It is up to you to determine which type is present on your transmitter. There are thicker and thinner types of coax, the difference being that smaller coax is more prone to signal strength loss. But the difference is negligible for mediumwave broadcast frequencies, so I recommend the smaller cable, which is cheaper and more flexible.

An extremely annoying problem that some people have is water leaking into the coax. If the coax is located in an area that is prone to rain, it can soak into the coax through the ends and travel down the line, causing a loss of signal strength. Worst of all, there is no real way to detect the leak other than by noticing a loss in signal strength over time via a calibrated field strength meter.

An effective countermeasure to this problem is to apply waterproofing putty to the exposed cable ends, which can be found at Radio Shack and most HAM stores. It is gross stuff, and will plague everything it touches with black gunk that will not come off without hard scrubbing and some kind of solvent. But it works very well, and has ended my waterproofing problems whereas other solutions have not. Do not use tape. Duct tape doesn't work at all, and electrical tape just leaves a messy black substance behind without helping your waterproofing. Wait until all configuration settings have been finalized before applying the putty. Another suggestion is to use manufactured cables, they are generally more water tight than custom crimped cables.

## Antenna

In most of the radio spectrum, the transmitter is the most critical component and the antenna is second nature. For an example, I was able to put a vertical VHF antenna together in an hour with 10 feet of wire and a spare PVC pipe. And it worked perfectly, at 40 watts.

Mediumwave antennas on the other hand require more effort. The problem is that the mediumwave band is very low in frequency, which means that the “wavelength” of signals is extremely large (as the frequency gets lower, the wavelength gets larger). In order for the antenna to work well, it has to be a fraction of the size of the wavelength. For local broadcasting this usually means a vertical antenna that is $1/2^{th}$ or $1/4^{th}$ the size of the frequency's wavelength. This might not be a big deal if your wavelength is only 9 feet, but if it's 984 feet (as is the case on 1000kHz), you can see just how large these antennas can get!

Most guides to mediumwave antenna design shrug off the technical problems associated with physical length and simply say a 1/4-wave antenna must be used, otherwise the antenna will not work. Many experienced engineers think nothing short of a 250-foot irrigation pipe with hundreds of ground wires will transmit AM signals properly. For amateur broadcasters, this is impossibly difficult to do.

In the real world, we have to deal with constraints like size, money, and safety. There are methods to make a Shortened Vertical, which is an antenna of reduced length that still works quite well. They don't transmit as well as 250 feet of irrigation pipe might, but they are practical, they work, and they are what almost every LPAM broadcaster uses. Smaller antennas are still less effective despite these tricks, so the length of the antenna still needs to be anywhere from 10-40 feet. Also, there will still need to be a “ground plane”, which is a set of wires expanding from the bottom of the vertical antenna. This will all be explained thoroughly in the Antennas chapter, I am simply pointing this out now so that antenna placement can be initially considered.

## Costs and Tools

Starting a low power radio station is certainly a lot cheaper than a commercial, professional station. But it still costs money, anywhere from a few hundred to a few thousand dollars depending on the equipment choices. Even if most of the equipment is made from scratch, the parts and other equipment can still be costly. Also, a good set of tools is necessary to do some of the work presented in this book (though it might be simple to borrow the tools from friends or other people working on the station). It's probably a good idea to come up with a cost estimate, so that you don't end up buying half the equipment and not being able to afford the rest of it.

I'll leave the tool requirements up to you, with three exceptions. First, you will probably need a soldering iron and pliers for making coils, and other wire connections. Second, I highly recommend a scientific or graphing calculator if you plan on using the formulas presented in the book, they can save a lot of calculation time. Thirdly, I recommend the cheap, 3 dollar “general purpose” wire stripper sold at radio shack. With a little practice, it is far more effective than the large clunky gauge-specific strippers.

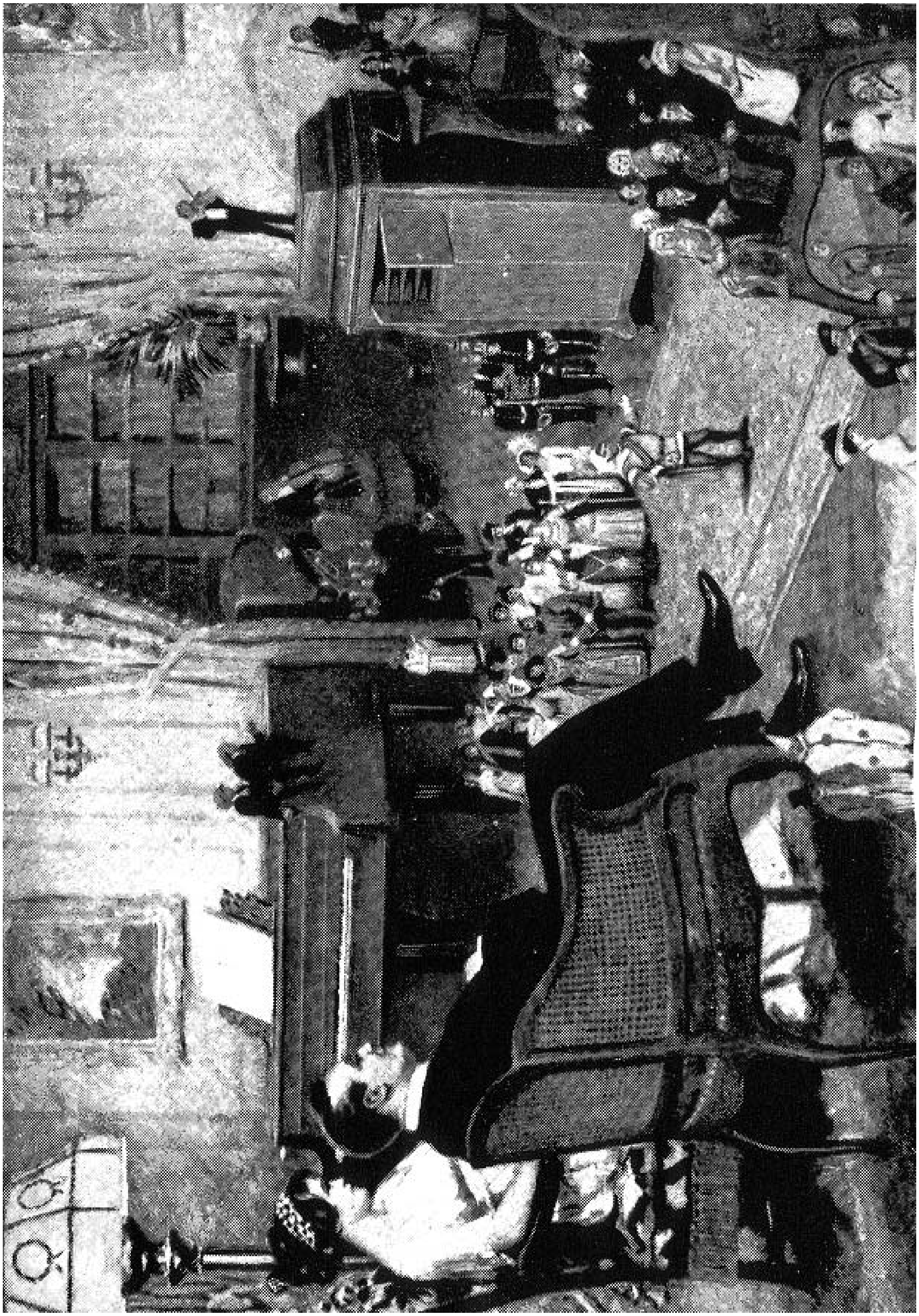
## Electrical Safety

A few quick notes need to be made about safety. Even at low power levels, it only takes a few milliamps to kill. Be careful!

Most LPAM transmitters use DC voltage at low levels, which cannot usually conduct through humans. However, some transmitters operate at AC voltages or use transformers that convert from AC to DC. If there is an AC power cord going into the transmitter, turn it off and wait a minute before operating on the unit. Be weary of all capacitors in the power supply section, especially if it is the “step-up voltage” variety. If the transmitter is purchased, observe all safety guidelines that the manufacturer has specified.

AC voltage circuits should not be modified while they are running. If close proximity to an AC circuit is needed, place on hand on your pocket. This way, if the worst happens, the electricity will (theoretically) go through your side instead of through your heart, which is how electricity usually causes death. If the case is metal and the transmitter uses a three-prong AC cable, check to make sure that the case is attached to ground. If the cable is two-prong and you're handy with electronics, installing a three-prong cable with a ground attached to the case is not a bad safety idea. Do not attempt to circumvent fuses; they are there for a reason!

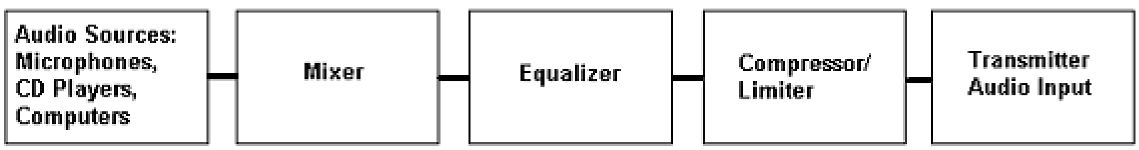
It should be noted that while DC cannot typically shock at lower voltages, it can still happen. It is best to avoid touching a circuit during operation, but if you need to bend or touch something, make sure your hands are dry and free of salty substances (wash your hands and then wait until they are completely dry before working). Better yet, get a non-conductive poking stick and use that to move anything around.



# 3 – Audio

The usage of equipment in broadcast stations can vary, depending on how available the equipment is, the format of the station, and budget considerations. The good thing about a lot of the audio equipment is that, unlike with the transmitter and antenna side, most of it isn't necessarily *required* to run the station. Obviously, it's hard to run a station without a mixer or a microphone. But if budget limitations were a serious factor, equipment such as the mixer could be substituted with a simple wire switch/couple, or by using more readily available equipment such as a home stereo receiver. Computers can be a significantly cheaper way to replace most or all needed audio equipment.

Here is a typical layout of a broadcast audio system:




This is just an example, to give a general idea of what might be needed. Sometimes there will be an equalizer placed between the mixer and the audio stage, with perhaps another equalizer for the microphone. In professional stations, there can be several compressors for each component in the station. Keep in mind that you will get diminishing returns on the quality of the signal with extra audio processing equipment. Placing more than one compressor in the system, for example, is a luxury that doesn't improve quality by a significant margin and adds to the cost of the station.

## Microphones

Microphones can sell anywhere from $10 to well over $700. In general, higher priced microphones are better. But after about the $30 range, microphones start to sound the same. In fact, I've played around with some expensive microphones that actually sound bad (because they were designed for specialized compressor systems at large radio stations). Try to find a place where microphones can be tried before purchase, and I don't recommend spending more than $100 on a microphone. Beware of computer microphones, most of them have atrocious audio quality.

There are two kinds of microphones that should be considered: Unidirectional and Omnidirectional. Unidirectional microphones are very focused and only hear noise directly in front of them, whereas omnidirectional are good at picking up very large areas. The important difference is that unidirectional microphones are insignificantly less noisy, and are less prone to picking up background noise such as side conversations and doors closing. For regular DJ use, unidirectional microphones are recommended.

Microphones are device specific. A microphone for a computer, for example, won't work with an audio mixer. Sometimes it will work, but the audio quality will be poor. The microphone must “match” the equipment it is going to be used for. For example, if a microphone is 1000Ω (ohms), and a mixer is 1000Ω, the microphone and mixer will work together. But if the microphone is 300Ω and the mixer is 1000Ω, you might run into trouble. If the microphone is designed for a computer it will typically say so, otherwise it is safe to assume it is designed for standard audio mixers.

Microphones also require amplification to work correctly. Before the audio can be sent to the mixer, it must go through what's called a microphone amp, or a pre-amp. In many cases the microphone amp is built into the mixer, otherwise you have to either make or buy one. I have include some simple microphone pre-amp circuits in the Schematics chapter.

## Audio Source

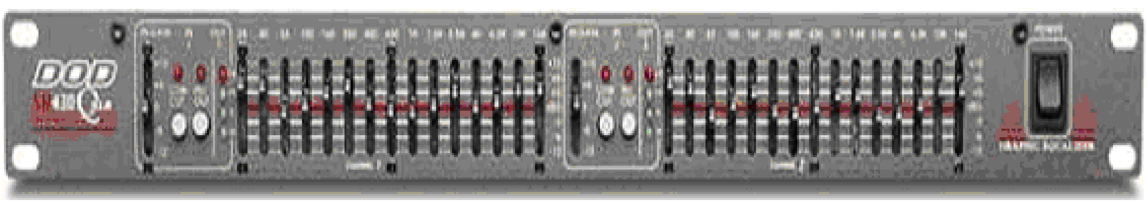
This is what you will use as a source for pre-record material, such as music or archived material. Just about anything can be used for this: CD players, turntables, tape decks, or computers.

Sometimes automated playback will be needed. Back in the pioneering days of low power broadcasting, the closest thing they had to automation was a tape machine. But cassette tapes could only hold 30 minutes of content, which is not long enough for unmanned playback. I have seen some pretty amazing setups for doing automated playback, using simple equipment with bizarre modifications for the mechanical looping of tapes. One LPFM broadcaster I met had a truly unique system for the playback of audio: VHS tapes. When set for SLP mode, VHS tapes can record up to 6 hours. If an audio signal is plugged into the VCR, it effectively becomes an audio tape recorder. Nothing is more amazing than an amateur broadcaster on a budget!

Nowadays there are more workable solutions for automation. The advent of computers has made it easy and cost effective to do extended automation in amateur broadcast stations, with the additional benefit of having much higher audio quality.

## Equalizers

An equalizer can greatly improve the sound quality of your station. Not all transmitters have the same audio qualities to them, and occasionally transmitters will need a little help to put out a good signal. Also, in the case of AM, you sometimes have to make a modification to the equalizer to make certain transmitters conform to standards (discussed later in chapter).





Equalizers improve sound quality by changing the volume of audio at specific frequencies. For example, if an audio signal contains too much bass, compensation can be made by reducing the lower frequency knobs of the equalizer. One trick to improving the “loudness” of audio is to increase the treble frequencies (the right side of the equalizer). This gives the audio more punch, and makes voices more recognizable. Equalizers are very similar to the 'Bass' and 'Treble' settings on audio equipment, except they are more frequency specific, which is helpful for making fine-tuned changes.

When calibrating an equalizer, the only effective way to hear the outcome is to listen to the transmitted signal. Get a good digitally tuned receiver, tune to the transmitter frequency, and use that as a monitor for equalizer changes. Broadcaster audio will sound considerably different than it sounds through the mixer. If possible, use a dummy load when making initial settings (though the audio quality can also vary between the use of a dummy load an an antenna, so final on-antenna calibration might be necessary).

Physical equalizers can cost quite a bit. One option is to build your own using schematics, but they can be tricky to build. If you are using a computer for playback, you can use a free software equalizer instead. Cheap and powerful audio processing is a big reason why computers are becoming popular with amateur broadcasters.

Besides tuning audio quality, there is another important thing that equalizers do for AM broadcast transmitters specifically. AM specifications call for

10kHz of audio bandwidth (specifically, a sharp cutoff after 10kHz), but most audio sources can go as high as 18kHz. Some transmitters don't do the “bandwidth limiting” on their own, and if you put an 18kHz audio signal into one, the transmitter will broadcast a 18kHz signal instead of 10kHz, and you will not be broadcasting according to the specs! This can lead to interference with neighboring stations, band sounding audio due to linearity problems, and a possible loss of signal strength. Not even the best AM receivers will pick up any audio above 10kHz, so the extra signal is just being wasted. With an equalizer for an AM broadcast station, you should set the knobs so that all audio above 10kHz is muted. That way, you don't have to hope the transmitter is doing it for you.


Example 1

In example one (to the left), the equalizer is set to a general position that is popular with LPAM broadcasters. The equalizer slowly climbs to 10kHz, and then a sharp cutoff is applied. Higher treble frequencies are given more strength than the lower bass frequencies, which helps to improve the clarity of the signal (and slightly makes up for the loss of higher frequencies). Audio has also been set to mono to make sure one of the channels is not getting lost between the computer and the transmitter. This is of course not a universal setting; your mileage will vary depending on personal tastes and the different fidelity properties of your computer's sound card and the transmitter.

## Mixers

Mixers do exactly as the name implies: they mix audio signals together. They also usually have a couple microphone amplifiers on board and a few gadgets for calibrating the audio, such as per-channel equalizers. This can be a great resource if you need something with multiple audio sources, for live recordings or interviews. They also allow the DJ to seamlessly switch between audio sources and do other tricks. They are a lot more “physical” and controllable than mixer alternatives might be.

Mixers can be expensive. Entry-level mixers can start at about $60, and only go up from there. One alternative is to use the switches on a home stereo to change between audio sources, but this usually only works on a per-source basis. Other alternatives are simple wire mixers, or using the computer as a mixer source (though this will only allow one microphone, and the microphone audio quality will be low). One alternative is to try homebrewing your own mixer from scratch, some schematics are provided in the Schematics chapter.

## Compressors

Compressors take audio signals that vary in loudness, and “level” them to a standardized volume level. As a result, the “loudness” of a station's audio can be increased without causing overmodulation due to varying audio levels. Overmodulation is when audio volumes that are too high are sent to the transmitter, and it causes loud clipping and static to appear on the transmitted signal. It is annoying to listen to and can generate interference, so broadcasters must take steps to avoid it.

The best compressors are the multi-band types. They are much more expensive, but they perform considerably better. Some companies have developed computer software versions of the multi-band compressors that work well and are considerably cheaper, more information on these can be found in the Equipment Sources chapter.

Compressors can be expensive, with entry-level units starting at $70. But with some tinkering, they do improve the quality of a broadcast signal.

## Limiters

Limiters are similar to compressors, except instead of normalizing an audio signal, they stop audio from going above a certain loudness point. This helps to reduce sudden spikes in loudness, which can create overmodulation. Most modern compressors come with limiters built in. Externally, they could sell for around $60.


CBS
WCCO

# 4 – Politics

This chapter will familiarize you with the rules and regulations regarding LPAM. It is important to understand these rules, whether you are attempting to broadcast legally or not.

## Rules for Over-Air (Antenna) Broadcasting

On the AM band, there are legally two types of broadcasting: Part-15, and everything else. **Part-15** is the FCC's section of rules and regulations regarding Radio Frequency devices. To be “Part-15” is to be compliant with the rules in this section regarding unlicensed broadcasting. Unlicensed stations not conforming to Part-15 rules are illegal. If you are doing an illegal broadcast, understand that you can get in trouble for it. Illegal (pirate) broadcasting will be discussed later in the chapter.

Here is a quick and simple list of the Part-15 limitations for antenna-based LPAM:

*The power going to the final amplifier of the transmitter cannot exceed 100mW (milliwatts).*

This basically means that the transmitter's output power cannot exceed 100mW.

*The length of the antenna, ground line, AND transmission line cannot exceed 3 meters (10 feet).*

Note that this includes the transmission line (coax cable). Because of this, Part-15 broadcasters don't use a coax cable, and instead feed the transmitter directly into the loading coil/antenna.

## Over-Air Exceptions

If you are on a college campus, you can use an alternative provision that was introduced in 1990. You are allowed to use as much power as you want within the campus. But when you reach the perimeter of the campus, the field strength must be less than 24000/(frequency in kHz) microvolts/meter, measured at a distance of 30 meters outside the perimeter.

Governmental entities, park districts, and local authorities may be eligible to receive a Travelers Information Station (TIS) license for the purpose of disseminating information to travelers. This service allows for a 10-watt transmitter and a 15-meter (49 foot) long antenna. No commercial information or music can be played, so the license is very restrictive. This license is not available to the general public. It is theoretically possible to have a government agency or a park service register a station and then have an all-talk radio format, but the legality of this idea is questionable at best.

The TIS service is administered by the Wireless Telecommunications Bureau. More information can be found by calling the FCC's phone center, or by visiting the TIS webpage at http://www.fcc.gov/mb/audio/bickel/tis.html.

## Carrier Current

Another exception to the above rules pertains to Carrier Current broadcasting. This involves coupling a radio signal into the powerlines, and using that as your “antenna”. Carrier Current carries a different limitation: the field strength must be less than 15uV/m from the power line, measured at 47,715/(frequency in kHz) meters from the transmitter. This means that if your station is broadcasting at 540kHz, the test point would be at a power line 88.4 meters (292 feet) from the transmitter. If conditions are right, this can go significantly farther than a Part-15 antenna signal.

Unfortunately, Carrier Current is a very erratic system. I've heard stories of carrier current stations going several miles, and some that won't even go across the street. One of the biggest problems with Carrier Current signals is the power line transformers. They are designed to zap and RF going through them, which will effectively stop any carrier current signals.

One idea I've heard for getting around this is to attach the RF feed to the return wire instead of the hot wire. This might work better. Another idea I've heard is to bypass the power line transformer itself by attaching a very high voltage coupling capacitor between the input and output of the power line transformer. <u>This is extremely dangerous, and should only be attempted by a qualified linesman.</u> And unfortunately, it is very doubtful that the power company would agree to make any such modification.

## General Rules

All unlicensed LPAM broadcasters, regardless of transmission method, must conform to the following requirements:

*You cannot interfere with a licensed AM broadcast station.*

*All emissions not inside the AM broadcast (mediumwave) band must be at least 20dB below the level of the unmodulated carrier.*

This means that your transmitter cannot cause a significant amount of external interference. This is covered in the harmonics part of the Interference chapter.

Note that Part-15 regulations do not create any restrictions on ground planes, so the ground plane should be made as efficient as possible to maximize signal strength. Ground planes are covered in the Antenna chapter.

Part-15 limitations are very restrictive. The unlicensed transmission rules were designed for little toys and other gadgets, not serious broadcasting. Some think Part-15 power levels are perfectly adequate, but many disagree. It might be just the thing for a large apartment or the inner city, but what about suburban/rural broadcasting? Take the fact that skywave interference can obliterate a Part-15 signal, mix it with a rural location, and Part-15 can be quite inadequate for many communities.

## Illegal/Pirate Broadcasting

If the broadcast equipment does not conform to Part-15 rules, it is illegal to broadcast without a license from the FCC. You can get in trouble for it, which can include fines or a visit to your broadcast studio by FCC field agents (with effort, they can trace your radio signal). There hasn't been an FCC enforcement action against an unlicensed AM station in years, but that doesn't mean it can't happen. Don't say (to me anyways) that you weren't warned.

To avoid troubles with the FCC, use common sense. Don't meddle, interfere with, or openly challenge and compete with neighboring radio stations. Don't broadcast anything racist or heavily controversial. Don't broadcast with too much power, use vertical instead of horizontal antennas, and make sure neighbors are not having any interference problems as a result of your station. Stations that only broadcast intermittently instead of constantly are also less likely to get into trouble. Nothing can fully stop the possibility of trouble, but broadcasting responsibly and not causing any problems can certainly reduce the chances.

## My Two Cents

It is my personal belief that the Federal Communications Commission holds far too much regulatory power in regards to radio broadcasting, which not only affects low power broadcasters but also the larger commercial stations. We regulate our broadcast system so heavily, that even over-the-air speech is a target (despite the clear protections given to it by the first amendment of the supreme law of the land), and the FCC can and does fine radio stations for "inappropriate content", a crime which they actually refuse to define (there is no official list of swear words, phrases, or political opinions you cannot use on the air).

It is understandable to have some government involvement in broadcasting. Like with roads, there needs to be police to regulate traffic and catch those who would endanger other drivers. But like limiting all roads to 5MPH or only giving away drivers licenses to special people, there is such a thing as dumb rules and unequal protection under the law.

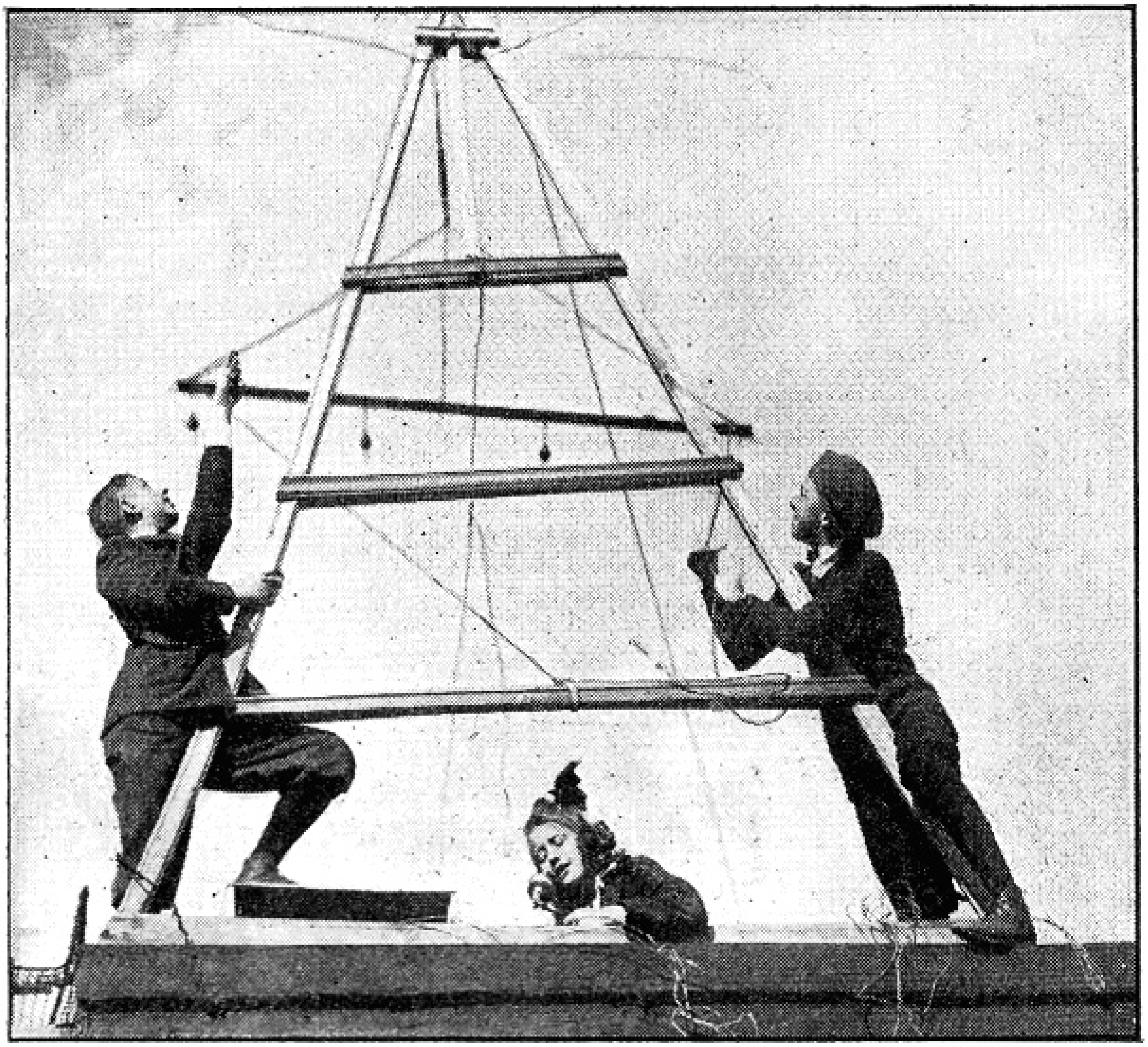
The FCC has adopted a policy of shutting down unlicensed radio stations, not because they are interfering with other radio stations, but simply because they do not carry licenses for power over minuscule levels (licenses which they refuse to give out). A much more fair (and liberty-centric) enforcement system would be to avoid going after unlicensed radio stations until they are actually interfering with something (not including the fake interference reports other station sometimes use to get rid of "competition") and present more of a problem than a service to the local community.

Some people have proposed creating a LPAM licensing system to resolve the problem. While it is a good concept, and I once supported it, I have since decided that it is a bad idea to further increase the power and size of the bureaucratic system that has created the problem in the first place. Furthermore, as with LPFM, the licenses would probably favor established entrenched special interest groups, most of which already had plenty of access to media outlets. Finally, giving the power of license to government gives more power to lobbyists to hijack or restrict the service, as we saw with LPFM.

Instead of trying to fix the problems of top-down statism with more state, it would be far easier and more effective to liberalize the restrictions on unlicensed broadcasting. Increase the maximum power level for legal unlicensed broadcasting from 100mW to perhaps 1-3 watts of power. Additionally, the antenna restriction (and the pointless transmission line inclusion) could be lengthened. A simple restriction on 'satelliting' other radio stations would stop a few large interest groups from gobbling up the entire band.

While this could obviously increase chances of interference, it should be pointed out that interference with licensed stations is illegal even with the existing Part-15 rules, so that wouldn't actually change. Also, despite dogma by special interest lobbyist groups, low power radio stations are not responsible for the large bulk of interference problems. Lobbyist scaremongers like to claim that interference from unlicensed low power broadcasters is going to make planes crash and break down emergency communications. In practice, the FAA themselves say that it is impossible for radio interference to crash a plane, and that most interference (of the non-crash variety) comes from commercial, licensed stations (infact, a lot of airplane interference comes from TV and radio towers operating at high wattages, and emergency response communications interference has recently been linked to cell phone towers, both of which are licensed and highly regulated by the FCC). LPAM stations (which broadcast with power levels far lower than most CB Radios) will never equal the interference capability of the powerhouse, licensed broadcasters that can go well over a hundred thousand watts. Even some of the best-engineered commercial broadcast stations typically produce more interference, simply because they put out far more power.

The only thing that would really change is that it would give people a chance to start local radio stations, enrich the content of the radio broadcast band, and strongly reduce the pointless, unrepresentative crackdown on “piracy”, which is in almost all respects a victimless crime.



# 5 - Antennas

Mediumwave antennas can be much more difficult to construct than antennas for other radio bands. Firstly, they are long. Secondly, they have to be vertical to work well. Thirdly, they need to have rather long ground radials for the same reason. I will get into why shortly, but just keep in mind that, despite your best efforts, practicality and the constraints of your property will severely limit the efficiency of the antenna you can construct. If you plan on building a Part-15 station, which limits the antenna size to 3 meters, your efficiency will be especially low. Efficiency for Part-15 antennas is measured in the single digits, and sometimes even less than that.

But don't read too far into this. Practical mediumwave antennas, while seemingly awful on paper, work very well in the real world. Mediumwave signals propagate better than higher frequency signals, which almost makes up for antenna inefficiency. Also, there are methods to make shortened antennas perform better.

Note that the focus of this chapter is on mediumwave vertical antenna performance, not on compliance with rules and regulations. Read the Legal chapter before attempting anything in here.

## Basic Antenna Design

First, it is important to understand that frequency can be measured in terms of physical length. To find the length of a given frequency, use this formula:

$$W = \frac{984{,}000}{kHz}$$

Where W is the wavelength ( $\lambda$ ) in feet, and kHz is the broadcasting frequency. This is important because we can use the wavelength to get an idea of how long the antenna should be. For example, to find out how long a wavelength for 1600kHz would be:

$$\frac{984{,}000}{1600} = 615'$$

Antennas are not made the full size of the wavelength, however. They are usually made in fractional sizes of the full wavelength. A 1/4 $\lambda$ antenna, for example, would be 1/4 the length of the full wavelength. Lets say you want to make a 1/4 λ antenna. Simply multiply the fraction into the previous equation:

$$\frac{984{,}000}{1600} \times \frac{1}{4} = \frac{984{,}000}{6400} = 153.75'$$

So if I wanted to make a 1/4 λ antenna for 1600kHz, I would make it 154 feet long. Similarly, we can find the wavelength of an antenna for a given frequency if we know its height:

$$A_\lambda = \frac{H}{W}$$

Where
A = Antenna wavelength
H = Height of antenna (in feet)
W = Wavelength of frequency (984,000/kHz)

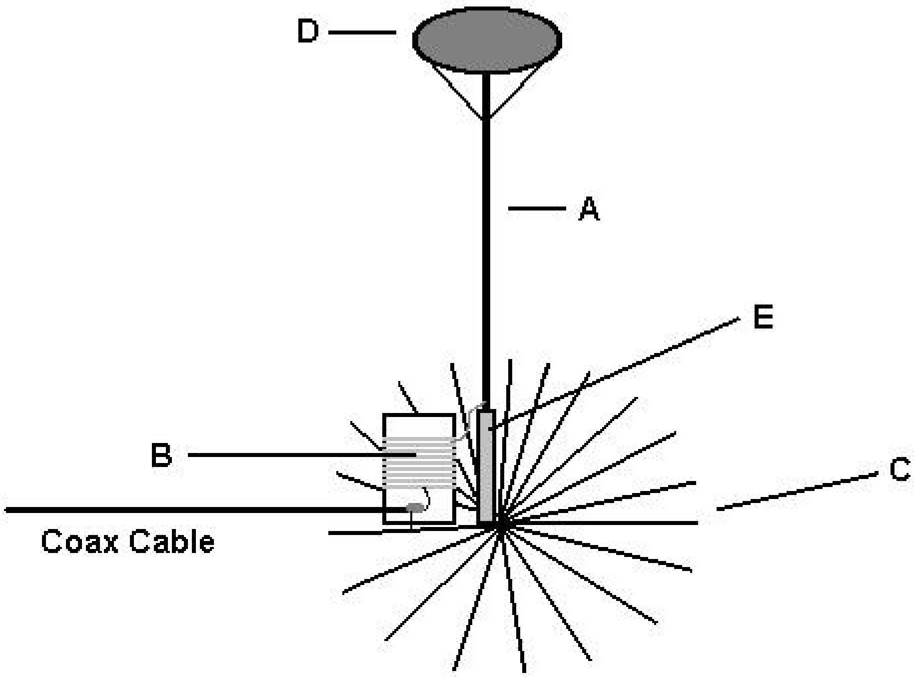
The optimum height for a mediumwave vertical antenna is 1/4 λ, for reasons explained later in the chapter. If you can get a 1/4 λ antenna, that's great. But unfortunately, a 1/4 λ antenna for mediumwave is very long and impractical for most people. From the above formula:

$$\frac{984{,}000}{1700} \times \frac{1}{4} = 144.7' \qquad \frac{984{,}000}{540} \times \frac{1}{4} = 455.5'$$

As you can see, these are very long antennas! For reasons of practicality (and in many cases legality), most people will have to settle for shorter antennas.

## Shortened Vertical Antennas: An Overview

Shortened antennas actually consist of five different elements. Each is a separate component that comes together to create the antenna.




The main components are as listed:

A) **Vertical Radiator**
B) **Loading Coil**
C) **Ground Plane**
D) **Capacitance Hat**
E) **Insulator**

## Vertical Radiator

The vertical radiator is the element that actually radiates the signal. It can be a thin wire, copper pipe, irrigation piping, or any other sort of metal conductive material (such as an existing radio tower).

Large physical radiators are the popular choice of commercial broadcasters. Putting up anything that bulky, however, requires guy wires to keep it from falling, and can be dangerous if not done right. This explains the popularity of wire antennas or smaller elements for LPAM broadcasters.

One popular material for making LPAM antennas is TV mast. Make sure to have plenty of guy wires to keep the radiator from falling, perhaps a set of three guy wires at the top and (if needed) another set halfway down the mast. It is suggested that you not try to make any large-diameter antennas too tall without having more advanced knowledge of antenna construction.

If you do use guy wires, use non-conductive ones, such as thick nylon wire.

Using conductive guy wires can cause a lot of problems. The diameter of the vertical has to be large (and sturdy) enough to keep it from bending. If you are just making a 10 foot Part-15 compliant antenna, a piece of copper piping should suffice, and it shouldn't be necessary to have guy wires.

If you have a long tree in the broadcast area, one idea is to string a wire antenna up using the tree as the support. To do this, take a trout sinker and tie it to fishing line. Using a slingshot, shoot the sinker over the tree or other support until you can get it to come down through the tree (this could take a few attempts). Once that is accomplished, tie some nylon string to the fishing line and pull the fishing line back towards where it was shot until the string has replaced the fishing line. Attach a wire antenna to one end of the string, with the other part of the wire antenna attached to an insulator or some sort of heavy weight. Pull the other end of the string until the wire antenna is firmly in place, and then tie it to a nearby tree.

To maximize the performance of your radiator, make the vertical as long as you can up to 1/4 λ . The longer the vertical is up to that point, the better the antenna will perform.

## Loading Coil

Impedance is a complex number, related to the resistance and reactance in a signal. It fails simple description, but for purposes of this guide consider it a “type” of signal, and that in order for your antenna to work well with the transmitter and coax cable, it must be the same impedance. If the output impedance of a transmitter and coax cable is 50Ω (ohms), the antenna impedance must also be 50Ω. A shortened antenna exhibits a high level of capacitive reactance; in essence, it behaves like a lossy capacitor. In order to make the antenna 50Ω, the excess capacitive reactance needs to be canceled out with its electrical opposite, inductive reactance, which is done with a loading coil.

A loading coil is, in all respects, a large inductor that tunes the antenna's impedance to that of the coax and/or transmitter, which is in most cases 50Ω. Loading coils are designed to be variable, because for LPAM broadcasters it is impossible to determine the exact impedance value of a homemade antenna.

Loading coils are made by taking insulated wire and wrapping it around a coil form, such as a piece of large diameter PVC pipe. Every 10 turns or so, there is a tap that comes out from the coil, giving you something to attach the transmitter signal to (via an alligator clip). You then tune the coil by selecting the tap that provides the best match for your antenna.

This method, however, only produces a coarse tuning. In order to get the maximum amount of power out of your antenna, you also need to be able to fine-tune the coil to the exact point of impedance match (called resonance). To do so, either a variable capacitor is inserted, or a variometer is constructed. These allow you to make small and precise changes to the total inductance of the loading coil. Loading Coil design is detailed later in this chapter.

Note: the closer to 1/4 λ the antenna is, the less inductance is needed to tune it. In the rare instance that you have an antenna longer than 1/4 λ, you may need to use a different tuning method (explained later in the chapter).

## Ground Plane (Counterpoise)

The counterpoise is one of the more confusing elements of an antenna. In a nutshell, it does two things. First, it's what the vertical portion of the antenna "pushes" off of, an electromagnetic behavior that is required to make antenna actually work. The second practical function of the counterpoise is to provide a low-resistance return for electromagnetic current near the antenna to make up for earth losses.

A ground plane is a type of counterpoise that consists of radials (wires) extending horizontally from the base of a vertical antenna in a spokes pattern. All vertical antennas have some sort of ground plane, as all antennas require one to work well. <u>You need a ground plane for your antenna to work well</u>. The major difference with mediumwave ground planes is that they are much longer than ones for higher frequency antennas. From the above formulas, a 1/4 λ radial for 1600kHz is 153.75 feet long.

Note that a ground plane is not the same thing as an electrical ground (though they are often electrically connected to ground via the return of the coax). That is to say, you cannot just bury a grounding rod and then use that as your "ground plane". The behavior and purpose of a ground plane is quite different than a simple low-resistance path to earth, though the use of the word "ground" for both elements often makes them sound like they are related. They are not.

If you place the radials on (or bury them in) the ground, you will have to use a lot of radials to make up for earth losses. Commercial broadcasters use as many as 120 1/4 λ radials for their stations, which is considered the optimal configuration. But this is a potentially time consuming and expensive task (at 1600kHz, you would need 18,450 feet of wire to do this!)

Like with the vertical radiator it is often impractical to achieve an optimal ground plane, but try to make it as good as you can. A lousy ground plane will work far better than no ground plane at all.

One way to reduce earth loss is to place the antenna on top of an elevated roof. If the roof happens to be metal, attach the electrical ground to it and the roof itself will serve as the ground plane. If the roof is not metal, placing the antenna on it will still probably improve range. Another benefit is that fewer radials will be needed. Elevated antennas only typically need 4-8 radials to achieve optimal efficiency, far less than are needed to reach the same level with a ground-based antenna.

Here are some general rules for constructing an effective ground plane:

- Have all radials equally spaced in a circle around the antenna. Attach each radial to a central location at the base of the antenna, such as a pie pan or a circular loop of thick copper wire. Make an electrical connection, such as an alligator clip, or solder the radials to the centerpiece.
- The radials should be as long as possible, keeping property size in mind. Optimal length for radials varies with the length of the vertical radiator, but generally the longer the better. Don't use radials longer than 1/4 λ unless you know what you are doing.
- The more radials the better, but the gain becomes progressively smaller. Increasing the number of radials from 4 to 16 significantly increases antenna efficiency, but after that the gains become less radical. Increasing the number of radials from 16 to 60 would provide less of a gain. If you are using an elevated ground plane, you shouldn't need more than 4-8 radials.
- More is better than longer. 8 radials of 1/8 λ are better than 4 radials of 1/4 λ .
- Insulated or bare wire can be used. Copper is preferred, but aluminum can be used if the acid level of the soil is low. Sizes can be anywhere from 5-20AWG. Go with what's cheapest.
- The radials don't need to be in a perfectly straight line from the antenna, nor do they have to be perfectly evenly distributed. They can be bent, risen, or lowered slightly to fit the property.
- Chicken wire fencing works very well. Making a large chicken wire ground plane would probably be cumbersome and expensive, but a small amount near the antenna can improve performance. I have used a 5x5' chicken wire screen that was soldered together for the center of an antenna, and it improved range considerably.
- If it's not possible to make a radials system, there are a few long-shot alternatives. One alternative is to bury a few ground rods or several copper pipes near the base of the antenna (eight feet into the ground), wire them together and then use that as your ground. You could also attach the ground t underground water pipes or a nearby faucet. It might be better than no ground system at all, but don't expect miracles.

### Capacitance Hat

A capacitance hat is a component that helps to even the current flow through an antenna. Without one, more of the signal is propagated at the bottom of the vertical radiator than at the top. If more of the signal is propagating at the top of the antenna, the signal does a better job of getting above trees and nearby objects. Capacitance hats also help to increase the bandwidth of the vertical radiator, which can lead to improved audio fidelity if the "Q" factor of the antenna is too high.

A capacitance hat can be a large metal disk, a pie plate with spokes of stiff copper wire extending from it, a pyramid of wires extending a few feet from the top and attaching to the guy wires, or simply anything metal coming out horizontally from the top of the antenna such as several wires stringed to insulators (anything non-conductive) on nearby trees. The capacitance hat needs to be electrically connected to the top of the vertical radiator. Capacitance hat construction is not critical, feel free to experiment with whatever works best for you.

### Insulator

This is the base of the antenna. It has to be non-conductive and sturdy enough to hold the antenna in place. Avoid using concrete and wood to *directly* insulate the antenna, because they can absorb water. Rubber and plastic insulators work best. If you are using a wire antenna strung from a tree, nylon string tied to something heavy on the ground serves as a good support to tighten and hold the antenna in place. If your vertical radiator is thicker than a wire, the insulator will probably have to be hammered/concreted into the ground for stability. Don't forget the guy wires.

## Building a Loading Coil

Four things are considered in the development of a loading coil. First, they need to be able to coarsely vary in inductance, which is implemented in the form of tap points in the coil at certain intervals. Secondly, they must be able to fine-tune to the exact level of inductance needed. Thirdly, they need to be sturdy, which means the wires must be firmly on the coil and the coil must be able to handle unfavorable weather conditions. And finally, they need to have enough inductance to properly tune the antenna. Variable loading coils can take a little time to make (a day or two), but once you build one you never have to do it again, even if you change frequencies or the antenna.

There is no standard for what wire size to use, but it's a good idea to use 20AWG or thicker wire to avoid loss due to wire resistance. The wire must be insulated when wrapped into a coil. Plastic insulated, litz, and enamel-coated wires work just fine. Enamel coated wire might look like bare copper at first sight but it isn't, it tends to have a darker, redder color than copper. Enamel coating can be removed with sandpaper, or burned off with a flame.

The coil form most people use is a 4 to 12 inch diameter PVC pipe. PVC piping can be purchased at most local hardware stores by the foot; 2-3 feet should be all that is needed. Basically anything that is round and doesn't cause significant RF loss will work well, such as a plastic drink container. If you do get PVC pipe, get the white kind. The other kinds of PVC have different "dielectric" properties and can be lossy at RF (though this is a bigger concern at higher frequencies than it is at mediumwave).

How much inductance (how many turns of wire) should your coil have? This depends on antenna length, antenna diameter, and operating frequency. We can approximate the amount of inductance required to tune an antenna, which is good enough for designing a loading coil. Make sure you design the coil so that it is somewhat larger than needed. If the coil is too small, you won't be able to tune it without adding more inductance, so good engineering practice calls for the design of a loading coil that has more inductance than is needed for the specific application.

There are multiple ways to determine the inductance needed to load an antenna. The easiest way is to use the values supplied in **Appendix D**. More complicated methods are presented in the next section of the chapter. Once the required inductance is known, the following formulas can be used to form the coil:

$$L = \frac{(0.5ND)^2}{4.5D + 10H}$$

or

$$N = \frac{\sqrt{L\,(4.5D + 10H)}}{0.5D}$$

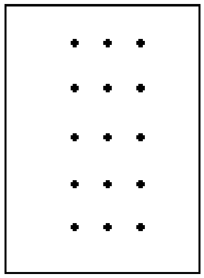
Where:

L = Inductance of coil in microhenrys ($\mu$H)
N = Number of turns
D = Diameter of coil in inches (twice the radius)
H = Length of coil in inches

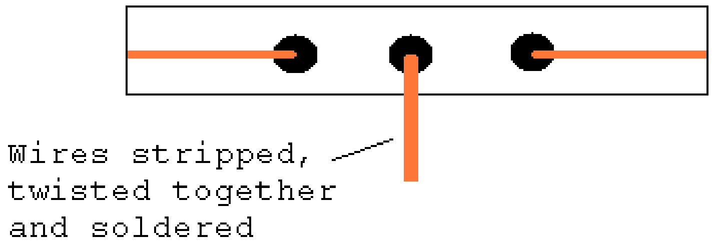
## Tapping the Coil

One of the "gotchas" of loading coils is that you cannot wrap together a large coil, sand off an up-down section of the insulation and tap the wires as-is. It simply doesn't work, because alligator clips cannot attach to the wire. Unless you are designing a roller-inductor (which is usually more difficult), you have to build taps into the coil while you are looping the wire. The best way I have found to make taps is to use this method:

Drilling outline



Close up wire diagram




First you drill three holes into the form every 1/2 inch or so, moving up until the coil has several sets of holes. Then, start wrapping the wire around the loading coil firmly, and when you come to one of the holes, push the wire into it, and then pull it out tightly through the center hole. Place the wire for the next segment in the other hole and through the center, strip off the insulation with sandpaper or a wire stripper, and then twist and solder the two wires together. Repeat for every hole until you have the desired maximum inductance. The inductance can be found by applying the inductance formula as you go along.

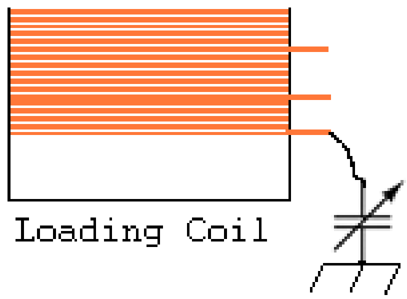
Another quick and dirty way that works is to simply twist the wire at each tap point as you are wrapping the wire to the form. After you are done, sand off the insulation from the twisted elements and you have coil taps. This could be difficult, because the loops might come unturned when tension is applied to make the wire fit the form tightly. One way to resolve this is to apply superglue or solder the twisted wire together as with the above method.

When you are looping the wire to the form, *keep applying tension to the wire*, otherwise it will loosen and the coil will deform. I have found that applying a small amount of superglue helps to keep the wires in place. Every tap point or so, dab some super glue near the taps and in a few places across the looped wires. Let it dry for a few minutes, and then continue.

### Fine Tuning Loading Coils

The coil tap method only gives a coarse tuning range. In order to get the best performance out of your antenna, you have to be able to fine-tune to the *exact* point of resonance. That is, we want to have the ability to both coarsely-tune and then finely-tune the loading coil. The coarse tuning part (the taps) will change the amount of inductance greatly, whereas the fine-tuning part will allow us to change the inductance a smaller but more precise amount. This involves either inserting a variable capacitor between the loading coil and ground, or making a variometer.

Inserting a variable capacitor between the coil and the ground allows for a fine tune, because it tunes more smoothly and precisely. Variable capacitors can only tune a small amount because of their low capacitance values, so coarse tuning is still required. With a variable capacitor, one sets the inductance to be slightly higher than is required for resonance, and then the capacitor is turned until the excess inductance is canceled out, which creates exact resonance.




The biggest drawback with a variable capacitor is that it can be hard to find them (your best bet is at HAM fests and old electronic parts stores). Also, after about 10 Watts they have to be high voltage or else they won't work (the RF electricity will arc across the capacitor's metal plates). If you run into this problem or can't find a suitable variable capacitor, an alternative is to use a variable-inductance method of fine-tuning, such as a variometer.

### The Pseudo-Variometer

A pseudo-variometer is basically a large outer loading coil, with a smaller inner coil inside of it. The inner coil can rotate, and is connected electrically in series with the outer coil. When the inner coil is turned, it slightly changes the overall inductance of the loading coil, allowing for a fine-tune.

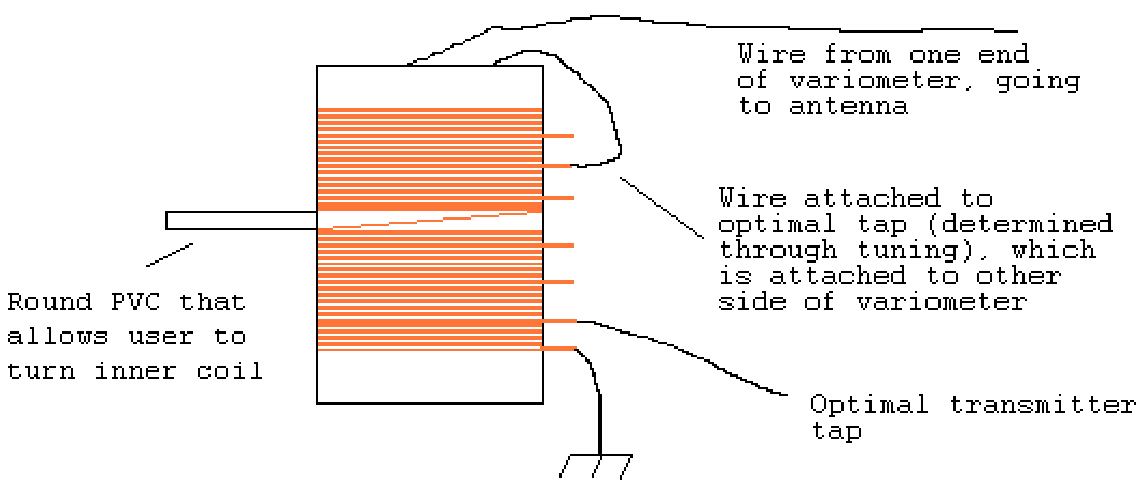
Variometers have become a rare item since the advent of high frequency communication. In the early days of radio they were used for tuning receivers, but were quickly phased out in favor of the more selective variable capacitors.

Despite being out of use for years, they have seen a recent revival in amateur broadcast antenna tuning. In my own work, I have found that variometers work very well for tuning shortened broadcast antennas. They can be built from scratch out of readily available parts, and aren't prone to shorting out at high voltages. Variometers will be slightly more lossy than variable capacitors, but not by a large amount.

*Real* variometers have a large amount of inductance on the outer coil *and* an equally large amount of inductance in the inner coil. This makes their tuning range very wide, which is why they were popular with early radio receivers. A pseudo-variometer is very similar to a variometer, except that the inner coil contains significantly less inductance. The idea is to make a coarse tune with the taps on the outer coil, and then to use the inner coil to change the inductance slightly.

Good engineering practice would call for the inner coil to be able to change the inductance more than the total amount of inductance between each tap point. Specific information on how to do this is provided in the next section of the chapter, but again the most important thing is to make the inner coil have more inductance than is needed.

The primary (outer) loading coil for a variometer can be made exactly the same way that the loading coils above are made, except that there is a space in the middle of the outer coil for a handle to turn the inner coil with. The construction details of the inner coil are not critical, 15-45 turns sloppily wrapped around a form 2-6” in diameter and perhaps 4-8” long (depending on the outer coil size) will work just fine. 40-80uH of inductance should be more than enough to do the tuning.




## Tuning the Antenna

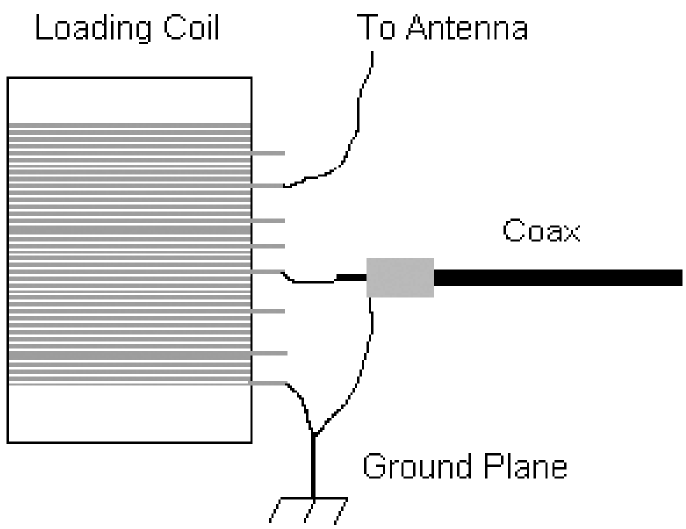
Once the loading coil is ready, you have to tune it to resonance. Tuning a mediumwave antenna is different than most other types of antennas. Because of the lower frequency, most commercially retailed wattage/SWR meters do not work. Because of this, a little bit of ingenuity is needed to actually know when you have tuned the antenna.

When the loading coil is properly tuned to resonance, the power level going to the antenna and the signal strength coming out will be maximized. Knowing this, we can determine the point of resonance by finding the peak rating on meters that determine either of these things.

The first way to do this is to put an RF ammeter between the loading coil and the antenna. This is the method most people use, but it requires an ammeter that works at mediumwave frequencies.

If you don't have an RF ammeter, the next best way is to use a field strength meter. If you don't have a field strength meter, you can make a crude one very easily. Field strength meters you can build are available in the **Schematics** chapter.

Homemade field strength meters won't give a calibrated reading, but they are good enough for determining the resonance point of an antenna. When using one, make sure to keep it within a few feet of the antenna, otherwise the transmitted signal will be too weak for the field strength meter to see. Then, simply tune the antenna until the highest point on the meter is reached.




Tuning the antenna is simple. First, attach the antenna clip to the uppermost tap and attach the transmitter clip to the lowermost. Turn the transmitter on (if power is variable, set to lowest power). Don't put any audio into the transmitter while tuning. Then, while looking at the meter, take the transmitter clip and keep moving it up, one tap at a time, until about the middle of the coil. Whichever tap gives the highest reading on the meter is the tap point you will use (if there's no noticeable difference, set it to the first tap after the ground). The point of this is to find the best impedance match for the transmitter clip.

The next step is to tune the antenna. Take the antenna clip and move it to the same tap as the transmitter. *Slowly* turn the variometer or the variable capacitor, and if the antenna doesn't resonate, move to the next highest tap and try again. You will notice that when the antenna has reached resonance the meter reading will go up *significantly*. Once the antenna is tuned and ready, set the transmitter to full power and you're ready to broadcast.

## Safety Factors

### Static Charge

In dry windy conditions, antennas can generate a static charge that can damage the transmitter. It can also shock you, which isn't dangerous, but could cause an accident if the antenna is on top of an elevated roof and the shock causes you to fall. A more likely problem is that a high voltage static charge could damage your transmitter.

Because the static charge is DC, it is relatively easy to separate and remove it from the antenna. Actually, if there is a connection between the vertical radiator and the ground on the loading coil, the static charge should drain off naturally. If not, you can install a high-inductance RF Choke between the hot wire and ground. The RF won't pass through, but the static charge (which is DC) will. Installing a 500k-1MΩ resistor between the antenna and the ground will help to bleed off the charge, but will take a small amount of power out of the antenna.

### RF Burns

An RF burn is the result of touching something carrying RF power (such as the antenna wire). It usually just creates a tingling sensation at the touch point, but at higher levels (greater than 10 watts) it can create a burn, similar to if a hot surface were touched. RF power usually conducts through the outer skin and therefore isn't typically dangerous to humans in terms of heart failure or shock. However, this "skin effect" is no guarantee: it is still possible to electrocute, shock, or even kill yourself with RF power.

It's a very good idea to take precautions to avoid exposure to RF power. If you are running higher power levels, put up a fence or warning sign to discourage others from touching the wire. When tuning the antenna, putting on rubber gloves will keep you from being burned.

### Lightning

Lightning is a daunting problem for low power broadcasters. If you live in an area that is prone to thunderstorms, some form of lightning protection will be needed. Don't think it can't happen to you! There are many stories of lightning hitting unprotected low power broadcast antennas, and the results are very destructive (though thankfully, I have yet to hear of a fatality).

When lightning hits an unprotected antenna, the electricity will enter the transmitter and destroy anything connected to it (audio amps, computers, ect). If a DJ happened to be on the microphone, he could also be the victim of a lightning strike. A defensive mechanism needs to be put into place to keep equipment and people safe in the broadcast room.

The common practice for radio broadcasters is to bury a ground rod (or copper pipe) under the antenna, and attach to it a thick copper pipe/wire with its end very close to the bottom of the vertical radiator without physically touching it. Lightning will spark across the small air gap to the copper wire, and then run into the ground rod. The ground rod must be at least 8 feet long to be effective. If you're paranoid, there are lightning suppressors that go in series with a 50 ohm coax cable, which also require a grounded wire. A combination of both methods could be used.

If you are extremely paranoid or are in a high risk area, additional steps can be taken with the transmitter. It wouldn't be a bad idea to put the transmitter in a different area than the broadcast room (remember that for Part-15, the transmitter needs to be at the antenna anyways). The bottom prong on three-prong AC outlets is electrically connected to a ground rod in most homes. If the transmitter case is metal make sure it is grounded, this provides another route for lightning. Another option is to separate the physical connection between the transmitter and the studio by using a wireless link, such as a WiFi Internet system or a Studio to Transmitter Link (STL).

## Summary

This section of the chapter was designed to be simple and understandable for newcomers to LPAM broadcasting. It is still fairly complex, and if you're new at this it might take a few reads through this chapter before the concepts and procedures make sense. Once you think you're familiar with the concepts presented in this chapter, you should move on to the next section, which contains more detailed information.

# Antenna Topics and Design Calculation

This section provides several discussions on improving the quality and performance of antennas. Much of this book is designed to help newcomers set up a radio station, and it's not very effective to flood those parts of the book with large formulas and contradicting information, which is why I have separated the more complex content from the rest of the chapter. With this information, it is possible to get a better grasp of how signal range can be improved by modifying equipment components and details.

The antenna is typically the weakest link in a mediumwave broadcast setup. Antennas are almost always shorter than optimal length, and electrical ground losses can be severe. Mediumwave signals still propagate extremely well despite these drawbacks however, and even an antenna with poor efficiency can perform surprisingly well. For a working example, I once loaded a 1000kHz 10W signal into a 30' antenna with a 5x5' long ground screen. Despite a poor ground system, bad loading coil, bad antenna location, and average conducting earth, I was able to receive a strong signal for up to five miles on a car radio.

Approximate antenna performance can be calculated (though not in terms of distance, as there are too many variables to make such predictions accurate). The first equation finds the radiation resistance of a shortened antenna, which is a measurement of how much energy is being converted to RF energy. [1]

$$R = 160\pi^2 \left(\frac{h}{\lambda}\right)^2$$

Where:
R = Radiation resistance in ohms (Ω)
h = Height in feet
$\lambda$ = Wavelength of frequency in feet (984000/kHz)

Example: A 1000kHz signal loaded into a 30' long antenna has approx. 0.37Ω of radiation resistance.
Once the radiation resistance is known, approx. antenna efficiency can be found by factoring in loading coil and ground losses:

$$E = \frac{100R}{R + G + L}$$

Where:

E = Percent of Antenna Efficiency
R = Radiation Resistance in ohms
G = Ground Losses in ohms
L = Loading Coil Losses in ohms (AC resistance; cannot be measured with a DC ohmmeter)

The following chart can be used to estimate ground loss. Lower numbers are better.

| | |
|---|---|
| Excellent | 2Ω |
| Good | 4Ω |
| Mediocre | 8Ω |
| Poor | 16Ω |
| Lousy | 32Ω |

Example: Guessing the loading coil has 2Ω of loss, and I am guessing the ground screen described above to be around 20Ω, which gives my above antenna setup an efficiency of 0.0165 or 1.65%.

Now, calculate the total power being broadcast by multiplying the transmitter power output by the antenna efficiency, and you have the total output. With the lousy antenna described above, I was able to output 0.165W or 165mW of power.

Now consider that I was still able to get a 5-mile signal distance with the above antenna despite its poor efficiency. As I hope I have shown, the mathematics severely underrate the ability of these antennas. Just think what signal distance could be acquired with a good ground system and a longer antenna and/or higher frequency signal! With a little work, an antenna with considerably higher efficiency can be made.

## Groundwave

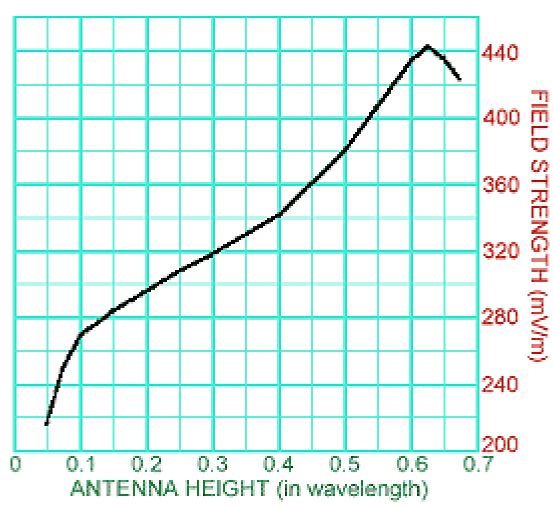
Lower frequency signals possess a strong propagation property that is commonly referred to as groundwave. As opposed to higher frequency signals which are basically “line-of-sight”, mediumwave signals can travel far beyond the horizon by traveling along the earth, a natural result of their longer wavelength. This leads to exceptional horizontal distance on the lower frequency bands, including mediumwave.

The amount of signal boost given by groundwave depends primarily on two things, the soil conductivity and the frequency of the signal. Buildings, varying soil conditions, and other objects will of course change the effectiveness of the groundwave in certain directions. Mediumwave signals travel nearly three times farther on saltwater than on soil with a conductivity of 3, and a signal at 550kHz travels nearly twice as far as a 1650kHz signal with the same amount of power.

But when analyzing groundwave effectiveness, antenna efficiency must also be considered. A 550kHz signal might travel farther than a 1650kHz signal, but a considerably larger antenna will be needed to have the same amount of antenna efficiency. If a shortened antenna is used, the groundwave effect is less enhancing than the level of antenna efficiency gained by increasing the operating frequency. Only when at least a $1/4\lambda$ antenna can be constructed *for a lower frequency* should groundwave be seriously considered for performance enhancement. [2]

## Antenna Length and Performance

Antenna performance varies with respect to the ratio of antenna height to frequency wavelength. This chart diagrams the increase in signal strength as the length of the vertical radiator is increased:




To a point, increasing the length of a vertical radiator will increase the efficiency of the antenna. Note that peak signal strength is reached at 5/8 . Despite being the optimal point for signal strength, it is not the optimal point for vertical antennas, as it is accompanied by a high angle of radiation (not visible in graph). This is undesirable, because it leads to skywave interference and a reduction of the groundwave.

Optimal antenna height for vertical antennas varies with power level, transmitter frequency, soil conditions, and numerous other things. However, it has been established that 0.53 λ (slightly above 1/2 λ ) is optimal in most situations. At this wavelength, the groundwave receives the most radiation, which reduces skywave interference and improves signal strength. [3]

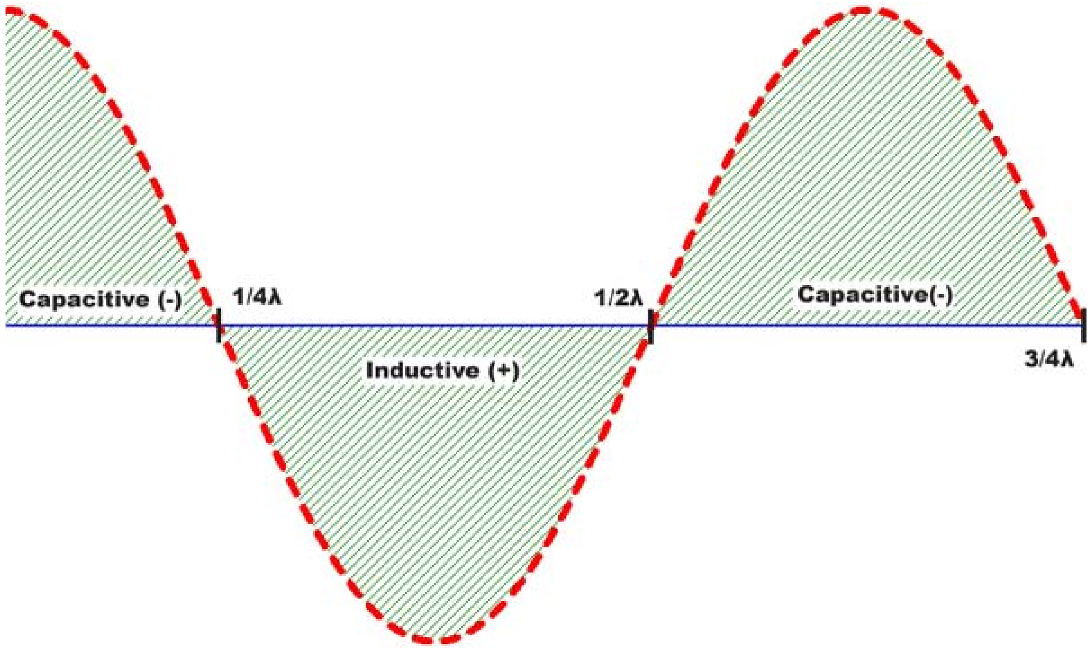
A quick note about horizontal antennas: Don't try them. It might be tempting to try to get a full 5/8 λ antenna by using a horizontal antenna, but it's a copout with consequences. In a horizontal antenna most of the energy will be poured into the ionosphere, which will lead to skywave interference. It probably won't perform well anyways, because it will create null points in local reception.

## Impedance/Reactance Considerations, and Length of Antenna

When I mentioned that 1/4 λ was the optimal height in the antennas chapter, I was being half truthful. While 1/4 λ antennas work very well and are in use by many commercial broadcast stations, 1/2 λ is the optimal height for the best signal strength. However, when considering how to load antennas, we also need to consider another factor: the impedance matching between the 50Ω transmitter/transmission line and the antenna.

When an antenna is shorter than 1/4 λ , it exhibits an amount of capacitive reactance. Reactance in electronics is actually the total level of inductive and capacitive reactance together. Inductive reactance is indicated with a positive (+) sign, and capacitive reactance is indicated by a negative (-) sign. We use a loading coil with shortened antennas to tune out the capacitive reactance to match our antenna to the 50Ω inductive (+) reactance that our coax cable will accept.

With a 1/4 λ antenna and a good ground system, the antenna has an impedance of just under 50Ω. The antenna almost matches the transmission line, and only a small amount of inductive reactance is needed to tune it.
But after 1/4 λ , the reactance becomes inductive instead of capacitive. When this happens, a variable capacitor is needed to tune the antenna to resonance instead of a loading coil, or you could add more inductance to bring the antenna to resonance at 1/2 λ . A graph of this behavior is provided. [4]




## Methods for Determining Required Loading Coil Inductance

Two mathematical methods are presented for finding the *approximate* amount of inductance required to tune an antenna. If a fixed inductance coil were being designed, a few turns would have to be added or removed before the proper amount of inductance was reached. When building a *variable* loading coil, the designer should make the inductance far larger than these formulas suggest, perhaps by as much as twice the amount (perhaps even more for inductances of 10uH or less). It is worse to have a coil that has too little inductance than to have one that has too much, because if there isn't enough inductance the coil will need to be modified to add more turns of wire.

### Method 1: Capacitance of Antenna

This formula finds the capacitance of an antenna:

$$C = \frac{17h}{\left(2.3\log\left(\frac{24h}{d}\right) - 1\right)\left(1 - \left(\frac{.001fh}{234}\right)^2\right)}$$

Where:

C = Capacitance in picofarads (pF)
d = Antenna diameter in inches
f = Frequency in kHz
h = Length of antenna in feet

This formula does not account for capacitance brought on by the use of a capacitance hat, so an estimate between 30-90pF is usually added to the answer to give further accuracy.

Once the capacitance is known, the required inductance of a loading coil can be found:

$$L = \frac{10^{12}}{4\pi^2 f^2 C}$$

Where:

L = Inductance in microhenries (uH)
f = Frequency in kHz
C = Capacitance in picofarads

### Method 2: Reactance of Antenna

This is the transmission line theory method:

$$X_c = \frac{138 \log\left(\frac{12h}{d}\right) - \left(60 + 69 \log\left(\frac{24h}{\lambda}\right)\right)}{\tan\left(\frac{2\pi h}{\lambda}\right)}$$

Where:

h = Height in feet
d = Antenna diameter in inches
λ = (984000/f)
f = frequency in kHz

Again, this formula does not compensate for a capacitive hat. Approximate 30-90pF, and then use this formula to find the extra reactance:

$$X_{caphat} = \frac{10^9}{2\pi f C}$$

Where:

C = Capacitance in picofarads (pF)
X = Capacitive reactance in ohms
f = Frequency in kHz

*Subtract* the capacitive hat reactance from the antenna reactance. Then use this formula to find the needed inductance:

$$L = \frac{1000X}{2\pi f}$$

Where:
L = Inductance in microhenries (uH)
X = Inductive reactance in ohms
f = Frequency in kHz

### Method 3: Software Analysis

There are many antenna analyzer programs of varying complexity available for doing the reactance calculations and much more. I don't use these programs enough to recommend any particular one, but I did use EZNEC for doing sanity checks of the above formulas.

### Making the Coil

Once needed inductance is found from one of the methods, this formula can be used to form a coil:

$$N = \frac{\sqrt{L\,(4.5D + 10H)}}{0.5D}$$

Where:

N = number of turns
L = inductance of coil in microhenrys ($\mu$H)
D = Diameter of coil in inches (twice the radius)
H = height of coil in inches

If you are unsure of what to use for length, use this to find the possible ratio:

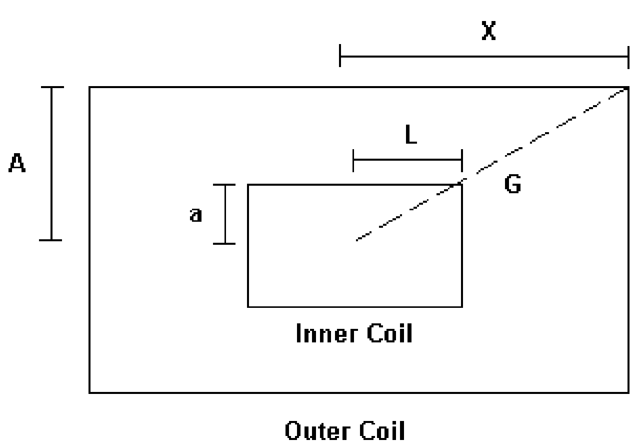
$$R = \frac{N \cdot A}{L}$$

Where:

N = Number of turns
A = Diameter of wire in inches, use AWG chart at back of book or measure wire diameter with millimeter ruler and divide by 25.4
L = Length of coil in inches
R = Ratio of wire diameter to length. If R > 1, then the length value given is not physically possible to wind and a larger length should be considered.

## Variometer Design

The mutual inductance in microhenries (uH) between two coils in a variometer can be found with this formula: [5] [6]



$$M = 0.0501 \frac{a^2 N_1 N_2}{G} \left[ 1 + \frac{A^2 a^2}{8G^4} \left( 3 - 4 \frac{L^2}{a^2} \right) \right]$$

Where:

$$G = \sqrt{A^2 + X^2}$$

$N_1$ & $N_2$ = Number of turns on inner & outer coil
A = Radius of outer coil
X = 1/2 the length of the outer coil
a = Radius of inner coil
L = 1/2 the length of the inner coil

Once the mutual inductance is found, the maximum and minimum inductance can be found:

$$L_{max} = L_1 + L_2 + 2M$$
$$L_{min} = L_1 + L_2 - 2M$$

Where:
$L_1$ & $L_2$ = Inductance of coils
M = Mutual inductance

When making a hybrid tapped-loading-coil/variometer, good engineering practice is to design the variometer so that the inner coil can tune more than the level of inductance between coil taps on the outer coil. Note that these equations assume that the entire outer coil is used, which is not true with a tapped design. When determining specific inductance using the above equations, measure the outer coil based on where the two taps are used.

## Optimal Ground Plane Length

The effectiveness of the ground plane varies wildly. The optimal length of ground radials is said to be 0.4 $\lambda$ , but this is a generalized average. Especially with shortened antennas, the optimal length can be significantly shorter, so much infact that I have recommended 1/4 $\lambda$ as a suggested maximum length. Actual optimal length has to be analyzed using an antenna modeling program or experimentation.

## Final Tips for Improving Antenna Performance

Improving antenna efficiency is the key to improving range, especially for Part-15 broadcasters who only get 100mW to work with. When power levels are that low, increasing the antenna efficiency even slightly can give significant range increases.

For Part-15 broadcasters, the FCC regulates power output and antenna height, but not antenna efficiency. The key to maximizing range in this scenario is to reduce antenna loss as much as possible.

One way to improve shortened antenna efficiency is to improve the ground plane. It is almost always responsible for the most loss. If you want to maximize efficiency and can afford the space, time, and money to put down a 120 radial 1/4 $\lambda$ ground plane, go for it. Even increasing the amount of radials from 8 to 32 will improve efficiency considerably.

The loading coil efficiency can be also be improved by replacing solid wire with less resistive (at RF frequencies) stranded or litz wire, and by using thicker wire. Remember that you cannot measure RF resistance using a DC ohmmeter. If you are very serious about reducing loss, you could try making a loading coil without a form, or with a form that has a lower dielectric than PVC. Some people have reported increased Q by making a formless coil, but doing this for large loading coils would be extremely difficult, and you are probably better off working on the ground plane.

Antenna elevation is also a significant performance enhancer. Part-15 antennas placed on top of a tall structure can turn a 1/2 mile signal into a 3+ mile signal. High elevation Part-15 antennas (also known as “whip & mast” antennas) work so well, that there is some debate as to whether the FCC could set height-above-ground limitations for them in the future.

# References and Further Reading

[1] Tom (W8JI). 2004. Radiation Resistance
http://www.w8ji.com/radiation_resistance.htm (21 May 2004)

[2] Knorr, “Crash”. 2002. The Mediumwave Alliance.
http://www.part15.org/mwa/ (2 Sep. 2003)

[3] Federal Communications Commission, AM Groundwave Field Strength Graphs, 47 CFR Sections 73.183 and 73.184.
http://www.fcc.gov/mb/audio/73184/

[4] Laport, Edmund. Radio Antenna Engineering. McGraw-Hill, 1952. p77.

[5] Terman, Frederick. Radio Engineers Handbook. McGraw-Hill, 1943. p845

[6] Terman, Frederick. Radio Engineers Handbook. McGraw-Hill, 1943. p. 71

[7] Ekeland, Norval. Basic Electronics for Engineering Technology. Prentice-Hall, 1981. p292-297.


RADIO
BROADCAST
PROGRAM

# 6 - Interference

Eliminating and avoiding interference is very important for radio broadcasters. Especially for unlicensed (but also for licensed) broadcasting, eliminating interference will keep you out of trouble, and ensure that your neighbors or the FCC don't come knocking on your door. Being informed on what interference is, what causes it, and how to fix it is a very elemental part of operating *any* broadcast station.

## In-Band Interference

This is the interference that is generated on the same band near the broadcasting frequency. If two radio stations are broadcasting close in frequency, they can interfere with each other. This problem tends to get worse as you approach the transmitter and diminishes as you go a farther distance, especially for lower power stations. When two AM signals bleed into each other, it can either create a cracking sound or the signals could mix together to form a single signal with both audio sources present. Either way, it is an extreme nuisance and a fine way to get complaints to the FCC from disgruntled neighbors trying to pick up their favorite station.

The obvious solution to this problem is to not broadcast near other radio stations. If possible, try to keep at least a 30kHz space between existing stations. Also, limit the bandwidth of the audio signal being sent to the transmitter to 10kHz. If the transmitter is broadcasting more than 10kHz of audio bandwidth, the overall bandwidth used by your station will be greater than normal (with no benefit to your received audio quality). Overmodulating the audio generates similar problems. Information on reducing the audio bandwidth to 10kHz can be found in the **Audio Equipment** chapter.

## Skywave Interference

At night when the sun is not directly facing your side of the earth, the ionosphere can make mediumwave signals "bounce" off of it, which can turn it into a very large reflector dish. Because of this effect, it is possible to have a radio signal that is transmitted hundreds of miles from its base of origin. The effects are exactly the same as with in-band interference, except that the distance is greatly extended.

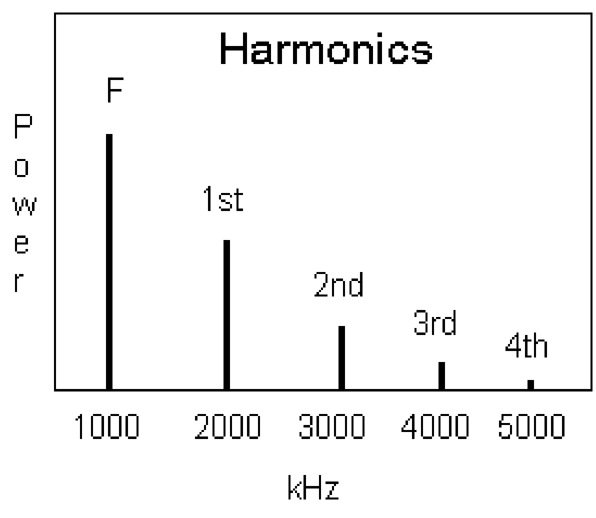
This problem is caused more often by large commercial transmitters than it is by low power ones, but even low power stations can generate skywave interference if they are not careful. The best way to reduce skywave interference is to not use a horizontal antenna. This should be done anyways, because vertical antennas tend to work better for local broadcasting.

## Telephone Interference

Some phone lines near the transmitter will act as AM receivers, which will make broadcasted audio appear on the phone lines. If this problem is observed on nearby telephones, try installing telephone interference filters between the line and the phone. Sometimes the phone itself is the problem, which is not usually fixable without some internal work. If this is the case, replacing the phone is a more practical solution. If there are any immediate neighbors to the broadcast station, it might be a good idea to talk to them and make sure they aren't having any phone line interference (or any other kind of interference for that matter) because of the station. Better to solve problems right away than to have tempers (or complaints to the FCC) flare up later.

Finally, there should be no phones placed near the transmitter case. Transformers inside the transmitter can put an audio signal into the telephone via electromagnetic coupling.

## Harmonic Interference




Harmonic interference is the worst type of interference, because it exists on all transmitters and is strong. Mathematically, a harmonic is a signal that appears on every multiple of the transmitter's output frequency. For example, an LPAM transmitter operating at 1650kHz would generate the first harmonic at 3300kHz and the second at 6600 kHz. This signal can be quite strong, sometimes as much as half the power of the operating frequency output. There are many harmonics, but the power level diminishes as they go along. Harmonics are the result of uncontrollable inefficiencies in amplifier circuits.

Harmonic interference has to be eliminated, otherwise interference to services on other bands can result. A low-pass filter (such as the half wave) reduces the power level of signals that have a frequency higher than the main one, which effectively traps harmonics and keeps them from being sent to the antenna. Many transmitters don't come with a harmonics filter preinstalled, but fortunately it is easy to build them.

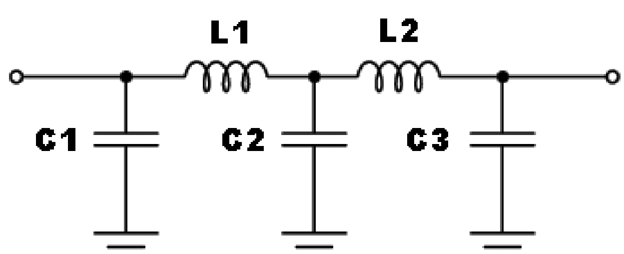
For our purposes, a 5 or 7 element Chebyshev style filter works best. The 5-element filter is adequate, but the 7-element filter is much more effective, reducing second harmonic power by 40dB or more (which is a 100:1 reduction). I recommend use of a 7-element filter to maximize interference reduction. Either way, the amount of reduction for all harmonics has to be at least 20dB (10:1), as per FCC regulations.

## Low-Pass Filter Design

The following is a list of methods you can use to make your own low-pass filters. All of the designs (except the half-wave) assume a transmitter input/output impedance of 50-ohms (the standard for most broadcast transmitters). Note that the open circles on the schematics represent the input and output, respectively (though these filters will work both ways).

### Half-Wave Filter Formula

This method was taken from an old electronics book. It works, but the amount of harmonic interference reduction might not be adequate.




$$L_{1\&2} = \frac{1000Z}{2\pi f}$$

Where:

f = operating frequency in kHz
L = inductance of coils in microfarads (uH)
Z = Impedance (in ohms)

If you don't know the output impedance of a signal, then use this formula:

$$Z = \frac{V_{cc}^{\ 2}}{2P_o}$$

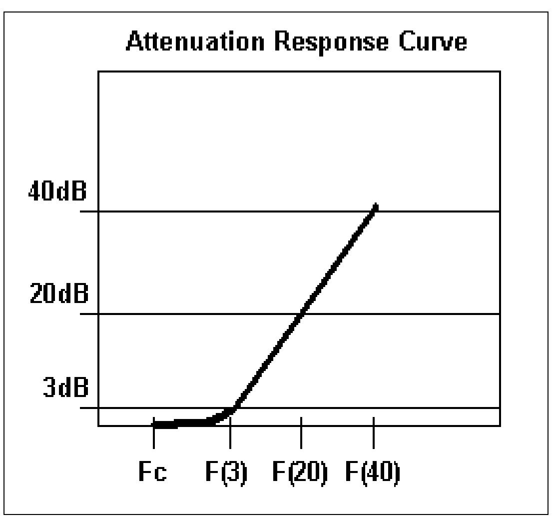
Where:
Z = Output impedance
Vcc = Voltage going to collector/drain of last transistor
Po = Approximate power output in watts. For Class A amplifier, estimate 50% of power from collector, for Class C amplifier estimate 70%.

$$C_{1\&3} = \frac{10^9}{2\,\pi f Z}$$

$$C_2 = 2C_1$$

Where:
C = capacitance in picofarads (pF)
f = operating frequency in kHz
Z = input/output impedance

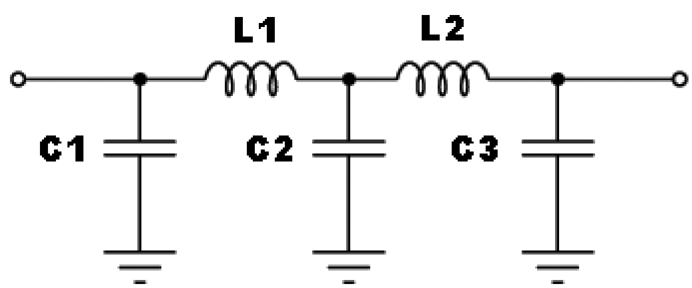
## Lowpass Filter Tables




The following is a list of pre-designed lowpass filter schematics. The cutoff frequency (Fc) is the point where the filter starts to reduce the power level as the frequency of the signal increases. After the attenuation reaches 3dB, there is a very sharp curve that reduces the harmonic interference significantly. Make sure the cutoff frequency is at least slightly above the operating frequency, otherwise the filter will reduce some of the *wanted* signal. The closer the cutoff is to the operating frequency, the more attenuation of the second harmonic will occur (especially for the 5-element filter, which has a flatter attenuation curve than the 7-element filter).

There are two tables for each filter below. The first is a simple calculated filter values chart. The second is an improved table. It is based on common capacitor values, and contains a performance analysis (the non-bold items). The decibel analysis shows how sharp the cutoff is. The filter is making your transmitter conform to FCC regulations when the 20dB frequency is *lower* than the second harmonic of your operating frequency.

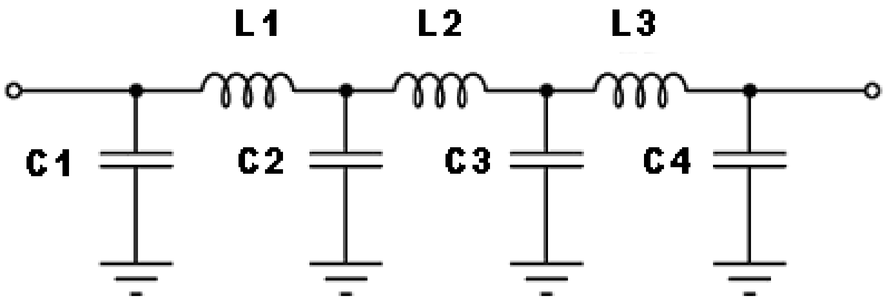
**Chebyshev 5-Element Low-Pass Filter**




| Standard 5-Element Table | | | |
|---|---|---|---|
| Fc(-3dB) (kHz) | L1 & L2 (uH) | C1 & C3 (pF) | C2 (pF) |
| 600 | 20.6 | 6900 | 11889 |
| 700 | 17.7 | 5917 | 10191 |
| 800 | 15.5 | 5178 | 8917 |
| 900 | 13.8 | 4602 | 7926 |
| 1000 | 12.4 | 4142 | 7134 |
| 1100 | 11.3 | 3766 | 6485 |
| 1200 | 10.3 | 3452 | 5945 |
| 1300 | 9.5 | 3186 | 5487 |
| 1400 | 8.8 | 2959 | 5095 |
| 1500 | 8.3 | 2761 | 4756 |
| 1600 | 7.7 | 2589 | 4459 |
| 1700 | 7.3 | 2437 | 4196 |
| 1800 | 6.9 | 2301 | 3963 |
| 1900 | 6.5 | 2180 | 3755 |
| 2000 | 6.2 | 2071 | 3567 |
| 2100 | 5.9 | 1972 | 3397 |
| 2200 | 5.6 | 1883 | 3243 |
| 2300 | 5.4 | 1801 | 3102 |
| 2400 | 5.2 | 1726 | 2972 |

| Improved 5-Element Table | | | | | | |
|---|---|---|---|---|---|---|
| Fc (kHz) | C1&C3 (pF) | L1&L2 (uH) | C2 (pF) | 3dB | 20dB | 40dB |
| **660** | **5600** | **16.6** | **9100** | 764 | 1030 | 1520 |
| **669** | **3000** | **14.4** | **6800** | 936 | 1350 | 2060 |
| **677** | **4300** | **16.0** | **8200** | 817 | 1120 | 1670 |
| **721** | **2700** | **13.2** | **6200** | 1020 | 1480 | 2260 |
| **748** | **3300** | **14.0** | **6800** | 956 | 1340 | 2020 |
| **782** | **2400** | **11.9** | **5600** | 1130 | 1640 | 2510 |
| **818** | **3000** | **12.8** | **6200** | 1050 | 1470 | 2220 |
| **825** | **3600** | **13.2** | **6800** | 989 | 1360 | 2020 |
| **866** | **2200** | **10.9** | **5100** | 1240 | 1800 | 2760 |
| **902** | **2700** | **11.6** | **5600** | 1160 | 1630 | 2460 |
| **911** | **3300** | **11.9** | **6200** | 1090 | 1490 | 2210 |
| **922** | **2000** | **10.0** | **4700** | 1350 | 1960 | 3000 |
| **964** | **2400** | **10.6** | **5100** | 1260 | 1790 | 2710 |
| **1020** | **3000** | **10.7** | **5600** | 1210 | 1650 | 2450 |
| **1040** | **2200** | **9.82** | **4700** | 1370 | 1940 | 2940 |
| **1050** | **1600** | **8.35** | **3900** | 1620 | 2380 | 3660 |
| **1100** | **2700** | **9.88** | **5100** | 1320 | 1810 | 2690 |
| **1130** | **2000** | **9.00** | **4300** | 1500 | 2120 | 3220 |
| **1150** | **3300** | **9.49** | **5600** | 1290 | 1710 | 2510 |
| **1150** | **2400** | **9.37** | **4700** | 1410 | 1950 | 2920 |
| **1170** | **1500** | **7.70** | **3600** | 1760 | 2570 | 3940 |
| **1230** | **1800** | **8.19** | **3900** | 1650 | 2340 | 3550 |
| **1260** | **2200** | **8.56** | **4300** | 1540 | 2130 | 3190 |
| **1270** | **1600** | **7.64** | **3600** | 1770 | 2550 | 3880 |
| **1310** | **1200** | **6.43** | **3000** | 2100 | 3110 | 4790 |
| **1390** | **2000** | **7.75** | **3900** | 1700 | 2350 | 3510 |
| **1460** | **1800** | **7.28** | **3600** | 1820 | 2540 | 3810 |
| **1510** | **1100** | **5.78** | **2700** | 2340 | 3440 | 5290 |
| **1540** | **1600** | **6.79** | **3300** | 1970 | 2770 | 4170 |
| **1550** | **2200** | **7.05** | **3900** | 1790 | 2410 | 3550 |
| **1650** | **2000** | **6.64** | **3600** | 1920 | 2590 | 3830 |
| **1700** | **1200** | **5.73** | **2700** | 2360 | 3400 | 5170 |
| **1750** | **1000** | **5.14** | **2400** | 2630 | 3850 | 5910 |
| **1760** | **1800** | **6.21** | **3300** | 2070 | 2810 | 4170 |
| **1890** | **1600** | **5.77** | **3000** | 2250 | 3080 | 4570 |
| **2050** | **820** | **4.28** | **2000** | 3160 | 4640 | 7130 |
| **2140** | **1000** | **4.64** | **2200** | 2910 | 4160 | 6310 |
| **2190** | **1200** | **4.85** | **2400** | 2740 | 3810 | 5710 |

**Chebyshev 7-Element Low-Pass Filter**



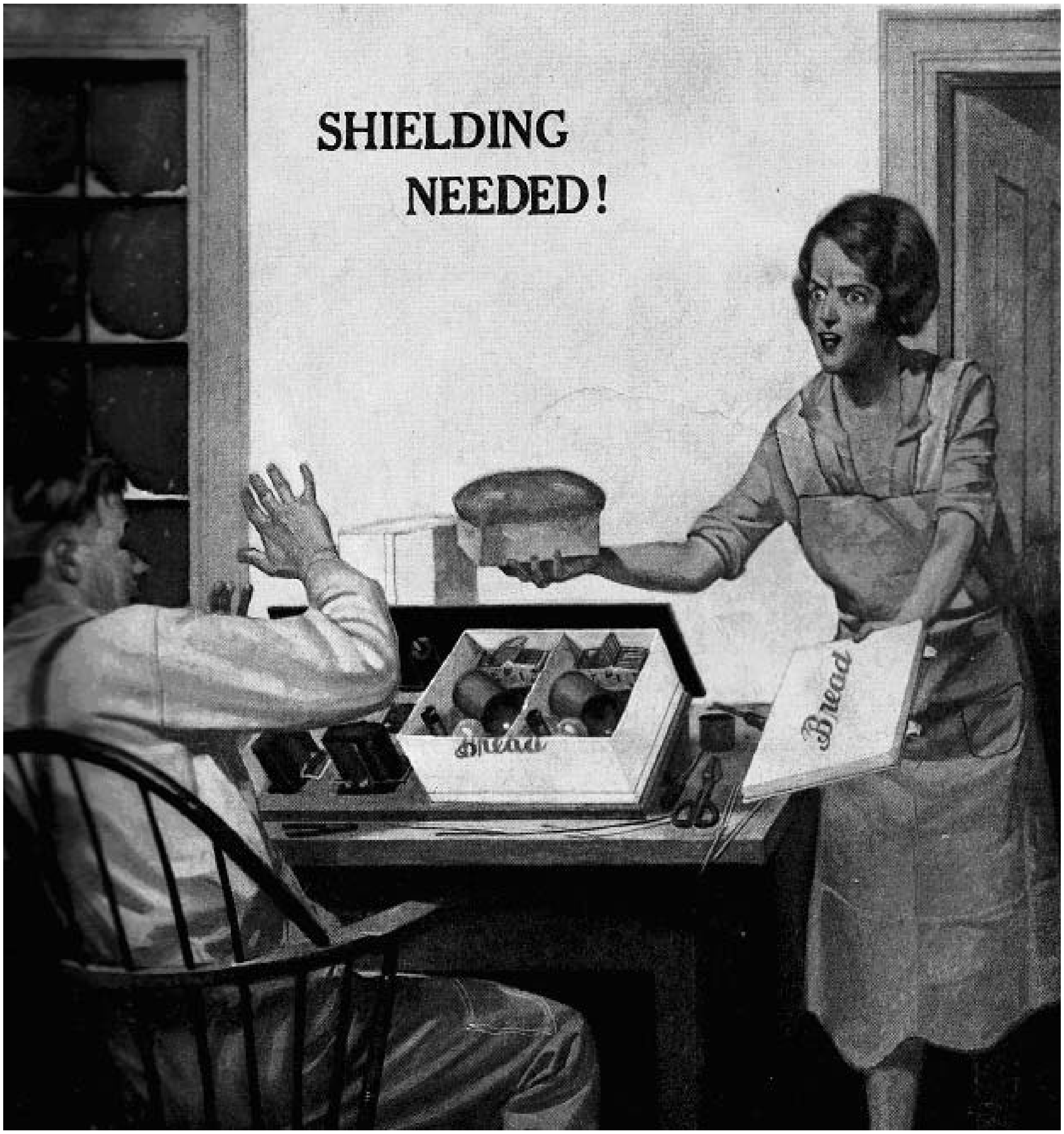

| Standard 7-Element Table | | | | |
|---|---|---|---|---|
| F(-3dB) | L1&L2 (uH) | L3 (uH) | C1&C4 (pF) | C2&C3 (pF) |
| 600 | 20.2 | 22.3 | 6692 | 11879 |
| 700 | 17.3 | 19.1 | 5736 | 10182 |
| 800 | 15.1 | 16.7 | 5019 | 8910 |
| 900 | 13.4 | 14.9 | 4462 | 7920 |
| 1000 | 12.1 | 13.4 | 4015 | 7128 |
| 1100 | 11.0 | 12.2 | 3650 | 6480 |
| 1200 | 10.1 | 11.1 | 3346 | 5940 |
| 1300 | 9.3 | 10.3 | 3089 | 5483 |
| 1400 | 8.6 | 9.6 | 2868 | 5091 |
| 1500 | 8.1 | 8.9 | 2677 | 4752 |
| 1600 | 7.6 | 8.4 | 2510 | 4455 |
| 1700 | 7.1 | 7.9 | 2362 | 4193 |
| 1800 | 6.7 | 7.4 | 2231 | 3960 |
| 1900 | 6.4 | 7.0 | 2113 | 3751 |
| 2000 | 6.0 | 6.7 | 2008 | 3564 |
| 2100 | 5.8 | 6.4 | 1912 | 3394 |
| 2200 | 5.5 | 6.1 | 1825 | 3240 |
| 2300 | 5.3 | 5.8 | 1746 | 3099 |
| 2400 | 5.0 | 5.6 | 1673 | 2970 |

| Improved 7-Element Table | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fc (kHz) | C1,4 (pF) | L1,3 (uH) | C2,3 (pF) | L2 (uH) | 3dB | 20dB | 40dB |
| **548** | **3600** | **18.5** | **9100** | **22.8** | 675 | 843 | 1100 |
| **569** | **4700** | **19.7** | **10000** | **22.9** | 644 | 780 | 1000 |
| **608** | **5100** | **18.8** | **10000** | **21.3** | 668 | 797 | 1010 |
| **617** | **3300** | **16.6** | **8200** | **20.4** | 752 | 936 | 1220 |
| **663** | **5600** | **17.1** | **10000** | **18.9** | 709 | 832 | 1050 |
| **736** | **2700** | **13.8** | **6800** | **17.0** | 904 | 1130 | 1480 |
| **798** | **3000** | **13.7** | **6800** | **16.2** | 927 | 1140 | 1470 |
| **858** | **3300** | **13.2** | **6800** | **15.2** | 959 | 1160 | 1480 |
| **886** | **2200** | **11.4** | **5600** | **14.0** | 1100 | 1370 | 1800 |
| **923** | **3600** | **12.4** | **6800** | **13.9** | 1000 | 1190 | 1510 |
| **972** | **2000** | **10.3** | **5100** | **12.8** | 1200 | 1500 | 1970 |
| **1020** | **3300** | **11.2** | **6200** | **12.6** | 1100 | 1310 | 1650 |
| **1030** | **1800** | **9.52** | **4700** | **11.9** | 1300 | 1630 | 2150 |
| **1040** | **2700** | **10.9** | **5600** | **12.6** | 1160 | 1400 | 1790 |
| **1050** | **2200** | **10.3** | **5100** | **12.3** | 1230 | 1510 | 1960 |
| **1100** | **1600** | **8.68** | **4300** | **11.0** | 1410 | 1790 | 2360 |
| **1120** | **2400** | **10.0** | **5100** | **11.7** | 1260 | 1530 | 1960 |
| **1120** | **2000** | **9.50** | **4700** | **11.4** | 1330 | 1640 | 2130 |
| **1130** | **3000** | **10.1** | **5600** | **11.3** | 1230 | 1450 | 1840 |
| **1210** | **2200** | **9.27** | **4700** | **10.8** | 1370 | 1660 | 2130 |
| **1210** | **1800** | **8.71** | **4300** | **10.5** | 1450 | 1790 | 2330 |
| **1230** | **2700** | **9.29** | **5100** | **10.4** | 1340 | 1590 | 2010 |
| **1320** | **1600** | **7.91** | **3900** | **9.62** | 1590 | 1970 | 2570 |
| **1420** | **2200** | **8.06** | **4300** | **9.14** | 1560 | 1860 | 3360 |
| **1440** | **1800** | **7.73** | **3900** | **9.04** | 1640 | 1990 | 2560 |
| **1510** | **1300** | **6.70** | **3300** | **8.27** | 1860 | 2320 | 3050 |
| **1520** | **1600** | **7.22** | **3600** | **8.54** | 1760 | 2150 | 2780 |
| **1570** | **2000** | **7.30** | **3900** | **8.27** | 1720 | 2050 | 2600 |
| **1660** | **1800** | **6.86** | **3600** | **7.83** | 1840 | 2200 | 2810 |
| **1680** | **1200** | **6.09** | **3000** | **7.47** | 2050 | 2560 | 3350 |
| **1750** | **1000** | **5.45** | **2700** | **6.89** | 2250 | 2840 | 3750 |
| **1770** | **1600** | **6.40** | **3300** | **7.37** | 1980 | 2380 | 3050 |
| **1830** | **2000** | **6.22** | **3600** | **6.90** | 1960 | 2300 | 2900 |
| **1960** | **1800** | **5.83** | **3300** | **6.50** | 2110 | 2490 | 3140 |
| **2020** | **1200** | **5.41** | **2700** | **6.40** | 2340 | 2860 | 3700 |
| **2110** | **1600** | **5.42** | **3000** | **6.08** | 2280 | 2700 | 3420 |
| **2150** | **820** | **4.44** | **2200** | **5.61** | 2760 | 3490 | 4600 |
| **2170** | **1000** | **4.86** | **2400** | **5.88** | 2590 | 3200 | 4170 |
| **2520** | **1000** | **4.38** | **2200** | **5.15** | 2890 | 3520 | 4540 |

## Notes

If you are using power levels above one watt, make sure you use components that can handle the step-up voltages. Capacitors will need to have high voltage ratings (200V+). If core-based inductors are used, the permeability of the core must be high enough to handle the amount of power. The inductance values for low-pass filters are usually low, so iron-core inductors are not necessary. Use hand-wound air core inductors with 16-18 AWG wire on a form such as a small piece of 1/2-1" diameter PVC piping. The inductance formula for winding your own inductors can be found in the appendix and elsewhere in the book.

If your transmitter's output impedance is not 50-ohms, you will have to make a matching network to use these filters (see the Transmitter Design chapter). It is possible to make a lowpass filter for other impedances, but it requires work beyond the scope of this book. There are many books on the subject of analog filters, which would serve as good references for making more complex filters with varying impedances.


SHIELDING
NEEDED!
Bread
Bread

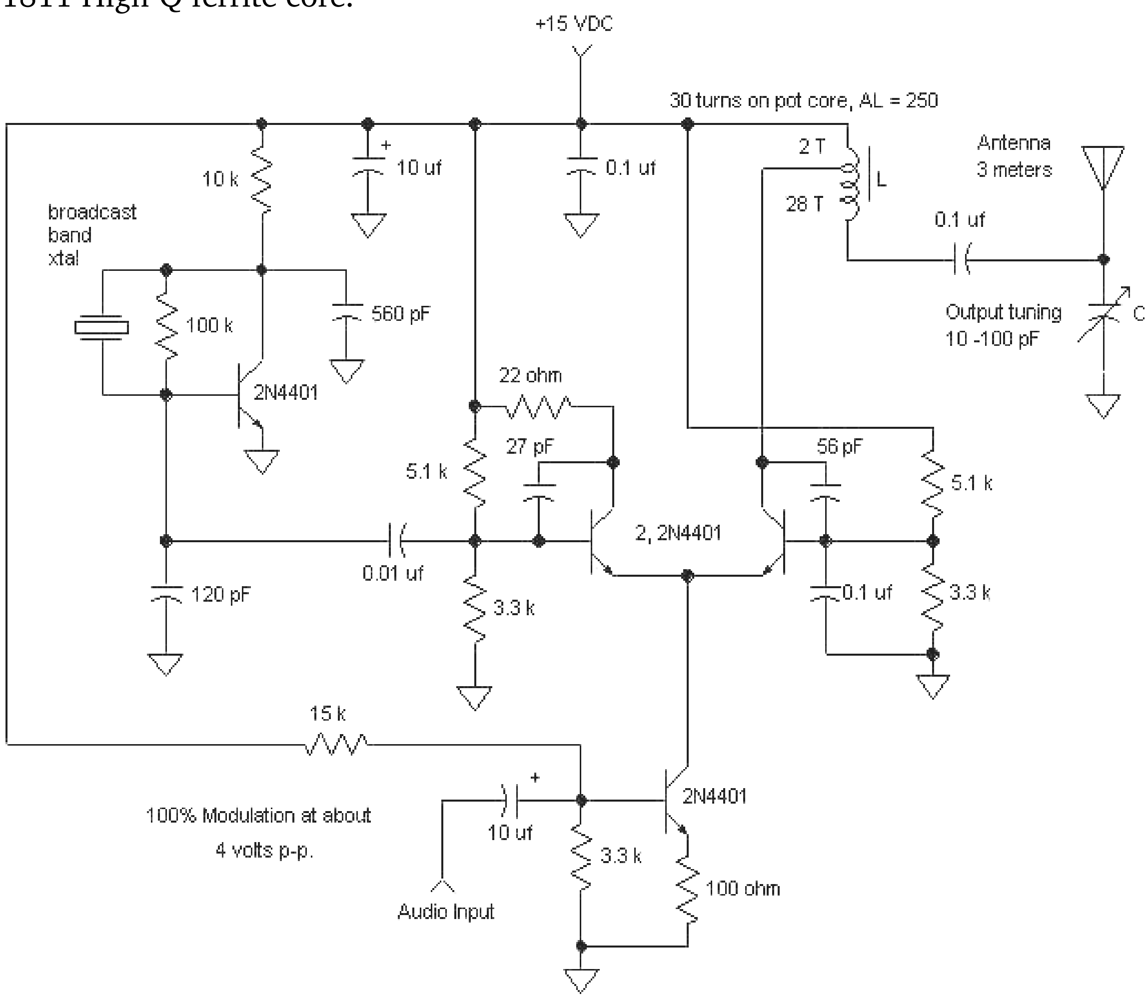
# 7 - Schematics

This chapter has some practical circuits for developers and people interested in assembling their own transmitters or other related equipment. Unless specified, resistors are 1/2 watt, and capacitors are 50v ceramic.

## Transmitter Schematics

### The Wenzel

The following Part-15 transmitter circuit was designed Charles Wenzel, and is a very popular circuit amongst the amateur broadcasting community. It is said to have good audio quality and is relatively easy to construct. Pot core is 1811 High-Q ferrite core.



## 10 Watt AM Transmitter

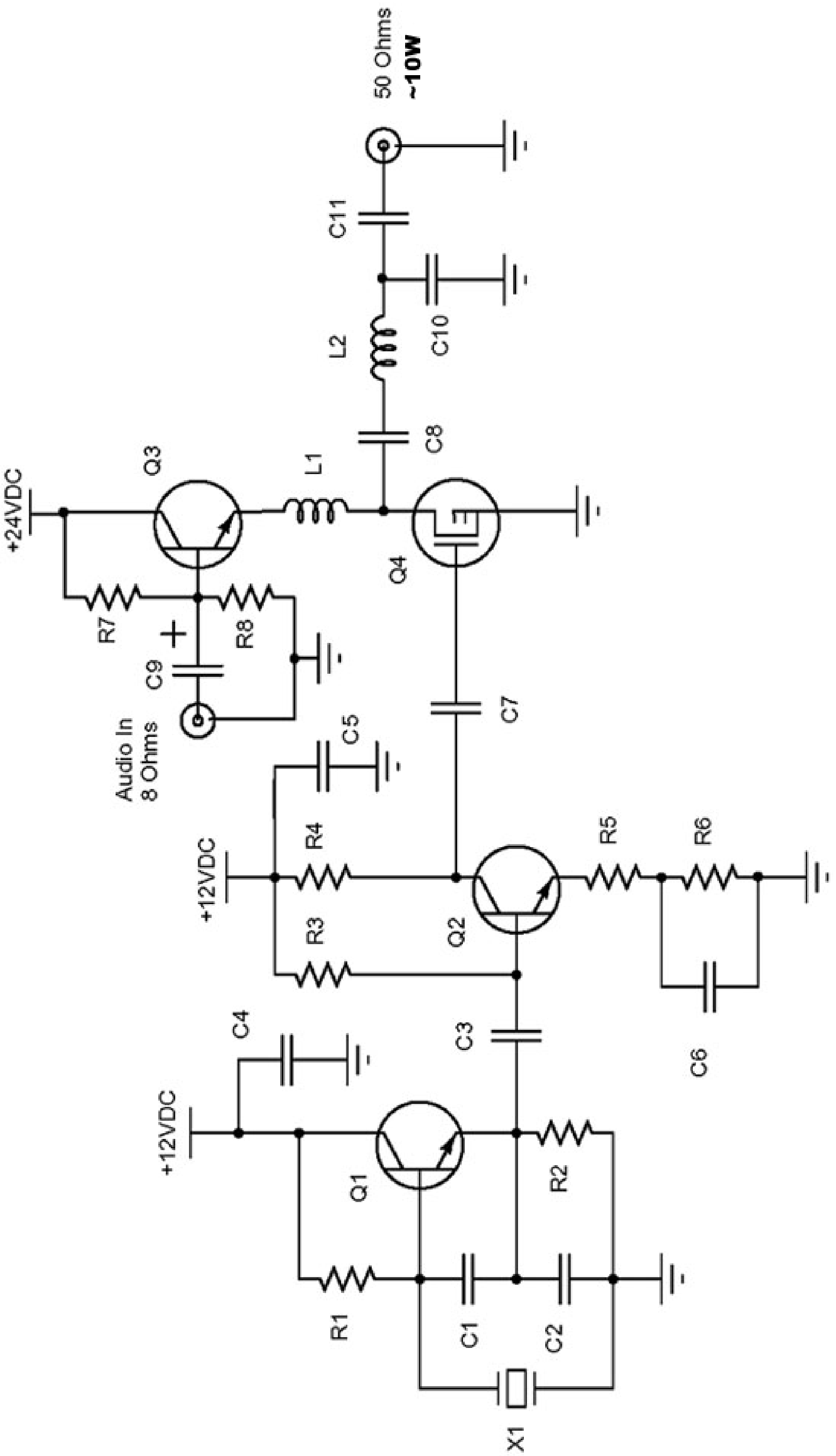
This transmitter is easy to build, and parts are easy to find (no goofy obscure transformer forms). This is no mistake; I designed the transmitter with the idea of simplicity and parts availability in mind. The transmitter can put out a 8-13 Watt signal, and uses series modulation to achieve higher audio quality than the transformer method.

The transmitter was designed for operation in the 1600-1710kHz band, and might need modifications to broadcast at lower frequencies (particularly to the matching network). The transmitter is designed to take input from 8-ohm audio amplifiers. This is very convenient for schematic builders, because the builder can simply use their home stereo receiver as an audio amp instead of having to build their own audio amp to supplement the circuit. The voltage is 24 volts (tested with 30 volt transformer), and the 12 volts for early stages is acquired by running the power into a 12V IC voltage regulator.

One of the weaknesses of the series mod design is that the transmitter can produce a lot of heat without a proper load. The last two transistors, especially Q3, will need good cooling. Use thermal paste (available at computer stores) to bond the transistor to its heatsink, which should be rather large. A small computer fan wouldn't hurt either.

It should be noted that this transmitter design has not yet been extensively tested. Please let me know if you find any problems or improvements.

Parts:
R1: 200K
R2: 1K
R3: 10K
R4: 1K
R5-R6: 100
R7: 680
R8: 1K
C1: 100pF C2: 680pF C3: 0.001uF
C4-C7: 0.1uF
C8: 0.47uF, 250V
C9: 220uF electrolytic, 50V
C10: 1380pF
C11: 820pF
L1: 100uH, 2A (Radio shack model)
L2: 4.4uH, large air-core (hand-made with 18AWG or thicker wire works well)
Q1 & Q2: 2n3904
Q3: 2n3055
Q4: IRF-510


50 Ohms
~10W
C11
C10
L2
C8
L1
Q3
+24VDC
Q4
R7
R8
C9
Audio In
8 Ohms
C5
C7
+12VDC
R4
R5
R6
R3
Q2
C3
C6
C4
+12VDC
Q1
R2
R1
C1
C2
X1

## The Anarchist 10 Watt Transmitter

The Anarchist is very similar to the previous design. Both use the IRF-510 as a final, and both take audio from an 8-ohm source. The biggest difference is that the Anarchist uses a different modulation method and pre-final, which does not require a 24-volt power supply.

Parts:

R1: 33K
R2: 4.7K
R3 & R6: 100
R4: 33
R5: 100, 1 watt

C1: 220pF
C2: 1000pF
C3: 10-100pF variable
C4 & C5: 0.1uF
C6: 3300uF, electrolytic, 25V
C7: 0.47uF, 250V
C8: Any high voltage capacitor having at least 4400pF of capacitance. Suggested type Arco 315 with additional 2000pF 250V capacitor in parallel.

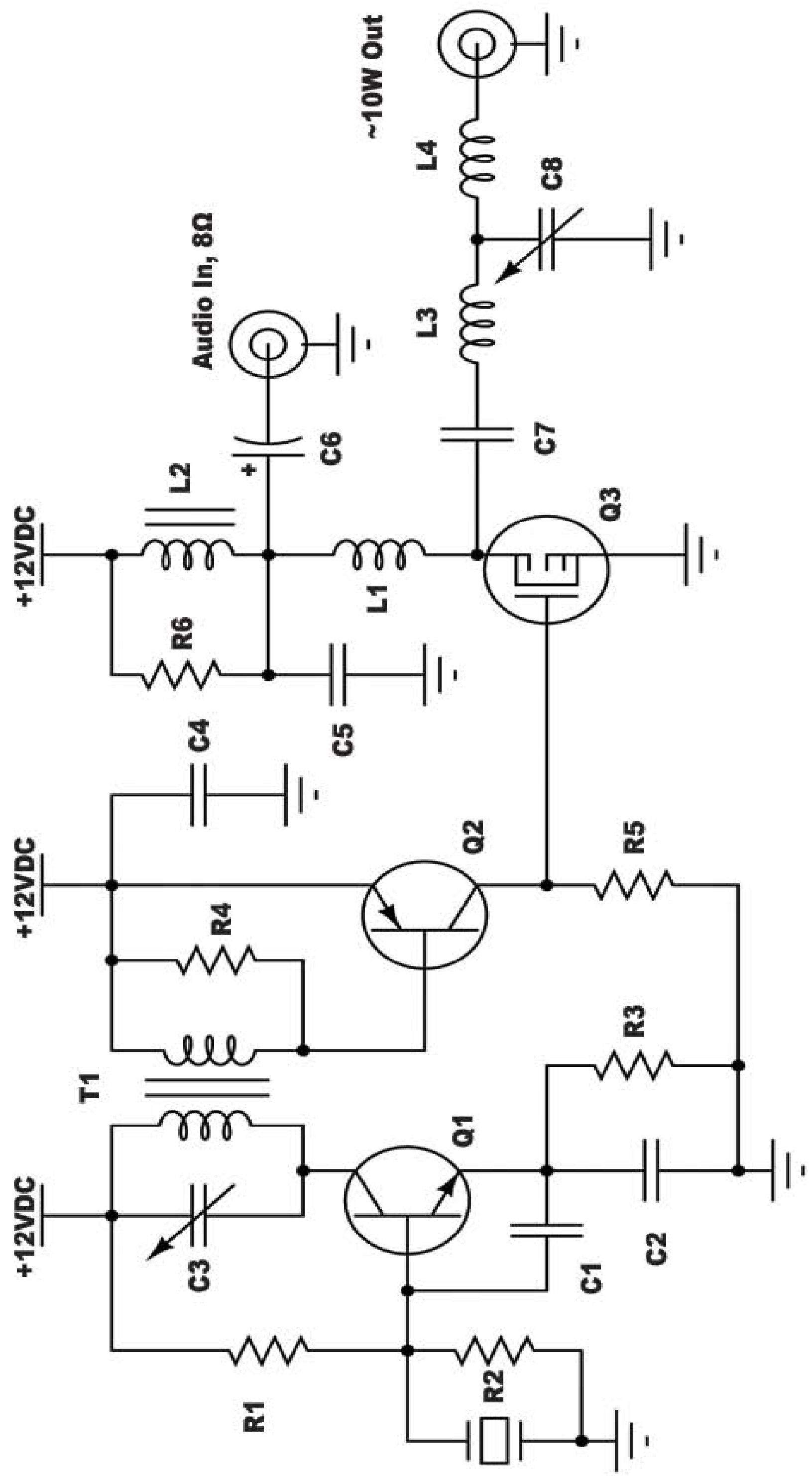
Crystal: 1600kHz and up suggested.

T1: Amidon T50-2 Toroid. Primary is 69 turns of 28AWG wire closewound. Secondary is 3 turns of 28AWG wire *over* the primary windings.

L1: 2.5uH or greater, 4A rating. Suggested Radio Shack 273-102A.
L2: 13mH or greater, 0.5 ohm or less DC resistance. Suggested Radio Shack 270-030A or JW Miller 7123 or JW Miller 7122.

L3: 10 turns of 16AWG wire on 1.25” form.
L4: 14 turns of 16AWG wire on 1.25” form.

Q1: 2N2222
Q2: 2N2907
Q3: IRF-510 (Radio Shack 276-2072A) or IRF-511

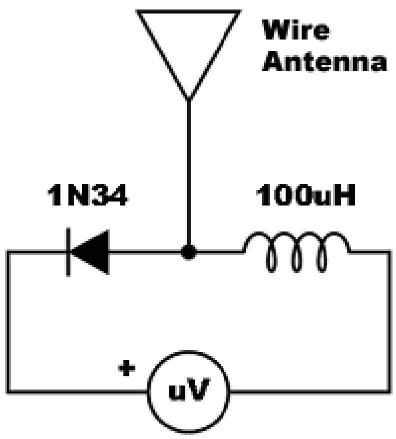


+12VDC
+12VDC
+12VDC
T1
C3
R1
R2
Q1
C1
C2
R3
R4
Q2
C4
R5
L2
R6
C5
L1
Q3
C6
Audio In, 8Ω
C7
L3
C8
L4
~10W Out

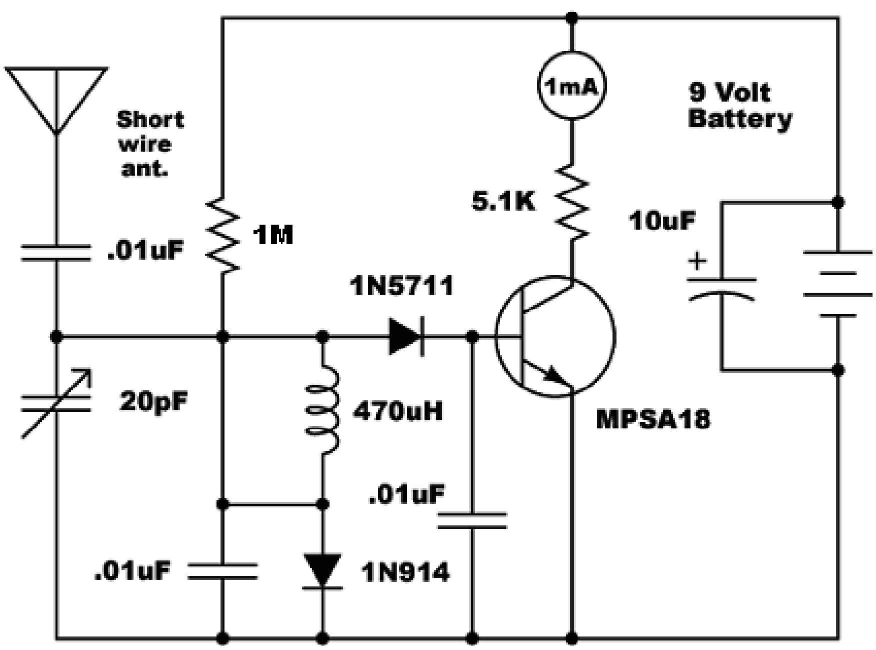
## Field Strength Meters

Crude field strength meters are easy to assemble. The following meters aren't calibrated, but for antenna tuning we are only interested in maximum relative field strength, so calibration isn't necessary.

The first schematic is a simple "throw-together" field strength meter:

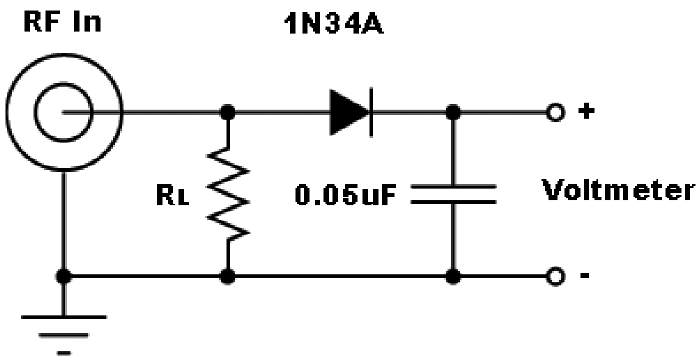



If something more powerful is needed, try assembling the next meter. The MPSA18 can be substituted for any high gain transistor. This circuit was designed by Charles Wenzel. The milliammeter can be replaced by two alligator clips and attached to a multimeter.



## RF Wattmeter/Voltmeter

The following is a simple no-frills RF wattmeter/voltmeter you can use with any DC voltmeter. The voltage measured will be the peak RF voltage. The 0.05uF capacitor can be substituted with a 0.1uF capacitor for convenience. The 1N34A can be substituted for most diodes. Germanium work best, silicon also work but can be slightly inaccurate (+-300mV).




$R_L$ is the load resistance, either a dummy load or a tuned antenna. If you know the load resistance, you can find the power and current:

$$P = \frac{V^2}{R_L} \qquad I = \frac{V}{R}$$

Where P is power in watts, V is volts DC, I is current in amps and $R_L$ is the impedance of the load (50 ohms for most transmitters).

## Miscellaneous Audio Schematics

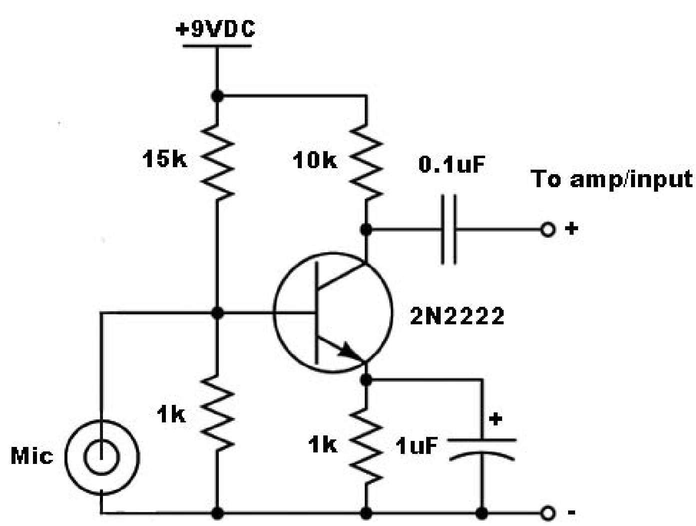
There are many good audio schematics circulating around, the following is a collection of audio circuits that could be useful. It is not hard to find more audio schematics, simply look for an electronic circuits collection, audio schematics book, or search the internet using keywords like “audio compressor schematic” and you will find many more. Most of the more advanced audio processing equipment is simply too advanced and complicated to be added to the book.

## Audio Amplifiers

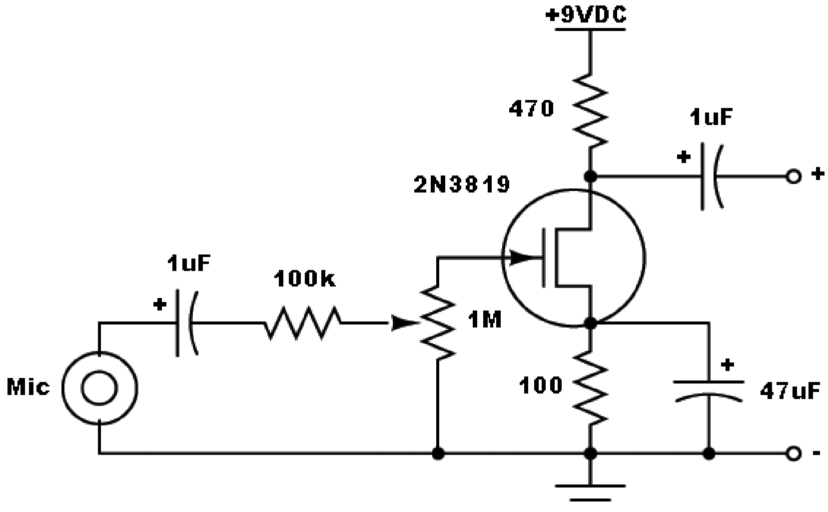
For those needing audio amplifiers to modulate the transmitter (or just in general), there are many sources of good amplifier schematics available on the web and in other books. If you are interested in something simple, I suggest looking at available audio amplifier ICs. They make building audio amplifiers extremely easy to do. The LM386 is a popular audio amp IC for power levels up to 450mW. If you need something in the 7-15W range the LM4752, TDA2003 and TDA2030 are popular choices. Audio Amplifier ICs with power levels above one watt will need good heatsinks. Each respective manufacturer of these components has several schematics that can be used by the designer; I will not repeat them here.

## Microphone Pre-amps

Microphone signals need to be amplified in order for the power levels to be sufficient for line input. The following simple microphone pre-amps can be used to accomplish this. The first one might need a variable resistor in series with the microphone to control the gain if the output is too high.

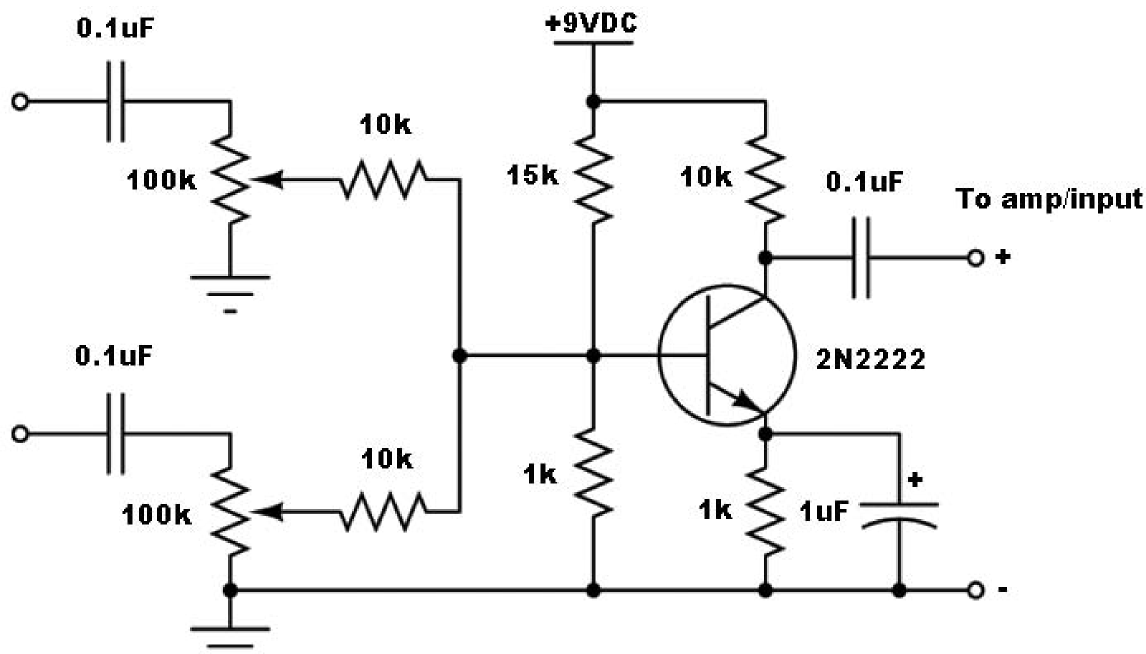



The following schematic is similar, except it is designed for high impedance, crystal type microphones (10,000  or greater).

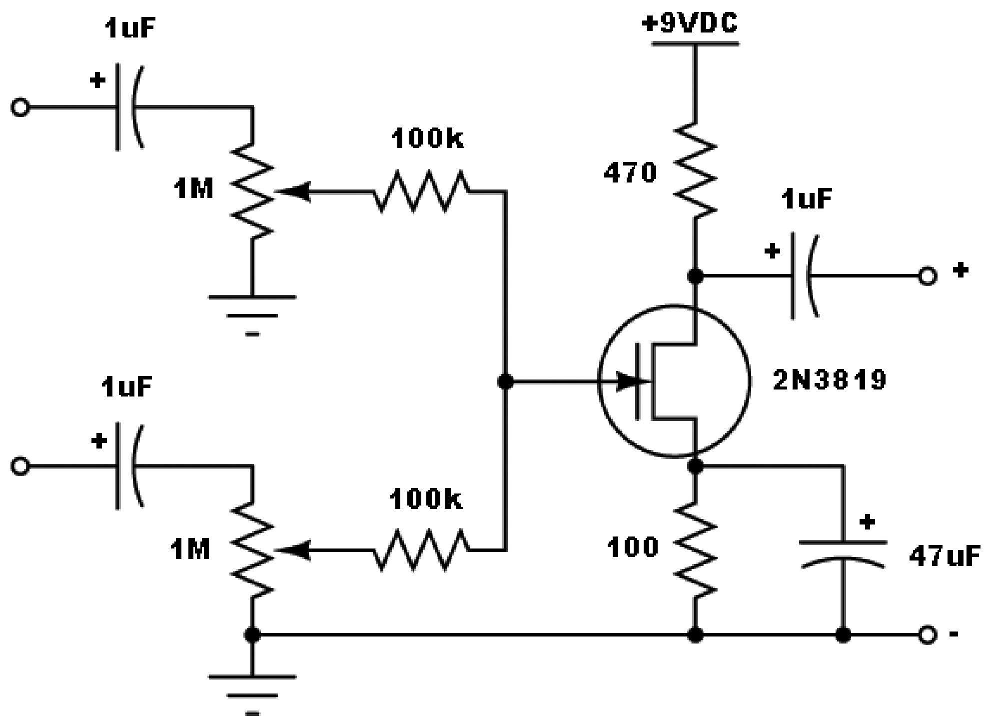



## Simple Mixers

For people who cannot afford a mixer, the following circuits could be a good alternative. Considering these amplifiers are similar to the above pre-amps, it shouldn't be necessary to have a pre-amp for each microphone. It wouldn't be hard to modify these circuits to have more than two microphone inputs.

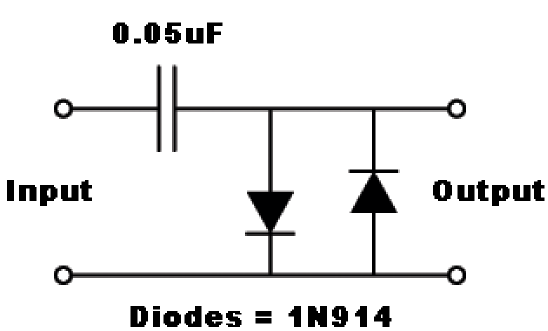


The following circuit is for high impedance microphones:



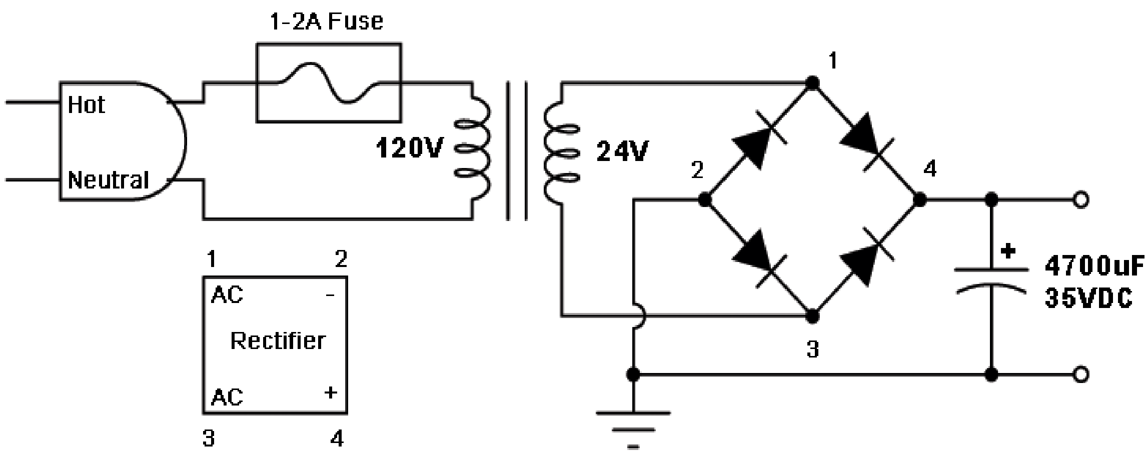

## Simple Audio Limiter

I have seen the following circuit used to reduce static and power spiking on speaker loads. I see no reason why this couldn't be used on a speaker input for a transmitter. The capacitor value might need to be modified.



## Power Supply Basics

Sometimes it is necessary to make power supplies. Assembled power supplies can be very expensive, and sometimes the builder can reduce costs significantly by constructing their own. Power supplies vary in design quality and ability to deliver power, but the following schematic is a basic power supply that can be thrown together if one is needed.




In this power supply, the 120V mains voltage is converted to 24V (though it varies with load and type of transformer - the Radio Shack 24V 2A transformer models are 38V unloaded and 30V loaded 1 amp). The bridge rectifier converts the AC voltage to pulsating DC. The large-value capacitor smoothes out the pulses; Not taking this step can lead to a 60Hz hum on the transmitted signal. I usually insert a 200K resistor in parallel with the capacitor to reduce the time required to discharge the capacitor. Without the resistor, the capacitor can hold a charge for days if the power supply is turned on with no load, and it's generally not a good idea to have the plugs on your power supply hold a long-term charge.

The entire circuit, of course, needs to be enclosed within a case and cannot be worked on when the power is applied. Make sure you put in a fuse; not having one in is a fire hazard (but keep in mind that a fuse does not stop the circuit from being potentially fatal, so be careful).

For low-power circuits (500mA or less), a voltage regulator IC can be used to filter power, such as the L7812 – a 12-volt, 1A max voltage regulator. I religiously use a regulator IC to power all my pre-final stages on transmitters.

## Sources

The Wenzel Transmitter - http://www.techlib.com/electronics/amxmit.htm

The Anarchist - http://www.frn.net/

Second Field Strength Meter - http://www.techlib.com/electronics/amxmit.htm

Randy Linscott's Electronic Plus –
http://home.maine.rr.com/randylinscott/index.html

Randy Linscott’s Electronic Plus -
http://home.maine.rr.com/randylinscott/index.html
Also a great resource for other useful circuits, such as audio amplifiers.

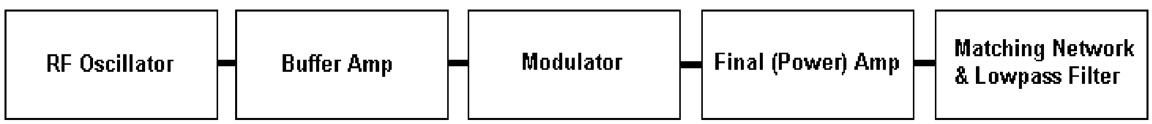
# 8 - AM Broadcast Transmitter Design

This chapter presents a *basic* overview of common AM broadcast transmitter design techniques. If you have a background in electronics and want to try putting together your own transmitter, this might be useful to you.

Construction details are not critical, due to the long length of mediumwave signals. The transmitters can be built on circuitboard, copper plates, or breadboards (though this will add some capacitance to the circuit).

## Sections of an AM Transmitter

This is the basic layout of an AM transmitter:



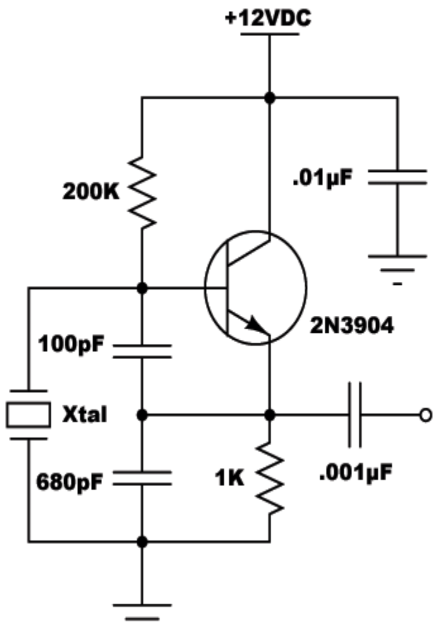

The components of a transmitter are labeled as stages. They each do a specific task, and then send their signal to the next stage to be processed further. The methods and orders of these stages can vary greatly. For example, in most cases the final amplifier and modulator are combined. I'll explain why in a moment.

### Oscillator

The oscillator is the component that generates the radio frequency, amplifies it to a useful level, and then sends it to the next stage. The oscillator can either be crystal, variable frequency, or PLL.

#### Crystal Oscillators

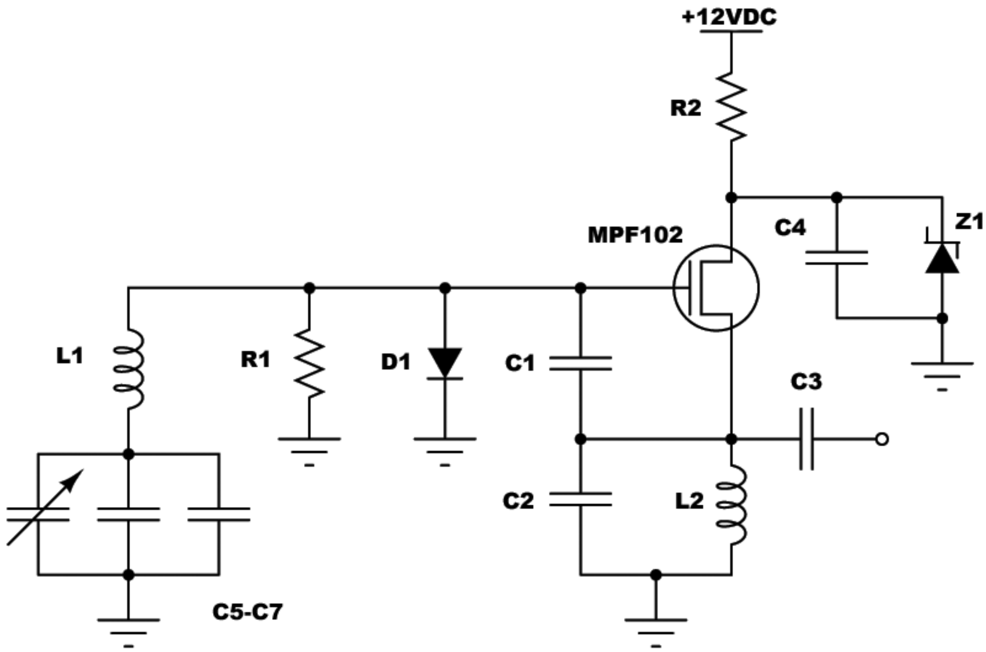
Transmitters with crystal oscillators use a quartz crystal to generate the frequency. Their main feature is that they are incredibly stable, they produce a high quality noiseless signal, and they are very reliable. The biggest drawback is that the frequency of the crystal is fixed, and must be made for the specific frequency that is being used. In addition, crystal suppliers are becoming increasingly difficult to find (some crystal sources are provided in the back).




I have had extremely good luck with this circuit in transmitters. It works well, and puts out a very clean powerful signal for the buffer amplifier stage. Drift is nonexistent.

### Variable L-C Oscillators

Variable L-C oscillators use electronic components to generate a frequency. They are extremely versatile and relatively simple to construct, and parts availability is adequate (good variable capacitors can sometimes be hard to find). Their biggest drawback is that they can be difficult to tune, which can lead to hours of frustrating effort to tune the transmitter properly. Also, if the circuit is not designed well it can suffer from oscillator runaway, which causes the frequency to drift as components in the circuit heat up.




Parts:

L1: 47uH *
L2: 1000uH (1mH)
R1: 100K
R2: 470
D1: 1N914
C1: 2200pF
C2: 2200pF
C3: 0.1uF
C4: 0.1uF
Z1: 8-9 volt 1/2 watt zener diode

C5-C7 = 200pF total. Suggested: C1 = 35pF, C2 = 100pF, C3 = 82pF *
(Ctotal = C5 + C6 + C7)

* The frequency of the oscillator is generated by L1 and C5-C7. To find/change the operating frequency, use this formula:

$$F = \frac{10^6}{2\pi\sqrt{LC}}$$

Where:

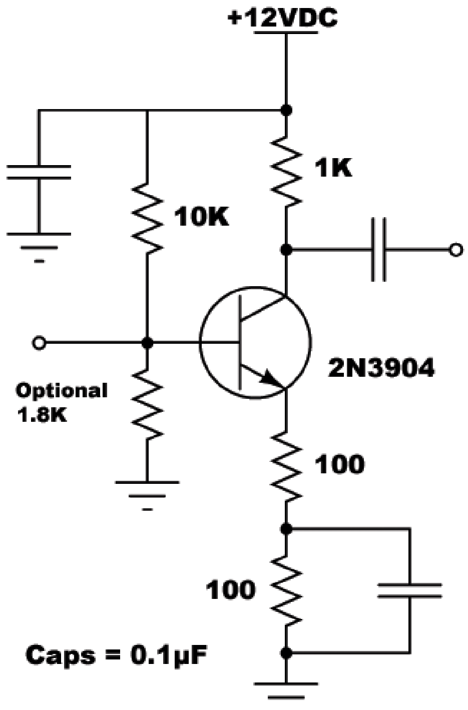
F = Frequency in kHz
L = Inductance in microhenries (uH)
C = Capacitance (Ctotal) in picofarads (pF)

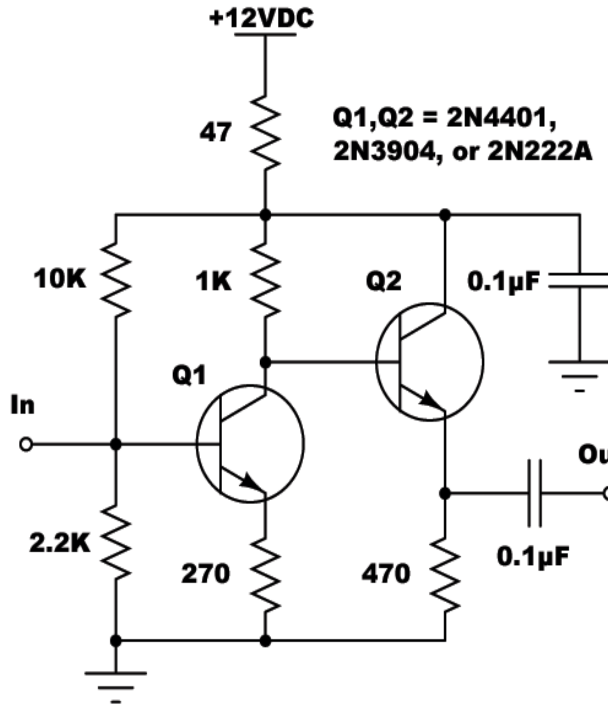
### Phase Lock Loop (PLL) Oscillators

PLL oscillators use a single crystal, and then use digital circuits to divide the frequency of the crystal down to the desired frequency. Because they use a crystal they are quite stable, and they can be tuned to many different frequencies. PLLs, in essence, mix the stability of the crystal oscillator and the convenience of the L-C to form the perfect oscillator. They are becoming very popular in radio electronics, and for good reason. Their main drawbacks are complex circuitry and part availability, as many of the chips used for PLLs stop being produced by their respective manufacturers. Also, if PLL circuits are not designed well they can generate large amounts of in-band noise.

## Buffer Amplifiers

Buffer amplifiers come directly after the oscillator. They are used to boost the signal of the oscillator signal, and at the same time separate the oscillator from the rest of the circuit. Changes in antenna loading and modulation can cause the other stages of the transmitter to “pull” on the oscillator, which can lead to frequency drift (especially with variable & PLL oscillators). It is not uncommon to have more than one buffer amplifier for an oscillator stage. The left amplifier is known to work with the above crystal oscillator.



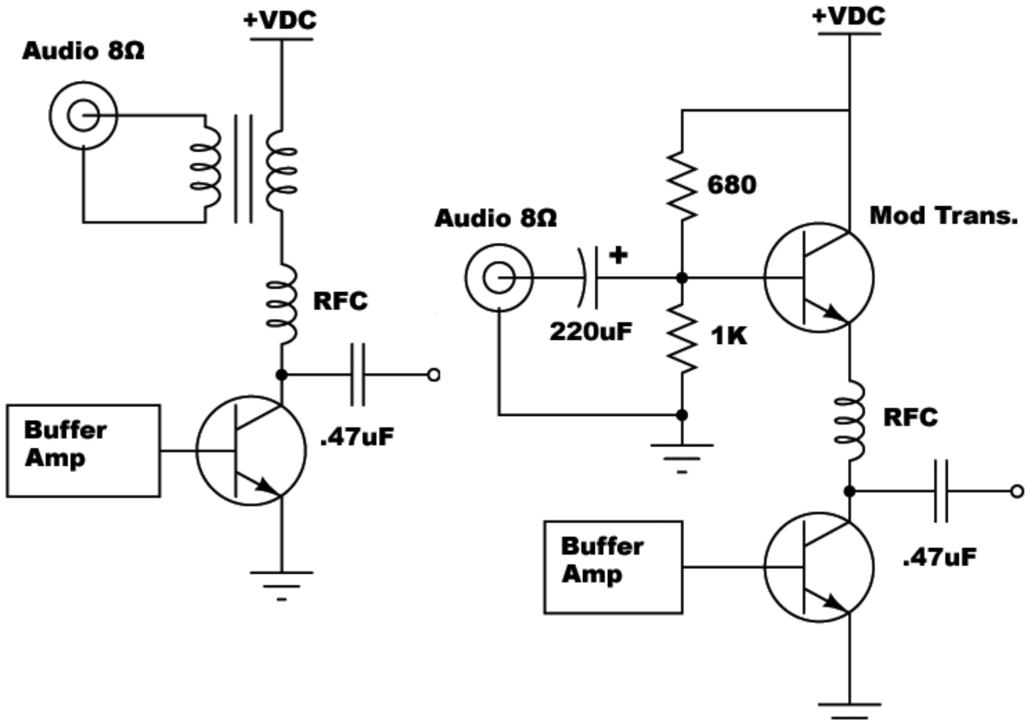

## Modulators

Modulators are the stage that take an audio signal, and mix it into the oscillator frequency to form the upper and lower bands of the AM signal. Remember that in order to conform to NRSC AM broadcast standards, the bandwidth of the audio must be set to cutoff after 10kHz, either with an equalizer or a filter built on the modulator stage.

## Final Amplifier

The final amplifier does the last power increase of the signal before it is sent to the lowpass filter and antenna. If you are using power levels above one watt, a cooling method will have to be employed, such as a large heatsink or a fan (or both).

In most AM transmitters, the modulator doubles as the final. This way, efficiency is increased and heat reduction is less of a problem (explained later).




Two types of modulator/final combos are presented here. The first uses a transformer to couple the audio to the collector/drain input for the final amp. This method is simple, but audio quality is poor. Firstly, a high current transformer is needed to make it work. Secondly, the proper impedance is required, which for 5W+ amplifiers can be almost an isolation transformer. Many people have used 1000 to 8 ohm transformers for these couplers, but they often present an improper match and audio quality suffers as a result.

RFC is an RF Choke, which keeps RF from going into the audio circuits and power supply. The choke optimally should be a minimum of 10 times the final impedance at the lowest RF frequency to be used, but values are not critical.

For the combo on the right, the final transistor will see half the voltage and current (and therefore half the power) of the first stage. The first stage is as a result not very efficient, but the audio quality is much better. Also, because the final only sees half of the power, the voltage has to be rather high to make up for it. A 12 volt power supply will not do it, but I have had success using this design with a 24V power supply (see my 10W transmitter schematic for a working example of this modulation method).

## Note on Linearity of Amplifiers

It is important to understand the linearity of an amplifier. When an amplifier is linear (Class A), it allows a large amount of bandwidth to go through it. When an amplifier is nonlinear (Class C), certain types of signals can be distorted.

The reason a linear amplifier is not always used is because it is inefficient. With a Class A amplifier, efficiency is only 50%. Class C, on the other hand, can be up to 70-90% efficient. When an amplifier is more efficient, more power is output and less heat is generated.

With FM transmitters, it is safe to build a nonlinear amplifier, but for AM a linear amplifier must be used. A modulator, however, does not require a linear amplifier. Many AM transmitters utilize this by making the modulation stage double as a final amplifier.

## Matching Network

The matching network is used to transform the impedance of a signal from one stage to fit the impedance of the next. It can be used in many different areas of the transmitter, but it is primarily used in the final amplifier to match the output of the stage to the standard 50  impedance output.

The final amplifier will have an impedance value that is lower or higher than the transmission line and/or the antenna. If the impedance of all sections is not "matched", transfer of power is poor, and the transmitter will not operate properly. Specifically, power transfer is maximized when the resistance of the load is equal to the resistance of the source, and the reactance of the source is the conjugate of the load ($jX = -jX$).

Matching networks accomplish this. They can either be component or transformer based. Both methods are discussed in this section.

## Harmonics Filter

The harmonics (Low Pass) filter is what blocks the harmonics interference produced by the transmitter. It is placed after the matching network and before the output of the transmitter. It is a very important component, but unfortunately it does not come standard on many transmitters. If one is not used, the transmitter will generate out-of-band interference, which can get the broadcaster into trouble.

Fortunately, Low Pass Filters are easy to construct. More information is presented in the **Interference** chapter.

### Summary of Transmitter Sections

Transmitter design can be a very complex and lengthy discussion. These sections were presented to help familiarize engineers with the basic design of an AM transmitter, but much more reading from books dedicated to the topic is required before more complex transmitters can be designed. Some concepts (PLL oscillator design) have entire books written about them. But still, AM transmitters can be very simple if the designer does not over-engineer, focuses on simplicity and part availability, and doesn't read too far into efficiency concerns.

## Designing Matching Networks

First, an approximation of the source impedance after a transistor stage can be made with this formula:

$$Z = \frac{V_{cc}^{2}}{2P_o}$$

Where:
Z = Output impedance (to be used as source in designing a matching network)
Vcc = Voltage going to collector/drain of transistor
Po = Approximate power output in watts. For Class A, estimate 50% of DC power from collector, for Class C estimate 70%.

### The Q-Factor

When designing a non-transformer matching network, the desired Q factor must be considered. This can confuse some people, because the measure of Q is used for many different things in electrical engineering. To further the problem, it is sometimes referred to as the "Quality Factor", which is vastly misleading.

The reason Q is used in many different areas is that Q is not a measurement, but rather a ratio that describes bandwidth. There are two types of Q factor that concern us for designing matching networks. The first is Loaded Q. Loaded Q is the desired amount of bandwidth for a matching network. Unloaded Q is a measure of the loss of an inductor, and is the only type of Q that does infact measure quality. The unloaded Q is typically low for inductors and very high for capacitors. The unloaded Q of a component is usually specified in manufacturer datasheets.

The bandwidth of Loaded Q can be found with this formula:

$$B = \frac{f}{Q_{EL}}$$

Where:
B = Bandwidth of loaded Q in given frequency units
f = Frequency of signal in given frequency units
$Q_{EL}$ = Loaded Q

Loaded Q must be larger than the bandwidth of the desired signal to avoid signal cutoff, which for AM broadcasting is 20kHz. Frequencies outside of the chosen bandwidth will face considerable loss. Some engineers exploit this property by designing for a high Q, which helps to reduce harmonic interference. In essence, the matching network can act very much like a bandpass filter. The problem with exploiting this is that doing so causes a loss of efficiency:

$$\eta = efficiency = \frac{1}{1 + \frac{Q_{EL}}{Q_U}}$$

Manipulation of this formula will show that efficiency is greatest when the ratio of Unloaded Q to Loaded Q is maximized. As a result, having a loaded Q of 1 always gives the highest efficiency, but in doing so the matching network no longer suppresses harmonic interference. It is important to note however that the purpose of the matching network is to change impedance. Harmonic suppression is added later in the form of a Low Pass Filter. In practical use, engineers tend to use a Loaded Q value between 5-12 for AM broadcast transmitters. This provides for a good amount of harmonic suppression at the expense of only a small amount of signal power. [*]

### Types of Matching Networks

There are many different variations of the matching network. The type ultimately used should be chosen based on efficiency, designer control, practical

* Hagen, Jon. Radio Frequency Electronics. Cambridge Press, 1996. p9-17.

component values and efficiency considerations. For AM, the L and L-C-C Type T networks tend to work best. **

These formulas return the reactance (X) value for each component. To use this value to find the component values, use the following equations:

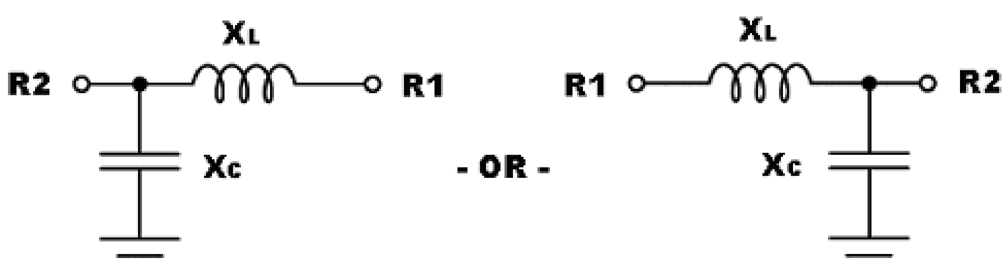
$$L = \frac{1000X}{2\pi f}$$

Where:
L = Inductance in microhenries (uH)
X = Inductive reactance in ohms
f = Frequency in kHz

$$C = \frac{10^9}{2\pi f X}$$

Where:
C = Capacitance in picofarads (pF)
X = Capacitive reactance in ohms
f = Frequency in kHz

**The L Network**




$$R1 < R2$$

$$X_L = \sqrt{R1R2 - R1^2}$$

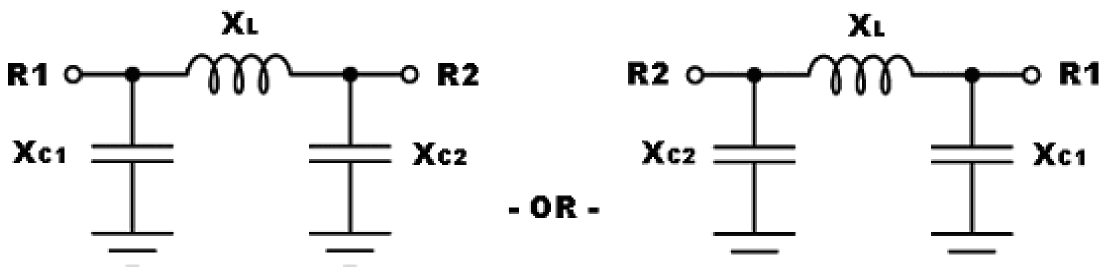
** Hayward and DeMaw. Solid State Design for the Radio Amateur. ARRL, 1986. p52-55.

$$X_C = \frac{R1\,R2}{X_L}$$

$$Q = \sqrt{\frac{R2}{R1} - 1}$$

The L network is simple and only uses a few components. The drawback is that the designer has no control over the value of Q, and in some cases the Q factor can be inadequate. The latter networks do not have this drawback, but can have other design limitations.

### The Pi Network




$$R1 \geq R2$$

$$A = \frac{R1}{R2}$$

$$(Q^2 + 1) > A$$

$$X_{C1} = \frac{R1}{Q}$$

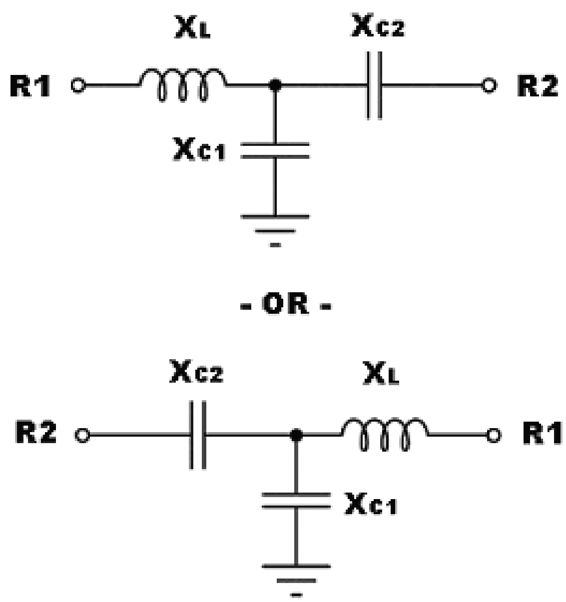
$$X_{C2} = R2\sqrt{\frac{A}{Q^2 + 1 - A}}$$

$$X_L = \frac{QR1 + \frac{R1R2}{X_{C2}}}{Q^2 + 1}$$

The Pi network is very popular with tube circuits. Wide ranges of impedance transformation are possible, and the low-pass nature of the network has a degree of harmonics suppression, which can make it appealing for radio engineers.

This type of network does have drawbacks. The transformation ratio is not unlimited, both greater-than equations must be true or else the transformation is not possible. Low values of Q cannot be used, and the component values are sometimes impractical.

### The L-C-C Type T Network




$$R2 > R1$$

$$A = \sqrt{\frac{R1\,(Q^2 + 1)}{R2} - 1}$$

$$B = R1\,(Q^2 + 1)$$

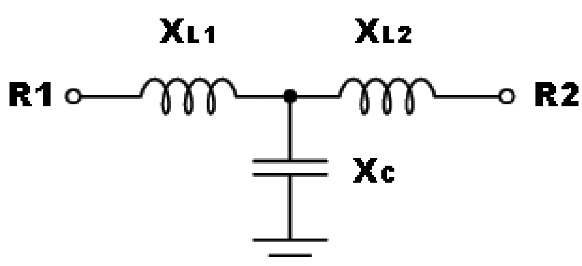
$$X_L = QR1$$

$$X_{C1} = \frac{B}{Q - A}$$

$$X_{C2} = AR2$$

This tends to be the most useful network for solid state transmitters. It matches the low impedances common to transistors very well, and component values tend to be practical.

### The L-C-L Type T Network




$$A = R1(Q^2 + 1)$$

$$B = \sqrt{\frac{A}{R2} - 1}$$

$$X_{L1} = R1\,Q$$

$$X_{L2} = R2B$$

$$X_C = \frac{A}{Q + B}$$

This network also has practical component values for solid-state transmitters, and has a good degree of harmonic suppression. The main drawbacks are lack of tuning range, and loss from inductors if unloaded Q is too low.

## Transformer Matching Networks

Transformer matching networks are less easy to write about in a general-purpose manner, because their design method differs based on the shape and make of the core. Detailed transformer design is covered in many other books, but a general design procedure is presented here.

A core must be used for the transformer. Iron Powder and Ferrite are the common choices. Iron Powder is used more for radio work in tuned circuits, whereas Ferrite is used more for broadband transformers due to its higher permeability at very high frequencies. Either type of core will be adequate for matching networks, though Iron Powder is generally preferred.

There are many shapes of cores, but toroid cores are the most popular for radio work. The toroid shape minimizes the size of the electromagnetic field, thus reducing loss and external signal coupling. For power levels above one watt, transformer cores should have an outside diameter of one inch or larger.

As a rule of thumb, the transformer should have an inductive reactance that is 5-10 times the source impedance at the lowest frequency to be broadcasted on, to ensure there is enough inductance. So, multiply the source impedance by ~8 to get needed reactance, and then use the reactance formula to find the needed inductance.

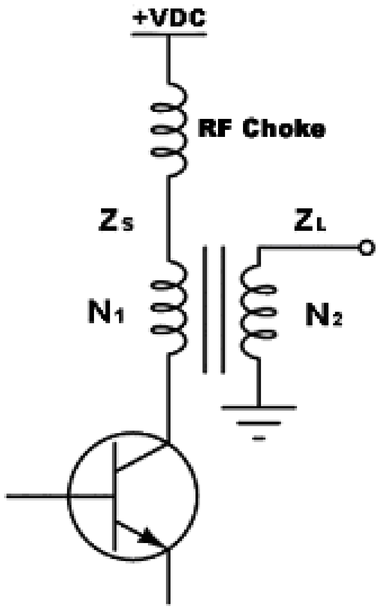
Once the required inductance is found, the number of turns on the core to get the achieved inductance must be found. This involves finding the permeability of the coil and the proper formula for calculating inductance, both of which are supplied by the manufacturer of the coil.

Once the required inductance and number of turns on the primary are found, the number of turns can be found:

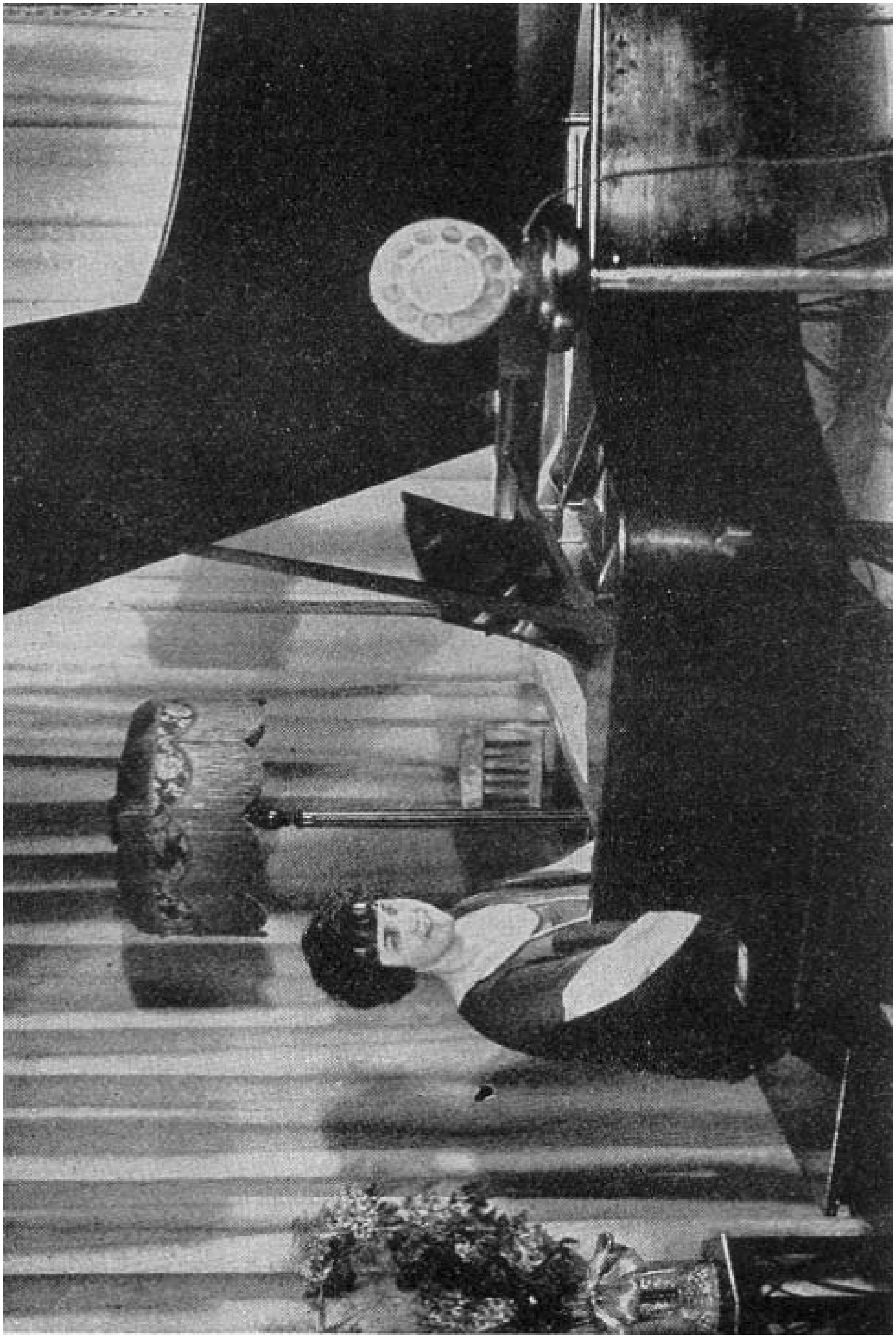
$$N_2 = \sqrt{\frac{Z_L N_1^2}{Z_S}}$$

Where:
$N_1$ = Number of turns on primary
$N_2$ = Number of turns on secondary
$Z_S$ = Input impedance

$Z_L$ = Desired output impedance




Make sure the wire is wrapped firmly on the coil. If necessary, apply a small amount of super glue to help secure the wire.



# 9 - Equipment Sources

If you are interested in buying a transmitter or a kit, this is a list of the known suppliers at the time of this writing. This list was compiled by Crash Knorr for his excellent Medium Wave Alliance website; many thanks are due to him. I make no guarantees about the quality or the reliability of these sources, because unofficial and word-of-mouth is all that I've heard about most of them.

## Assembled Transmitters

**The Rangemaster** - An FCC certified Part-15 transmitter. Quality is high, audio is said to be good. Prices range from $600-800.

http://www.am1000rangemaster.com/

**Information Station Specialists (ISS)** produce several kinds of transmitters, from Part-15 to Travelers Information Systems for government organizations. Their prices start in the upper hundreds.

http://www.issinfosite.com/

**TalkingSign.com Inc.** creates FCC certified transmitters for Part-15 broadcasting. Prices start at $500.

http://www.talkingsign.com/index.htm

**DiPonti Communications** sells transmitters by Ultra Sensors, Inc. They are exceptionally high quality, but expensive.

http://www.wblq.org/diponti.htm

**Wild Planet Toys** makes a Wild Planet Radio DJ, which is a toy transmitter that operates on 1610kHz. It is not a very good transmitter, as it's designed to be a childrens toy, but it has been modified by others to get more distance, audio quality and range. They sell for $30 or less at toy stores and online retailers.

**Vintage Components** sells the Gizmo and the Metzo, two feature rich Part-15 transmitters that are reasonably priced. They include PLL oscillators, which makes stable tuning a no hassle.

http://www.vcomp.co.uk/

**PCS Electronics** sells a feature rich 10 watt, PLL tuned transmitter that is actually capable of broadcasting on Longwave and Shortwave as well as Mediumwave. It has a built in compressor, limiter, and can do AM and CW. Prices start at $250.

http://www.pcs-electronics.com/en/products.php?sub=am_transmitters

**The Low Power Radio Broadcast Company** develops a few transmitters for around-the-house broadcasting. They also have a vintage tube transmitter, for the nostalgics out there.

http://www.ontheair3.com/

**Radio Systems** sells transmitters for Carrier Current, TIS, College Campus and Part-15 uses. They are high quality transmitters, prices are expected to be in the upper hundreds.

http://www.radiosystems.com/

**Chris Cuff** develops Part-15 AM Stereo transmitters that use the C-QUAM stereo standard. Quality is said to be very good. Anyone interested in acquiring a transmitter should contact Christ at ccuff@in4web.com.

## Transmitter Kits

**SSTran** sells a very good and inexpensive Part-15 AM transmitter kit. It is PLL tuned, audio quality is good, it has a compressor/limiter, and an antenna tuner (no external loading coils needed). Transmitter is priced at $90, which includes power supply and case.

http://www.sstran.com/

**Vectronics** sells a small AM transmitter kit. It's not great, but for its price ($30) it is a very good kit. The audio is very clean, and it gets pretty good distance. The biggest problem is that it generates the frequency variably using a CMOS chip, which means that it can be hard to tune and drift. Also, the surrounding radio spectrum is filled with a noise from the impurities in the CMOS oscillator. Still, it is not a bad choice for doing around-the-house broadcasting.

http://www.vectronics.com/

**Ramsey Electronics** sells a couple of Part-15 AM transmitters. The first, the AM-1, is easy to assemble and cheap, but suffers from mediocre audio quality and drift. Their second model, the AM-25, has better audio quality, and a PLL tuner. A jumper allows the power to be raised slightly higher than Part-15 if wanted. Reports are mixed, but most people seem to have no problems with the AM-25.

http://www.ramseyelectronics.com/

**Antique Electronic Supply** is a company that stocks large amounts of older radio components. It is an extremely good source for finding rare parts and books. They also sell a tube-based Part-15 transmitter kit, which is fun and easy to build but is not technically a very good transmitter.

http://www.tubesandmore.com

**North Country Radio** sells the AM88 Part-15 kit. It is a good transmitter, but the kit is supposedly very hard to construct, because it has a lot of components and many surface mount chips. They also sell a carrier current transmitter, but is designed for frequencies slightly lower than the mediumwave band, so modifications would be needed to make it suitable for broadcasting.

http://www.northcountryradio.com/

## Radio Crystal Sources

Custom crystal grinders are getting harder to find, but there are still sources. I have done business with PR Crystals, they are fast and prompt and will grind crystals for mediumwave broadcast frequencies.

**Petersen Radio Co., Inc.**
2735 Avenue A
Council Bluffs, IA 51501
712-323-7539
jjk51503@aol.com

The following sources were recommended to me, I have not done business with them. They may or may not be able to grind custom crystals.

**Bomar Crystal Co.**
201 Blackford ave.
Middlesex, N.J. 08846
Web Site: http://www.bomarcrystal.com
800-526-3935 / 732 356-7787
Fax 800-777-2197
Contact: Ms Anna Diefenbacher
E-mail: sales@bomarcrystal.com

**Cal Crystal Lab Inc.**
1142 N. Gilbert
Anaheim, CA
(714) 991-1580

**C & E Service**
Merrill T. See
5651 North 8th St
Kalamazoo, MI 49009
1 616 375 0171
mtsee@kalamazoo.net

**Crystek Crystals**
2351/2371 Crystal Drive
Ft. Myers, FL 33907
800-237-3061

# Computer Software

## Automation

**Arrakis Systems** has a program called Digilink, which does automation for radio stations. It is a very full featured program. There are two versions of the program, one which is free and is popular with amateur broadcasters.

http://www.arrakis-systems.com

**Ots Labs** makes another powerful automation program called OTSDJ, with bundled equalizers and compressors. They sell the radio station version of the software for $200.

http://www.otsdj.com

**Nullsoft** makes Winamp, a basic but free mp3 player. It can accept playlists and has a built-in equalizer, but it cannot do advanced scheduling. For doing compression and limiting, try using the RockSteady plugin available in the plugins section of the website.

http://www.winamp.com

**Black Cat Systems** makes an automation program for Macintosh users called Nicecast that is very good, has a built-in limiter/compressor, and only costs $30.

http://www.blackcatsystems.com

**UBS** – Uninterrupted Broadcast System - A daemon for running the operations of a radio station.

http://aboleo.net/software/ubs

**College Radio Database** – A database for storing information useful to college or larger radio stations.

http://wmbc.umbc.edu/~ray/database

## Compressor/Limiter/Equalizer Processors

**Toshi** makes an excellent Limiter/Compressor/Equalizer program called MultiMax. It uses a multi-band audio processor, which is the method that the top quality systems for professional radio stations use. It can be set to do real-time or pre-processing. It can also be used to process audio input into the sound card's line-in. The only noticeable drawback is that it only directly supports wav files, so if you have an existing mp3 library it might have to be decoded before it can be processed; it cannot be done on-the-fly. It sells for $25.

http://hp.vector.co.jp/authors/VA009014/index_e.htm

**Cakewalk** makes a program called the Cakewalk Audio FX Dynamic Processor. It embeds into the DirectX system on windows and provides real-time audio processing for all existing programs. The program sells for $130.

http://www.cakewalk.com

It should be noted that some sound cards come with driver software that includes an equalizer and a compressor.

## Audio Editors

**Cakewalk** sells several audio editing programs.

http://www.cakewalk.com

**Syntrillium** makes an audio editor called Cool Edit, which is popular. It was sold to Adobe and is now called Adobe Audition.

www.adobe.com

Additionally, the Creative Sound Blaster software comes with a simple-but-effective audio editing program called WaveStudio.

There is a lot of active work in the field of computer radio automation, and this is just a basic list of the more popular software. A way to find more software is to go to a search engine and look for ‘Radio Automation’. For Linux/Unix users, www.freshmeat.net is a good place to look.

## Component Sources

**Digikey**
701 Brooks Avenue South
Thief River Falls, MN 56701
http://www.digikey.com/

**Newark Electronics**
4801 N. Ravenswood
Chicago, IL 60640-4496
http://www.newark.com

**Jameco Electronics**
1355 Shoreway Road
Belmont, CA 94002
http://www.jameco.com/

**Antique Electronic Supply**
6221 South Maple Avenue
Tempe AZ 85283
602-820-5411
http://www.tubesandmore.com

## Misc

**Panaxis Productions** – Plans and informative booklets. Plans/guides for AM transmitters, carrier current systems and antennas. The antennas guide has some interesting ideas for making more efficient shortened vertical antennas, which might be of interest to more advanced broadcasters looking for more antenna efficiency.

PO Box 130
Paradise, CA 95967
phone 530-534-0417

http://www.panaxis.com

**DC Electronics** - Some parts, kits for PLL oscillators, projects, ect.
PO Box 3203
Scottsdale, AZ 85271
http://www.dckits.com

**MFJ Enterprises** - SWR meters, dummy loads, lowpass filters, ect.
Box 494
Miss. State, MS 39762
http://www.mfjenterprises.com

# Appendix A:
## American Wire Gages (AWG) Sizes and Resistances

| AWG wire size (solid) | Area CM* | Resistance per 1000 ft (ohms) @ 20 C | Diameter (inches) |
|---|---|---|---|
| 00 | 133080 | 0.078 | 0.3648 |
| 0 | 105530 | 0.0983 | 0.32485 |
| 1 | 83694 | 0.124 | 0.2893 |
| 2 | 66373 | 0.1563 | 0.25763 |
| 3 | 52634 | 0.197 | 0.22942 |
| 4 | 41742 | 0.2485 | 0.20431 |
| 5 | 33102 | 0.3133 | 0.18194 |
| 6 | 26250 | 0.3951 | 0.16202 |
| 7 | 20816 | 0.4982 | 0.14428 |
| 8 | 16509 | 0.6282 | 0.12849 |
| 9 | 13094 | 0.7921 | 0.11443 |
| 10 | 10381 | 0.9989 | 0.10189 |
| 11 | 8234 | 1.26 | 0.09074 |
| 12 | 6529 | 1.588 | 0.0808 |
| 13 | 5178.4 | 2.003 | 0.07196 |
| 14 | 4106.8 | 2.525 | 0.06408 |
| 15 | 3256.7 | 3.184 | 0.05707 |
| 16 | 2582.9 | 4.016 | 0.05082 |
| 17 | 2048.2 | 5.064 | 0.04526 |
| 18 | 1624.3 | 6.385 | 0.0403 |
| 19 | 1288.1 | 8.051 | 0.03589 |
| 20 | 1021.5 | 10.15 | 0.03196 |
| 21 | 810.1 | 12.8 | 0.02846 |
| 22 | 642.4 | 16.14 | 0.02535 |
| 23 | 509.45 | 20.36 | 0.02257 |

| | | | |
|---|---|---|---|
| 24 | 404.01 | 25.67 | 0.0201 |
| 25 | 320.4 | 32.37 | 0.0179 |
| 26 | 254.1 | 40.81 | 0.01594 |
| 27 | 201.5 | 51.47 | 0.0142 |
| 28 | 159.79 | 64.9 | 0.01264 |
| 29 | 126.72 | 81.83 | 0.01126 |
| 30 | 100.5 | 103.2 | 0.01002 |
| 31 | 79.7 | 130.1 | 0.00893 |
| 32 | 63.21 | 164.1 | 0.00795 |
| 33 | 50.13 | 206.9 | 0.00708 |
| 34 | 39.75 | 260.9 | 0.0063 |
| 35 | 31.52 | 329 | 0.00561 |
| 36 | 25 | 414.8 | 0.005 |
| 37 | 19.83 | 523.1 | 0.00445 |
| 38 | 15.72 | 659.6 | 0.00396 |
| 39 | 12.47 | 831.8 | 0.00353 |

The U.S. wire gauges (NOT SWG) refer to sizes of copper wire. This table corresponds to a resistivity of

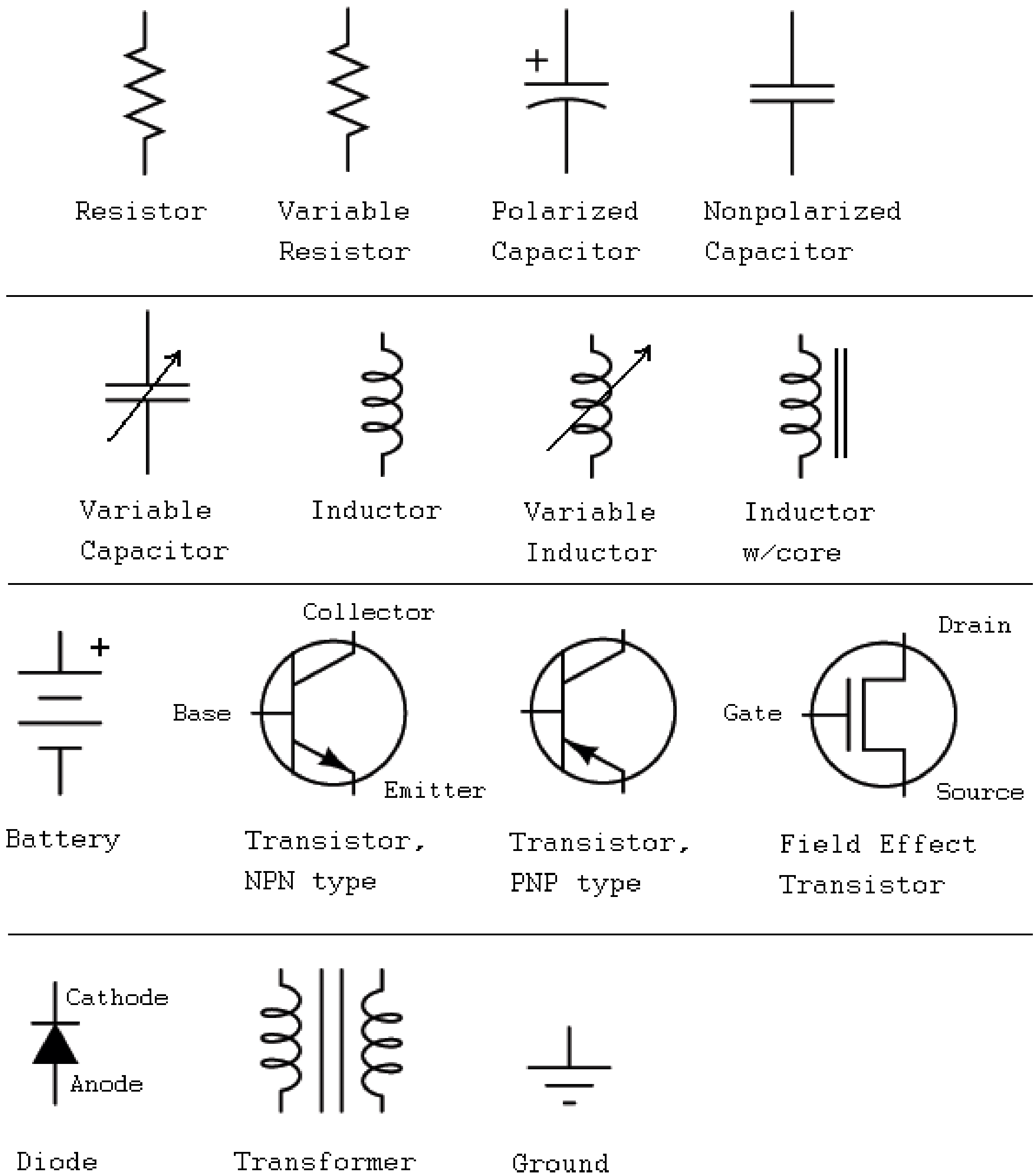
$$\rho = 1.724 \times 10^{-8}\ \Omega\ m$$

for copper at 20 C.

*The AWG system states areas of round copper wires in "circular mils", which is the square of the diameter in mils. 1 mil =.001 inch.

Source: Floyd. Electric Circuit Fundamentals, 2nd Ed.

# Appendix B:
## Schematic Components



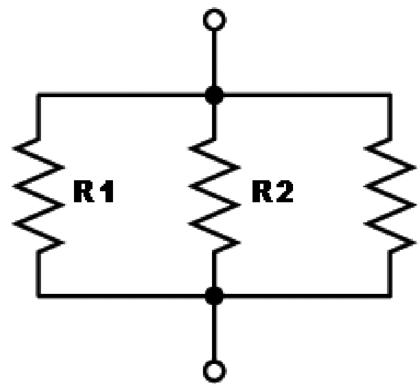
# Appendix C:
## Series & Parallel Components

### Resistors

**In Series**


$$R_T = R1 + R2 + \ldots + RN$$

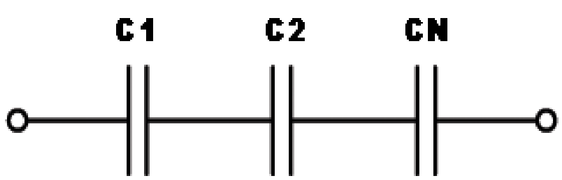
**In Parallel**




$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \ldots + \frac{1}{RN}}$$

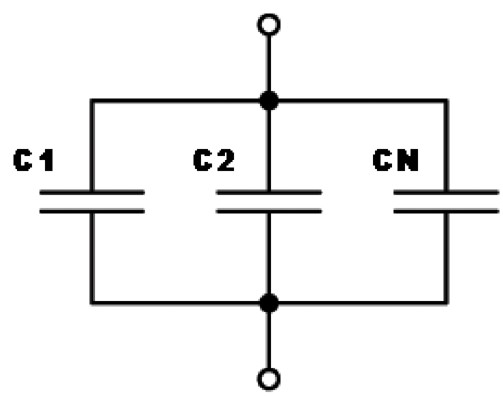
### Capacitors

**In Series**



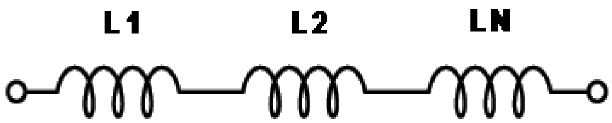
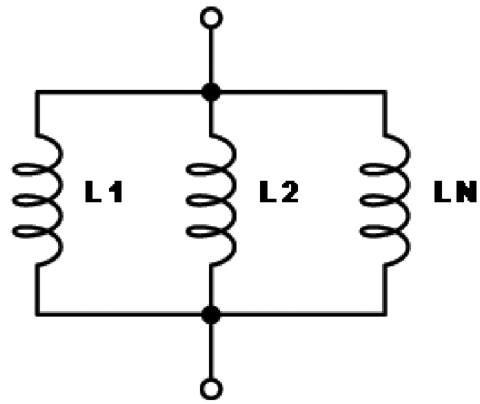

$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \ldots + \frac{1}{CN}}$$

**In Parallel**




$$C_T = C1 + C2 + \ldots + CN$$

# Inductors

<table>
<tr><td>In Series<br><br>$L_T = L1 + L2 + \ldots + LN$</td><td>In Parallel<br><br>$$L_T = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \ldots + \frac{1}{LN}}$$</td></tr>
</table>

# Appendix D:
## Loading Coil Inductance Values

| Frequency (kHz) | Height (ft) | Diameter (in) | Load Inductance (uH) |
|---|---|---|---|
| 1600 | 10 | 1/16 | 134 |
| 1600 | 30 | 1/16 | 86 |
| 1600 | 50 | 1/16 | 62 |
| 1600 | 10 | 1/2 | 119 |
| 1600 | 30 | 2 | 62 |
| 1300 | 10 | 1/16 | 204 |
| 1300 | 30 | 1/16 | 133 |
| 1300 | 50 | 1/16 | 97 |
| 1300 | 10 | 1/2 | 181 |
| 1300 | 30 | 2 | 95 |
| 1000 | 10 | 1/16 | 345 |
| 1000 | 30 | 1/16 | 256 |
| 1000 | 50 | 1/16 | 168 |
| 1000 | 10 | 1/2 | 305 |
| 1000 | 30 | 2 | 162 |
| 700 | 10 | 1/16 | 703 |
| 700 | 30 | 1/16 | 463 |
| 700 | 50 | 1/16 | 349 |
| 700 | 10 | 1/2 | 623 |
| 700 | 30 | 2 | 333 |
| 500 | 10 | 1/16 | 1379 |
| 500 | 10 | 1/16 | 910 |
| 500 | 50 | 1/16 | 689 |
| 500 | 10 | 1/2 | 1222 |
| 500 | 30 | 2 | 654 |

The above chart lists common inductance requirements given by shortened vertical antenna capacitance formulas. The inductance values were found using the first method in the Antenna Topics section, with an extra 50pF added to compensate for a capacitance hat. Note that as the frequency, height, and diameter go lower, the inductance values increase. For variable loading coils, this can almost be looked at as a table of minimum support. For example, if you want a coil that is capable of loading a 10 foot 1/16" diameter antenna at 1000kHz, then choose that value for your loading coil. Then, that coil will be capable of tuning any antenna longer than 10 feet, thicker than 1/16”, and higher frequency than 1000kHz. This is why it is recommend that the designer add more inductance than is needed.

# Appendix E - Formula Reference

**Ohm's Law**

$$V = IR$$

V = Volts
I = Current in amps
R = Resistance

**Power**

$$P = VI$$

V = Volts
I = Current in amps
P = Power in watts

## Wavelength

$$W = \frac{984{,}000}{kHz}$$

W = Wavelength ( $\lambda$ ) in feet
kHz = Broadcast frequency in kilohertz

## Inductance of a cylindrical air coil core

$$L = \frac{(0.5ND)^2}{4.5D + 10H} \quad \text{or} \quad N = \frac{\sqrt{L\,(4.5D + 10H)}}{0.5D}$$

L = Inductance of coil in microhenrys ($\mu$H)
N = Number of turns
D = Diameter of coil in inches (twice the radius)
H = Length of coil in inches

## Output impedance of collector or drain output (common emitter) transistor amplifier

$$Z = \frac{{V_{cc}}^2}{2P_o}$$

Z = Output impedance
Vcc = Power supply voltage going to collector/drain of transistor
Po = Approximate power output in watts. For Class A amplifier, estimate 50% of power from collector, for Class C amplifier estimate 70%.

## Oscillating frequency of an LC series circuit

$$F = \frac{10^6}{2\pi\sqrt{LC}}$$

F = Frequency in kHz
L = Inductance in microhenries (uH)
C = Capacitance (Ctotal) in picofarads (pF)

## Radiation resistance of antenna

$$R = \frac{400 \cdot h^2}{\lambda^2}$$

R = Radiation resistance in ohms (Ω)
h = Height in feet
λ = Wavelength of frequency in feet

## Efficiency of antenna

$$E = \frac{100R}{R + G + L}$$

E = Percent of Antenna Efficiency
R = Radiation Resistance in ohms
G = Ground Losses in ohms
L = Loading Coil Losses in ohms (AC resistance; cannot be measured with a DC ohmmeter)

## Capacitance of antenna

$$C = \frac{17h}{\left(2.3\log\left(\frac{24h}{d}\right) - 1\right)\left(1 - \left(\frac{.001fh}{234}\right)^2\right)}$$

C = Capacitance in picofarads (pF)
d = Antenna diameter in inches
f = Frequency in kHz
h = length of antenna in feet

Approximate 30-90pF more if capacitive hat is used.

## Quality Factor Bandwidth

$$B = \frac{f}{Q_{EL}}$$

B = Bandwidth of loaded Q in given frequency units
f = Frequency of signal in given frequency units
$Q_{EL}$ = Loaded Q

**Efficiency of Q**

$$\eta = efficiency = \frac{1}{1 + \frac{Q_{EL}}{Q_U}}$$

$Q_U$ = Unloaded Q (given by manufacturer or Q-meter)

## Reactance formulas

| | |
|---|---|
| $L = \frac{1000X}{2\pi f}$ or $X = \frac{2\pi f L}{1000}$<br><br>L = Inductance in microhenries (uH)<br>X = Inductive reactance in ohms<br>f = Frequency in kHz | $C = \frac{10^9}{2\pi f X}$ or $X = \frac{10^9}{2\pi f C}$<br><br>C = Capacitance in picofarads (pF)<br>X = Capacitive reactance in ohms<br>f = Frequency in kHz |

## Transformer impedance matching

$$N_2 = \sqrt{\frac{Z_L N_1^2}{Z_S}}$$

N1 = Number of turns on primary
N2 = Number of turns on secondary
$Z_S$ = Input impedance
$Z_L$ = Desired output impedance

Inductance formula/core permeability supplied by core manufacturer