Some Notes on FM BC Antennas
Part 1: A Few Basics

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The past 4 decades since I was a DJ for a small west Texas AM radio station have seen a continuous process of trivialization of broadcast radio. The trend conquered AM first, but has since overrun FM as well. Listeners have decreased just in proportion to the rise in hype for stations--once known proudly by FCC-issued call signs, but now going under aliases such as "poop 102" or "pasture apple 88."

As local FM stations sound increasingly alike, one has to search far and wide for a station to suit one's listening desires. Hence, searchers have acquired an interest in antennas to increase the range of their searches. Questions about FM antennas show up in my e-mail at a rate of a couple a month. This past month, I received 4 messages, which suggested that some notes may be in order.

In this small set of notes, I shall cover some basics about FM antennas and antenna systems. Then we shall turn to some strategies for covering the 88-108-MHz band with high-gain, directional antennas that one can build at home. Among the antenna types that we shall examine are Yagi directional beams and log periodic arrays. Both of these antenna types a horizontally planar, that is, they are wide and long, but not vertically thick. We shall also examine an antenna that is wide and high, but does not share the long boom length of the other arrays.

Antenna and Antenna Systems

Fig. 1 shows the distinction between an antenna and an antenna system. The antenna device itself is only one part of the system. The system includes the antenna, the feedline (properly, the transmission line), and the FM receiver, plus some auxiliary devices.

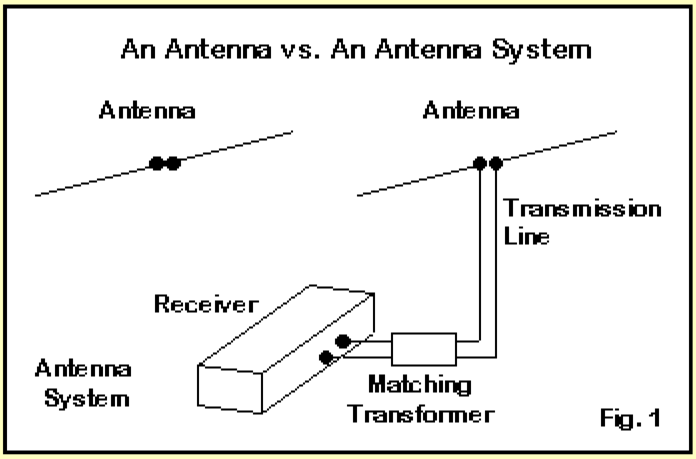


Fig. 1

Let's start at the FM receiver. Most AM receivers come with a built-in antenna, usually a ferrite bar wound with a long stretch of thin wire. The antenna is adequate for local reception and occasionally for some catch-as-catch-can nighttime DX.

FM receivers normally lack antennas. Some may use a short lead to a piece of thin metal folded over the line cord (for AC-powered receivers). Some may have rabbit ears. And some may include that ubiquitous folded dipole that hangs limply because no one keeps the instructions on how to hang it and use it.

If you feel the need for an external antenna, either in the attic or above the roof, it pays to begin with a simple antenna and work upward to something fancier. One reason (but not the only one) for this strategy is that some FM receivers are subject to overload from strong signals. If you add an external antenna for improving the reception of weak signals, you will discover that local signals may be proportionately stronger. How well your receiver handles very strong signals varies from one model to another, with low-end receivers being most susceptible to various forms of distortion and false signals. So proceed slowly as you progress toward antennas with higher gain.

It may be the case that simply having a simple antenna in a higher location may provide all of the sensitivity increase that you need. FM reception is largely line-of-sight, and increasing the antenna height increases its "seeing" distance to the horizon. In addition, the main floors of most houses are filled with metallic objects that can shield the antenna from its desired signals. By raising the antenna to an area that is mostly free and clear of metallic clutter, we can often obtain the performance we want. (Of course, once we get used to this performance level, we may yearn for even higher levels.)

Between the receiver and the antenna is the transmission (or feed) line. **Fig. 2** shows the two most common types: parallel line, sometimes called TV twinlead, and coaxial cable. TV twinlead is inexpensive and--when properly installed--low loss. Coaxial cable tends to have higher losses, although the loss levels vary considerably from one type to the next. However, if you experience unwanted interference pick-up on twinlead, you may need coaxial cable. Again, it may pay to begin simply and inexpensively and then proceed to higher-cost materials as needed.

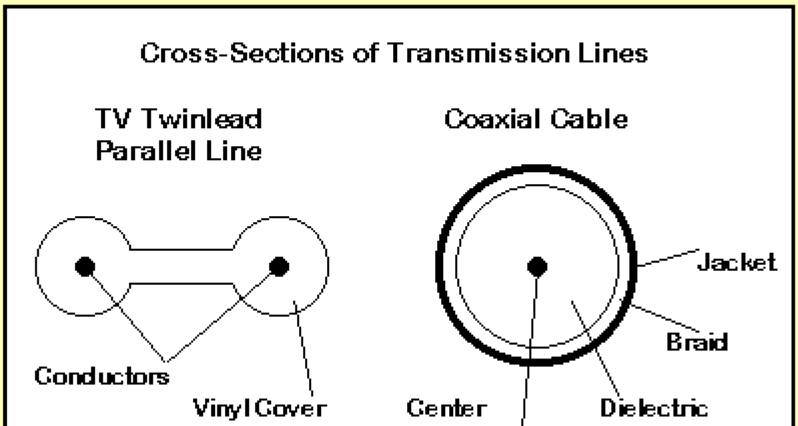


Fig. 2

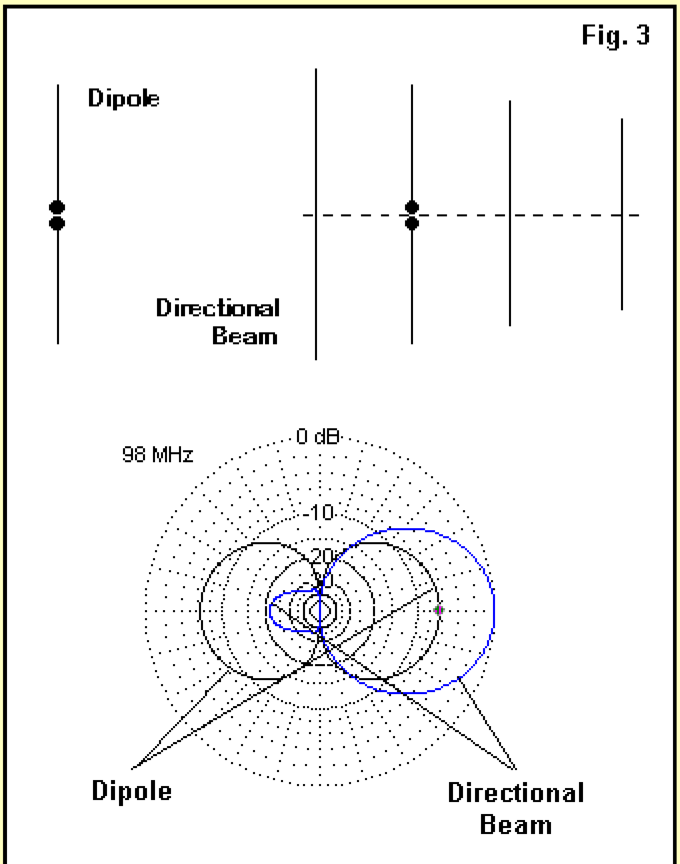
TV twinlead has a characteristic impedance around 300 Ohms (although I have seen some very cheap stuff with an impedance closer to 200 Ohms). If your run has any section exposed to weather, use a high quality line. Your receiver may have one or both of two types of antenna connectors. One type is a set of screw terminals: these are designed for TV twinlead connection. The other type is a connector, normally type F, for a coaxial cable. F-connectors are standard in the cable industry and cheap, although quite effective when installed correctly. Their size is suited to 75-Ohm cables: I recommend that you use the cable type rated for cable TV service rather than RG-59 for lower losses. The longer a coaxial cable run, the more important it becomes to use a low-loss cable type.

Suppose that you wish to use coax, but have only screw leads. Or vice versa. There are inexpensive feedline transformers available from Radio Shack and other outlets to transform 300 Ohms to 75 Ohms or 75-Ohms to 300 Ohms. These are actually 4:1 ratio transformers, and so they will also do a decent job transforming between 50 and 200 Ohms. However, they are power rated only for receiving applications.

So now we have progressed from the receiver through the transmission line and any required transformers to the antenna proper.

Some Antenna Basics

FM broadcast signals--like television signals--are normally horizontally polarized. Therefore, a vertical antenna is unlikely to do much good in the quest for better reception. Instead, the most likely antenna that you might use will be a dipole or an antenna based on a dipole.



A Typical Dipole and a Typical Directional Beam
Outlines and Azimuth Patterns

Fig. 3 shows a dipole and a directional beam in outline form, along with the general shape of the patterns of reception for each. On the pattern graph, the line shows an equal level of receiving sensitivity all the way around the antenna. It is called an azimuth pattern. Since virtually (but not quite) all reception is line-of-sight, this pattern is a fairly good guide to what you can expect from a given antenna type. Of course, each antenna model will have its own unique pattern, although the two shapes shown are typical.

The dipole has a bi-directional pattern roughly shaped like a figure 8. The directional pattern from the beam is stronger in one general direction than the dipole, but considerably weaker in most other directions. Both types of antenna exhibit very weak sensitivity directly off the ends of the element (or elements, for the beam).

Comparing antenna performance is a matter of comparing the maximum power gain of one antenna to another. For reception, we measure the maximum sensitivity in the most favored direction against a standard. For most purposes, the standard is an isotropic radiator that radiates equally well in all possible directions. So we set down the maximum gain in decibels relative to an isotropic radiator or dBi. The dipole might have a gain of 7 dBi while the beam might have a gain of 12 dBi. In the favored beam direction, a received signal will be 5 dB stronger than a signal from a dipole.

Decibels are a logarithmic function. Hence, 3 dB comparative gain advantage means a signal that is twice as strong. A 6-dB advantage is a power gain of 4. A 10 dB gain advantage is a power gain of 10. From these handy checkpoints, you can interpolate other values without calculating the a power gain in dB equals 10 times the log of the power ratio. In the other direction, to be 3 dB weaker is to be half as strong, etc.

I have specified dBi as the standard that I shall use in these notes. There are older standards, like dBd, or decibels gain over a dipole. However, that figure is a conventionalized gain for a dipole in free-space. Hence, the gain in dBd is always simply 2.15 dB less than the gain in dBi. One reason for using dBi is that dBd can be confusing. For example, our sample dipole, when placed high over real ground, has a gain of about 5 dBd or dB over a dipole. That is to say, the gain of our dipole over ground is about 5 dB better than the gain of a perfect dipole in free space (away from any reflective ground surfaces).

Both of the antennas in **Fig. 3** are directional. That is, each is more sensitive in some directions and less sensitive in others. We simply call "uni-directional" antennas directional. The dipole is an example of a bi-directional antenna, that is, one equally sensitive to two directions. Note that the directions of sensitivity are broadside to the dipole, with a total lack of sensitivity off the element ends. In contrast, the beam favors a single direction. However, it has a less sensitive rearward structure to its pattern. For directional beams, we can specify a second performance characteristic besides maximum forward gain. The new parameter is front-to-back ratio, usually specified as the ratio of sensitivity in the forward direction to the sensitivity rearward. Hence, we specify it in dB. The higher the ratio, the better the rejection of unwanted signals to the rear of the antenna. Of course, the dipole has a ratio of 1:1 or zero dB. Hence, we never mention front-to-back ratio when thinking of dipoles.

Directional and bi-directional antennas require a method of pointing our antenna at a desired station. If we have only one station for which we need more sensitivity. then we can mount our antenna so that it points toward that station. However, if we want to scan the horizon, then we shall need to add to our antenna system a method for turning the antenna. TV rotators are available for this purpose. So we have another auxiliary piece for our antenna system. The rotator will not only require the motorized turning unit, but as well a multi-wire cable connecting the motor unit to the control unit, which is usually installed near the receiver. **Fig. 4** shows a typical system in outline form. The more demands that we put on our antenna system, the more complex and expensive it becomes.

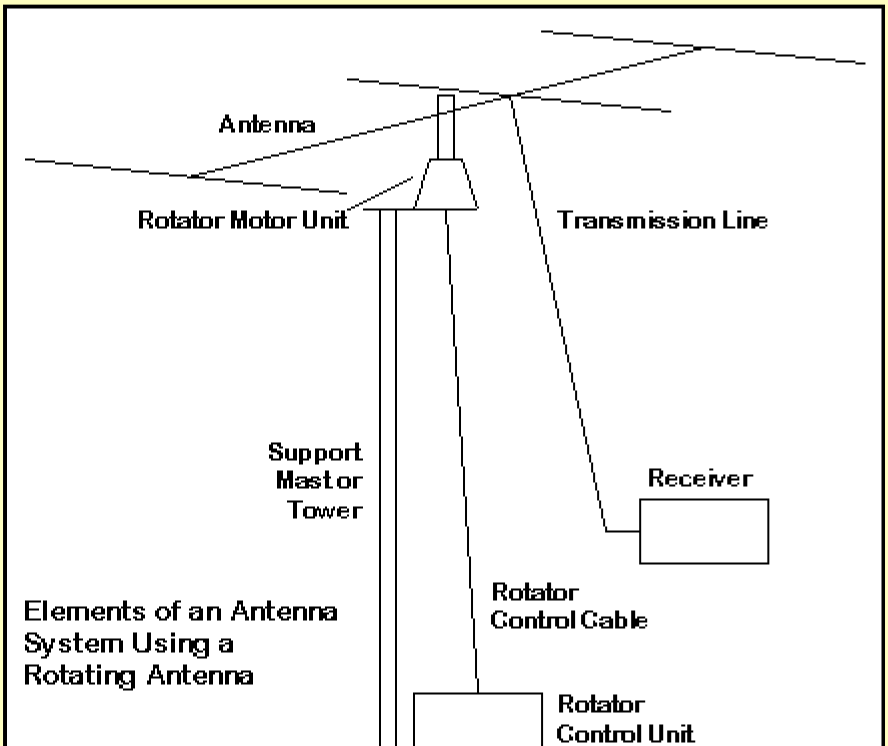
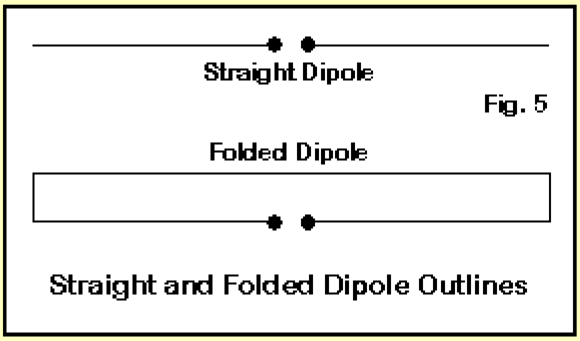


Fig. 4

The Dipole

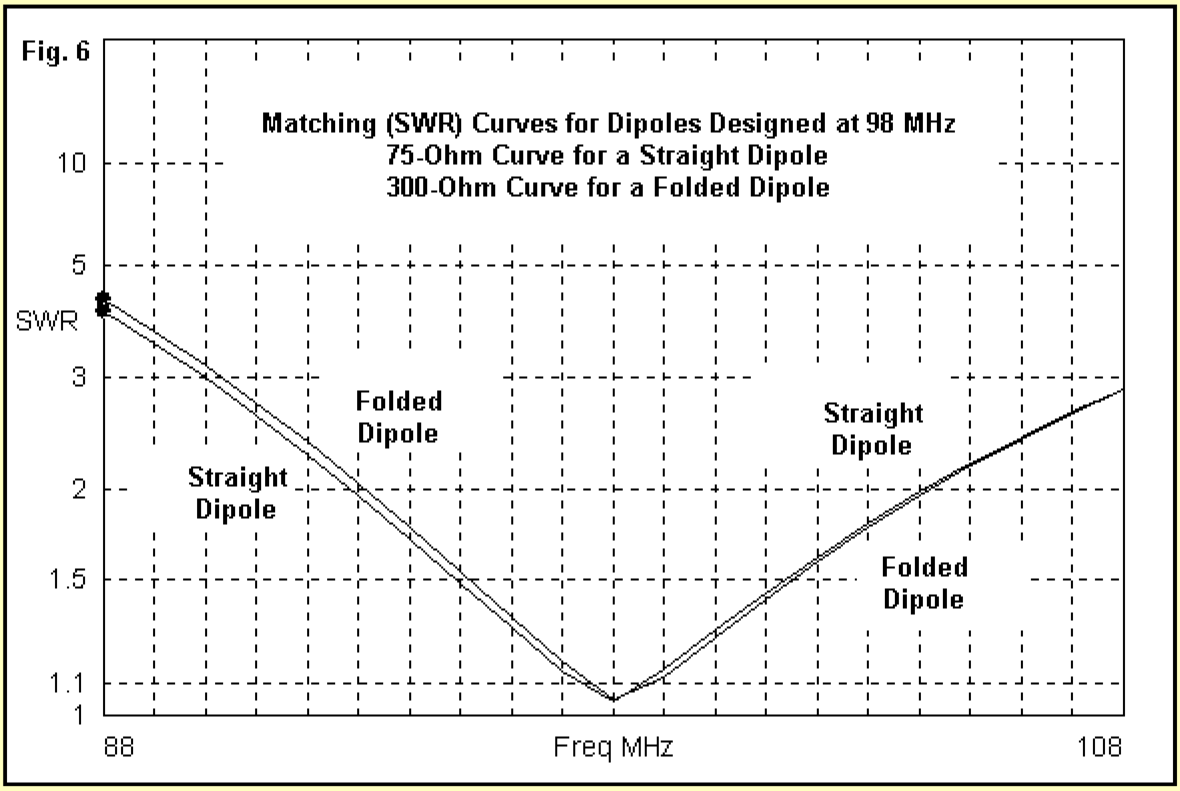
Let's begin our investigation of antennas with the most rudimentary: the dipole. A dipole is a center-fed, resonant (or near-resonant), half- wavelength antenna. However, the moment that we turn from abstract definitions to actual antenna practice, we meet with two types of dipoles: the straight and the folded. See **Fig. 5**.



There is no basic difference in the performance potential for the two types of dipoles. Indeed, most of the advantages assigned to one or the other disappear into a fog on the frontiers of antenna performance. Perhaps the folded dipole has one advantage: since it forms a complete loop, the element does not build up a static charge between element tips. However, the azimuth patterns for each are the same.

The chief advantage of one over the other is the feedpoint impedance. The straight dipole has an impedance at resonance of about 70-72 Ohms, a good match for 70-75-Ohm coaxial cable. A folded dipole of standard design has a resonant impedance of about 280-288 Ohms (4 times that of a straight dipole), and the impedance is a good match for 300-Ohm twinlead. However, if we wish to mix and match our dipoles and transmission lines, we can always insert one of those 4:1 transformers so that we obtain a good match.

The FM broadcast band is very wide, since it extends from 88 to 108 MHz. The band has about a 20% bandwidth (the difference between the upper and lower end frequencies, divided by the center frequency, times 100 to get a percentage). Over that range, the sensitivity of a dipole--straight or folded--will not significantly change. However, the feedpoint impedance will change. That fact leads us to the subject of Standing Wave Ratio or SWR.



The SWR is a measure of the closeness of the match between the antenna feedpoint impedance and the characteristic impedance of the transmission line. The lower the SWR value, the closer the match. As **Fig. 6** shows, there is no difference between the curves of a straight dipole connected to a 75-Ohm coaxial cable and a folded dipole connected to 300-Ohm twinlead. (If we mix and match, a high-quality transformer will add nothing to the SWR.)

We cut our dipoles for 98 MHz, the center of the band. Incidentally, a 98-MHz straight dipole made from 0.25" diameter rod will be about 57.2" long end-to-end. The same dipole made from thinner wire, say AWG #14 house wire, will require 58.0" A typical twinlead dipole will be about 57" end-to-end. A common question I receive is whether the gap at the center where we connect our transmission line in series with the wire is part of the overall length or adds to the overall length. It is part of the overall length and is not very critical. Gaps from a quarter inch to nearly 1 inch do not affect the end-to-end length. If you wish to move the SWR minimum lower in the FM band, then add about 4 inches to the lengths suggested. If you prefer the upper end of the band, subtract about 4 inches. If you wish to be more precise about the length to which you cut your dipole or folded dipole, then the following table will serve as a guide. The 91-MHz version will cover the low end of the band with a good match to 70-75-Ohm coaxial cable, while the 105-MHz version will do the same for the upper end of the band.

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FM Band Dipoles

	Length in inches		
Straight Dipoles	**91 MHz**	**98 MHz**	**105 MHz**
Diameter			
0.25"	**61.6**	**57.2**	**53.4**
AWG #14 Wire	**62.5**	**58.0**	**54.1**
Folded Dipole			
Twinlead	**61.4**	**57.0**	**53.2**

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I may seem to be a bit cavalier in my treatment of lengths in the face of the fact that the curves show end SWR values around 4:1. In fact, these SWR values are not of great concern for receiving purposes--although they might be for transmitting. SWR is an indicator of, but not a measure of, losses in the antenna system from the antenna to the receiver. If you use good quality transmission line and the lead is well-installed and not too long, then you will not likely detect any difference of performance between the band edges and the band center.

Note that this generalization applies to dipoles, but it may not apply to other antenna types. Some directional antennas have inherently narrow operating ranges, that is, the range through which the pattern characteristics of the antenna are approximately the same. So some beam antennas will show significant differences in performance as we move from one end of the band to the other. We shall examine both narrow- and broad-band beams in the course of our little safari through the antenna jungle.

If bi-directional reception is suitable for your needs and if you only need more sensitivity, then a dipole in the attic or on top of the roof may be all the antenna that you need. You can make an assembly from PVC and use wire or rod inside of it for weather protection. With a Tee fitting at the center, you can drop your cable down the center and use the vertical PVC section as the mast. Compared to hanging a dipole in the basement or living room, the added height it takes to reach the attic or roof can add considerably to received signal strength.

You can make folded dipoles from TV twinlead or from bent rod, wire, or tubing. If you plan to mount the antenna out of doors, I do not recommend use of the folded dipoles often packed inside the FM receiver box. Their durability in weather is always suspect. However, you can hang a wire folded dipole in the attic by tying cord to the two ends and nailing the cord to roof beams. However, in any attic installation, be sure that the roof is not lined with foil-faced insulation above the antenna. Such insulation can be like throwing the antenna inside an old coffee can in terms of shielding it from its real work.

An Omni-Directional Antenna

Suppose that you wish to have an attic or rooftop antenna for increased sensitivity, but do not want to add a rotator to a directional beam. Then you may need an omni-directional antenna. However, as we noted in the beginning, we shall need a horizontally polarized antenna, and verticals do not meet this need. So our antenna becomes somewhat more complex.

The most common type of antenna used for omni-directional antenna is the dipole turnstile. The antenna derives its name because the elements resemble an old-fashioned turnstile used in stadiums and subways. **Fig. 7** shows the general outline of a dipole turnstile using straight elements.

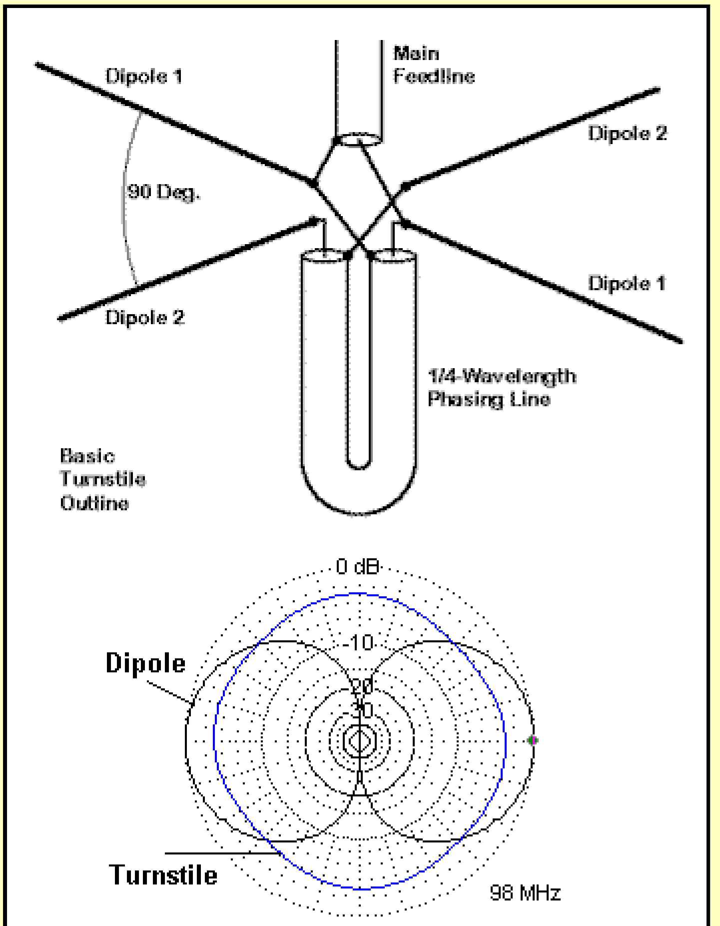


Fig. 7

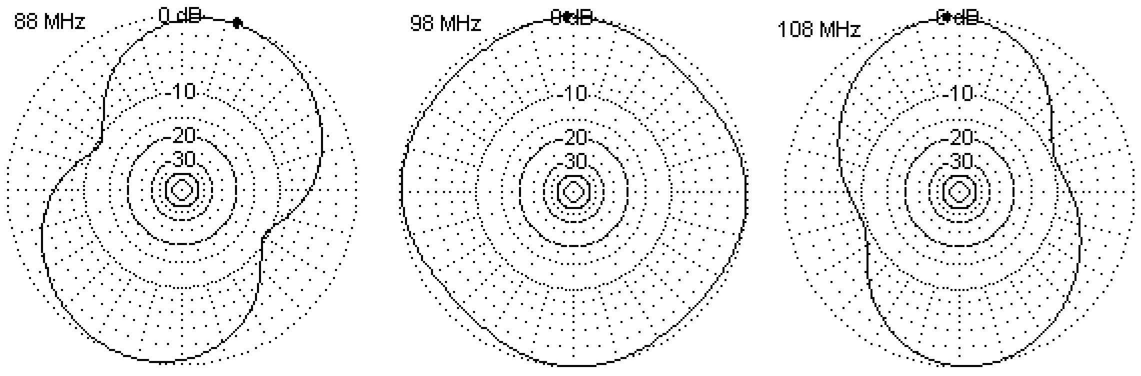
The figure also shows the pattern of the turnstile along with a dipole pattern for comparison. An antenna has a fixed overall sensitivity. The dipole shows that sensitivity in two lobes, one on each side of the wire. However, if we take that same sensitivity and spread it around in a nearly perfect circle, then the sensitivity level at an given point is less than maximum gain of a dipole (but stronger than the minimum gain of that dipole).

The turnstile consists of two dipoles that do not touch each other. We send our main feedline to the feedpoint of one dipole. From those terminals to the feedpoint of the other, we run a 70-75-Ohm transmission line that is 1/4-wavelength long and called a phase line. At 98 MHz, the center of the FM band, 1/4-wavelength is 30.11". However, every transmission line has a velocity factor that makes it electrical length longer than its physical length. If we use foam-type coax for our phaseline, then the velocity factor will be about 0.78. So we multiply our true 1/4-wavelength by the velocity factor to come up with 23.5", the physical length for our phase line.

The main feedpoint impedance will be 1/2 the value for a single dipole. That value will be about 36 Ohms for our straight dipole turnstile. A 50-Ohm coax lead would provide an adequate match for the system at both ends of the line.

We can also substitute folded dipoles for our straight dipoles. In this case, we would make our phase line from 300-Ohm twinlead. Many types of twinlead have a velocity factor of 0.8, which would make our 1/4-wavelength line 24.1" long. The main feedpoint impedance will now be about 140 Ohms. If we install a 4:1 transformer, we end up with a 35-Ohm impedance for the same 50-Ohm coaxial cable transmission line to the receiver.

Before you run out and build or buy a straight or folded dipole turnstile, lets examine one more property of the antenna. The SWR curve for a turnstile is very shallow, so in terms of its ability to match a feedline, it is a very broadband antenna. However, its pattern is actually very narrow-banded. To see what I mean, examine **Fig. 8**.



98-MHz Dipole Turnstile Azimuth Patterns **Fig. 8**

The graphic shows the nearly circular pattern at 98 MHz, the frequency for which I designed the array. However, as we move away from that frequency, the pattern becomes less and less circular. By the time we reach the band edges, the pattern has evolved into deformed peanuts, indicating a bi-directional sensitivity in differing directions at the two band edges. The pattern distortion results from the fact that the phase line is no longer exactly 1/4-wavelength at the lower and the higher frequencies, and so the phasing is imperfect.

This property is not necessarily fatal to the antenna. However, the pattern shifts may mean that you will do a lot of fine antenna turning before locking it in place. The turning is to locate your most favored stations at each end of the FM band. If you are lucky, you may hit them all in the most sensitive areas of the antenna pattern.

An alternative is to create a dipole turnstile for the portion of the FM band that you most prefer. Use the dipole lengths from the earlier cutting table for the bottom, middle, or top of the band. The 91-MHz straight dipole turnstile would need a 25.3" length of 0.78 VF coax for its phase line, while the 105-MHz version would need a length of 21.9". The folded dipole turnstile using TV twinlead uses a 25.9" phase line for 91 MHz and a 22.5" length for 105 MHz.

Bigger Antennas

If you cannot fit your listening desires into what the turnstile or the dipole have to offer--or if you desire even greater sensitivity--then you may need to think in terms of a directional antenna along with its rotator. In the next episode, we shall look at some strategies for using directional antennas to improve FM weak signal reception. However, be forewarned that beam antennas are not a simple cure-all for every situation. They have limitations, complexities, and expenses.

Directional beams are for the very serious FM DXer who needs or deeply wishes to capture weak signals. For those who simply need a boost to their reception capabilities, an attic or roof-top version of one of the simple antennas that we have so far covered will likely do the job. Even if you think that you may wish to go to a bigger antenna, one of these antennas is a good intermediate step so that you can evaluate your situation. You can set up a dipole on a temporary mast that extends just over your roof-top. Mount the mast securely, but not so tight that you cannot turn it.

Now listen to the quality of reception to you get. Check for strong local station overload of your receiver. Check weaker stations and see if you can null out stronger ones that are near in frequency and that seem to want to capture the frequency of the weak one. Turn the dipole slowly to see if the strong station weakens significantly when the dipole end points toward it. If you have a distant station that you wish to hear, check its performance with the dipole and see if you need further improvement to arrive at comfortable and quality FM reception.

Once you have performed a thorough evaluation of you listening needs (if any) above and beyond a simple elevated dipole, you can decide if you need to explore the realm of directional beams--and the following episodes of this series. Even if you decide not to go further, you will have learned some important things about the performance of antennas. The first lesson is that bigger is only better if you really need it and have the wherewithal to go after it.

Special Note: Brian Beezley, K6STI, has done some extensive design and modeling of both simple and complex FM antennas, with a special emphasis on circular polarization. All of the articles are inter-linked. so you may begin with any one of them. For example, he designed a simple **circularly polarized attic antenna** that makes a good starting point.

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