Some Really Cheap Antennas

So you think you can't afford a beam antenna for your VHF station? Think again. You can build a bunch of Kent's "Cheap Yagis" for less than the cost of your feedline!

Back in 1993, Arnie Coro, CO2KK (who also writes for *CQ VHF*), spoke to the Central States VHF Society Conference in Oklahoma City on the incredible difficulty of building advanced-design antennas in the Third World (...just run out to the local store, pick up your 6061-T6 aluminum rod, Delrin® Insulators, Teflon® dielectric coax baluns...)—even if they were affordable, these items simply are not available.

Arnie's talk got me thinking; how can someone without access to fancy parts or big money use all the advanced technology and modeling software we have today to make antennas easier to build? And how can even "rich Americans" build up a VHF Rover station without putting hundreds of dollars into the antennas? Enter...the "Cheap Yagi."

"So how can someone without access to fancy parts or big money use all the advanced technology and modeling software we have today to make antennas easier to build?"

The booms are made from wood, and the reflector and director elements are cut from solid aluminum ground wire available by the roll at RadioShack and elsewhere (other materials will also work if they're more readily available; see "Cheap Yagis—the Nitty Gritty" for details). The driven element (only) is made from bare #10 copper wire. With the wood booms and ground wire reflector and director elements, you can build up a handful of these antennas for about $10.

Over the last five years, hundreds of the antennas have been successfully constructed and over 30 variations designed. I'm currently using them on bands from 50 to 1296 MHz (see Photo A for all but the 6-meter version). This month, I'll give you the details for building a variety of these antennas for the 70-centimeter band (we'll talk about the 144- and 222-MHz versions of these antennas in the next column).

Impedance Magic...um, Matching

Let's take a quick look at some of the theory behind these antennnas. In Figure 1a, we have a *simple dipole*. The impedance of a simple dipole is about 72 ohms. As we put other elements around the dipole, the impedance loads down. So if you carefully control the spacing between elements, you can control the impedance of the dipole (which, in a beam antenna, serves as the driven element). In Figure 1b, we have a simple dipole with a wide spaced reflector and director added—a basic three-element Yagi. The loading effect of these elements brings the impedance of the driven element down to 50 ohms. Now 50-ohm coax can be directly connected to the antenna—no matching bars, no baluns, no gamma matches.

Figure 2a is a *folded dipole* element, which has about 300 ohms impedance by itself. By bringing the additional elements in real close (Figure 2b), 300 ohms can be loaded down to 50 ohms; again, resulting in a simple 50-ohm match. All impedance matching is done in the structure of the antenna itself!

I ended up using a 150-ohm "J" for the driven element on my Cheap Yagis. As you can see in Figure 3 and Photo B, the "J" is kind of a cross between a dipole and a folded dipole, and it has several advantages over either of the other options. First, the folded dipole design required the first director to be mounted very close to the driven element, and this spacing was extremely critical (read that as difficult to build). And the straight dipole required very loose coupling and I couldn't get good gain numbers. Also, the straight dipole couldn't be used to make 72-ohm versions for those with better access to 72-ohm feedline than to 52-ohm (more on that in a later column).

For a while, I wondered if I had invented a new driven element. But it turns out

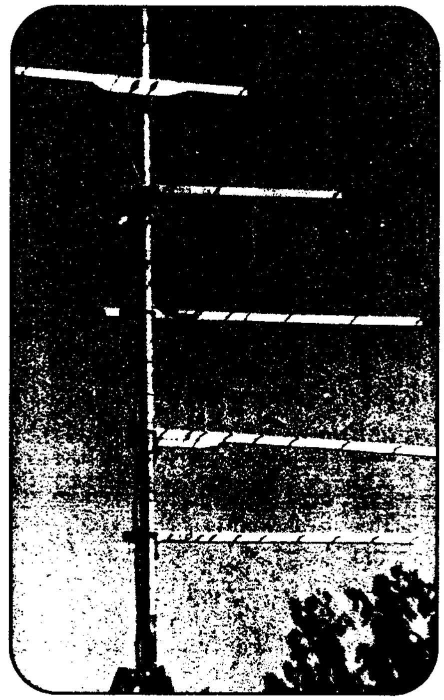


Photo A. I have a stack of "Cheap Yagis" on 144, 222, 432, 902, and 1296 MHz. These antennas are all veterans of numerous rover expeditions and VHF contests.

By Kent Britain, WA5VJB (WA5VJB@cq.net)

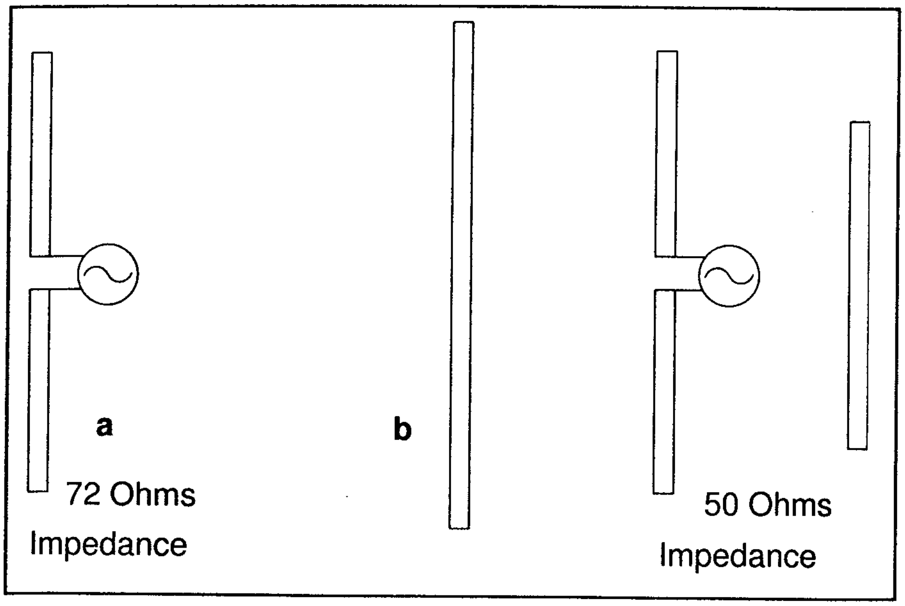


Figure 1. The impedance of a simple dipole antenna (a) is approximately 72 ohms. Adding a reflector and director (b) can lower the impedance to 50 ohms as well as turning the dipole into a three-element Yagi.

"With the wood booms and ground wire reflector and director elements, you can build up a handful of these antennas for about $10."

that my "invention" is at least a half-century old. Zack Lau, W1VT, at the ARRL dug up a book written in 1950, called *Understanding Amateur Radio*. One of its projects was a three-element, 2-meter beam using a "J" driven element. Story of my life!

Designing and Building the Cheap Yagis

The family of "Cheap Yagis" was designed with the *Yagimax* program, tweaked in *NEC* (another antenna design program), and the specific dimensions of the driven elements were experimentally determined on the antenna range. Actually, Yagimax will give you a good "ballpark" indication of the driven element impedance. Since I want to load 150 ohms down to 50 ohms, I designed the antennas for a 17-ohm (that's about 1/3 of 50) driven-element impedance. This wasn't exact, but it was close enough to let me move on to the next step: building models of the antennas and tweaking them on the antenna range. It doesn't take long to get the SWR down to 1.1:1 or lower and confirm the gain numbers. (*For more on antenna ranges, see "Inside an Antenna Range" in the August, 1997, issue of* CQ VHF.*—ed.*) All of the antennas you see in the photos have been prototyped, tested, and are in the air (well, maybe we lost a few of them this spring).

NEC software predicts 11.2 dBi (*decibels over* isotropic, *a theoretical perfect radiator—ed.*) for the six-element version of this antenna at 70 centimeters, 12.6 dBi for the eight-element design, and 13.8 dBi for the 11-element model (Photo C shows the six- and eight-element versions). These gain numbers have held up well in several antenna contests.

"NEC software predicts 11.2 dBi...for the six-element version of this antenna at 70 centimeters, 12.6 dBi for the eight-element design, and 13.8 dBi for the 11-element model....These gain numbers have held up well in several antenna contests."

Theoretically, there is another .5 dB (that's point-five) of gain available...*IF* we went to a more complicated driven element, changed the dimensions to hundredths of an inch (see my pet peeve below), and tweaked for gain instead of a clean pattern. But these guys are cheap, easy to build, and idiot resistant (I know better than to say idiot-*proof*) as is, with perfectly respectable gain figures.

It should be noted, however, that the gain figures are based on using a wood boom. A wood boom not only saves money, it makes several design problems disappear. As a Yagi element passes through a metal boom, the effects of the boom change the element's electrical length. The amount of change depends on the diameter of the boom, mounting method, dielectric constant of the spacers, and a bunch of other stuff. With

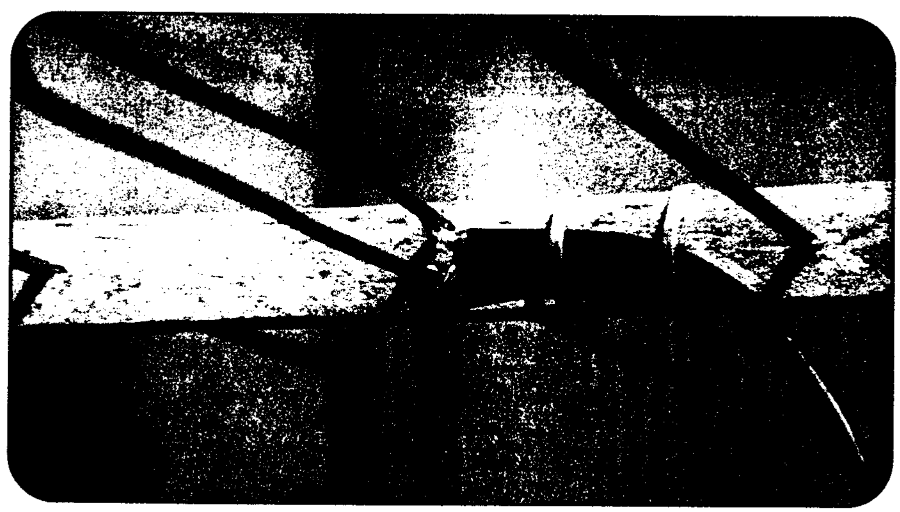


Photo B. A close-up view of the driven element, which is bare #10 copper wire. The shield of the coax is soldered to the center of the element; the center conductor of the coax is soldered to the bottom of the J. The center of the driven element is a null point, so we can solder the coax directly to it without affecting it.

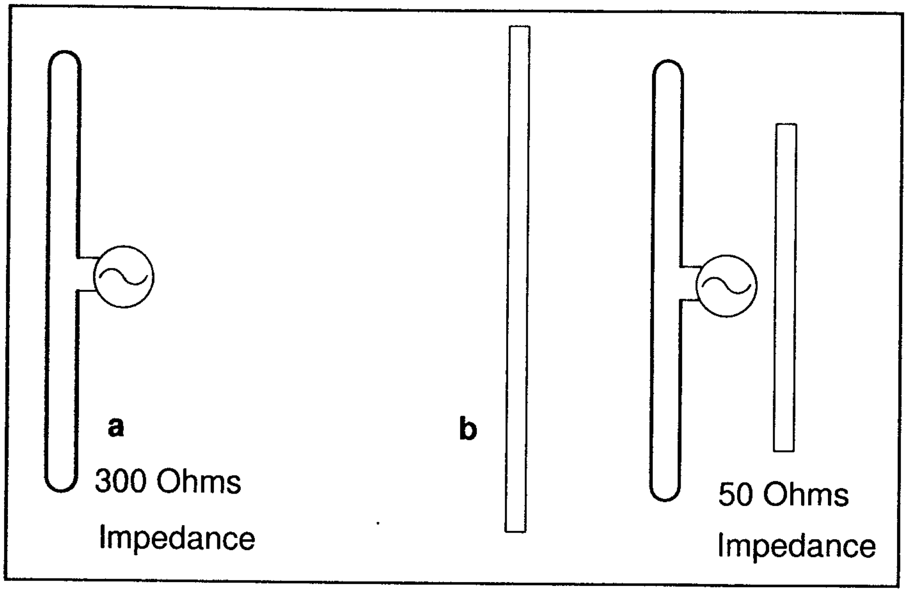


Figure 2. A folded dipole has a characteristic impedance of approximately 300 ohms (a), which can also be lowered to 50 ohms (b) by using the same technique as seen in Figure 1. However, element spacing is critical and the director must be very close to the driven element, making construction difficult.

wood, none of this is a problem. If you want to substitute a metal boom, you're on your own.

Look, Ma—No Balun!

The "Cheap Yagi'" design doesn't use a balun...and doesn't really need one (*a balun is a transformer to match a* balanced *antenna to an* unbalanced *feedline—ed.*). I have tried quarter-wave chokes and ferrite beads on the coax, but I just haven't been able to measure any RF running around on the outside of the coax. If you really believe that your antenna *has* to have a balun, you can

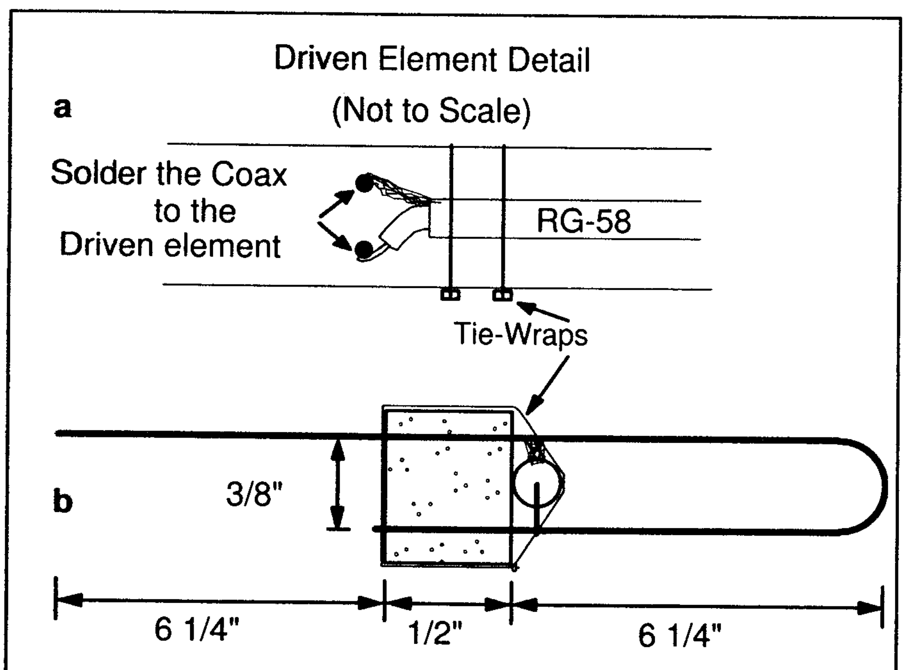


Figure 3. The "J" driven element has a characteristic impedance of 150 ohms and a variety of advantages over dipoles and folded dipoles, as discussed in the text. One advantage is that the feedline may be soldered directly to the antenna element (a). Use the dimensions in (b) to make the driven element for all versions of the "Cheap Yagi" described in this article.

Looking Ahead in CQ VHF Ham Radio Above 50 MHz

Here are some of the articles that we're working on for upcoming issues of *CQ VHF*:

- "A Repeater-Internet Interface," by John Hansen, W2FS
- "High-Speed CW Meteor Scatter—Portable," by Jim McMasters, KM5PO
- "A Wind-Powered Repeater," by Cesar Amaro, NP3H

Plus these equipment reviews...

- ...Cherokee AH-50 6-Meter Handheld, by Heather Hampton, KE6HEY
- ...G3WDG 13-Centimeter Transverter Kit, by Simon Lewis, GM4PLM

If you'd like to write for *CQ VHF*, you may download our writers' guidelines from the *CQ VHF* World Wide Web site at <http://members.aol.com/cqvhf/> or FTP to <ftp://members.aol.com/cqvhf/General> and look for the file, "writguid.txt." Or, you may send a written request along with an SASE (self-addressed stamped envelope) to *CQ VHF* Writers' Guidelines, 25 Newbridge Rd., Hicksville, NY 11801.

Cheap Yagis—the Nitty Gritty

Here are all the dimensions, etc., that you'll need to build your own "cheap Yagi" for 70 centimeters. We'll cover other bands in future columns.

432-MHz Cheap Yagi

Driven Element:	#10 bare copper wire
Boom:	1/2 x 3/4-inch wood
Reflector and Directors:	1/8-inch diameter rod (aluminum ground wire, hobby tubing, or silicon bronze welding rod will all work well.)

Note that the driven element (DE) for all versions is the same. See Figure 3b for details of dimensions. Other abbreviations in the Tables below are for the reflector (Ref.) and the directors (D1-D9). All dimensions below are in inches; spacing measurements are cumulative, and all refer back to the "zero point" at the reflector.

Six-Element

	Ref.	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.5	*	12.5	12.0	12.0	11.0					
Spacing	0	2.5	5.5	11.25	17.5	24.0					

Eight-Element

	Ref.	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.5	*	12.5	12.0	12.0	12.0	12.0	11.25			
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.75	38.0			

11-Element

	Ref.	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.5	*	12.5	12.0	12.0	12.0	12.0	12.0	11.75	11.75	11.75
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.75	38.0	45.5	53.0	59.5

* See Figure 3b for details on driven element dimensions

435-MHz Satellite Version

Same driven element and same materials as the 432-MHz version. Again, all dimensions in inches, and spacing figures refer back to the "zero" point.

Six-Element

	Ref	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.4	*	12.4	12.0	12.0	11.0					
Spacing	0	2.5	5.5	11.25	17.5	24.0					

Eight-Element

	Ref	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.4	*	12.4	12.0	12.0	12.0	12.0	11.1			
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.3	37.75			

11-Element

	Ref	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
Length	13.4	*	12.4	12.0	12.0	12.0	12.0	11.75	11.75	11.75	11.1
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.3	37.73	45.0	52.0	59.5

* See Figure 3b for details on driven element dimensions

mount a few ferrite beads on the coax about an inch from the driven element, or you can build a quarter-wave sleeve/Bazooka Balun (see "Resources"). But I really don't think you'll need one.

In the design process for these antennas, I kept all dimensions to tenths of an inch or even quarters of an inch. This is one of my pet peeves. Recently I saw a construction article for a 20-meter beam. All dimensions were listed to the nearest *1/10,000 inch*! Get real, guys! Antennas should not be that critical to build. Maybe, just maybe, a good machine shop could build this antenna (for a fortune!), but a 1-degree change in temperature would throw off everything as the metal expands/shrinks! This is just someone getting carried away with numbers. As Tom Clark, W3IWI, likes to say, "Why

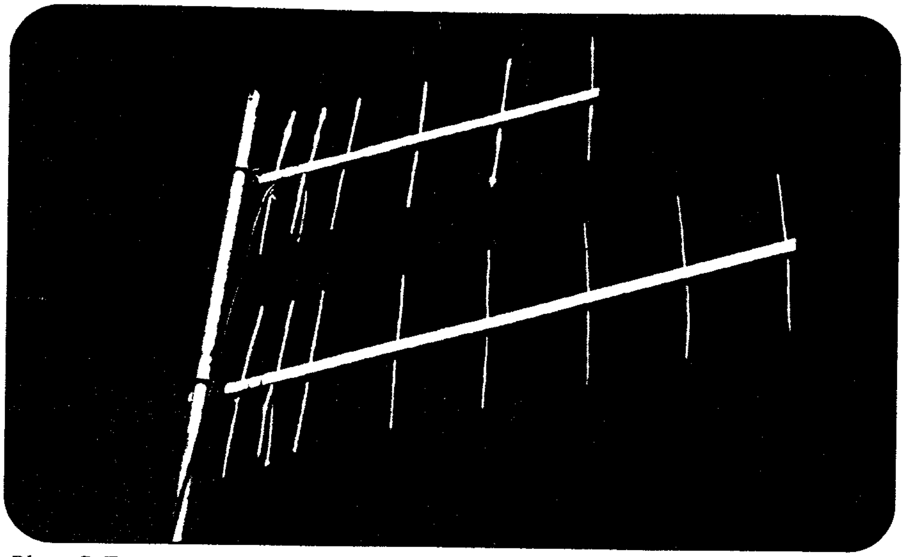


Photo C. Two 440-MHz versions of "Cheap Yagis." With the wood booms and ground wire reflector and director elements, you can build up a handful of these antennas for about $10.

"Why be approximately correct when you can be precisely wrong?"—Tom Clark, W3IWI

be approximately correct when you can be precisely wrong?"

Speaking of dimensions, you'll find all the numbers you'll need for six-, eight- and 11-element versions of the "Cheap Yagi," cut either for 432-MHz SSB/CW work or 435-MHz satellite work, in "Cheap Yagis—the Nitty Gritty."

Using Your "Cheap Yagi"

In general, I don't recommend "Cheap Yagis" for long-term tower use. I had a 902-MHz version of this antenna on my tower for about four years. The weather did get to it after a while, but I put Spar Varnish (available from boating supply stores) on the later versions and they've held up pretty well. Even so, these antennas are not ideal for long-term outdoor service. On the other hand, I have four of them mounted inside my attic for ATV and 1290-MHz repeater service, and they should last until the termites get them. I keep my Rover antennas in the garage when not in use and they've held up well for the last five years. But even if you do leave 'em outside, remember—they'll be as cheap to replace as they were to build the first time!

That's about all for this month. Next time, we'll look at the numbers for expanding your "Cheap Yagi" collection to include 2 meters and 222 MHz.

We Get Letters...

I was really expecting the article on quads (April '98 issue) to generate a lot more feedback. The main point in the letters I *did* receive was that since quads have wire going in both polarizations, then the quad should be all polarizations.

An interesting concept, but you really need to measure the current in a quad loop. The currents on each side are traveling in opposite directions and the fields cancel out. So if you feed the loop at the bottom, the horizontal currents add, vertical currents cancel out. A bottom-fed loop radiates horizontal polarization only. And a side-fed loop radiates vertical polarization only. ■

Resources

A more extensive discussion of "Cheap Yagis" has been published in the *Proceedings* of the 1994 Central States VHF Society Conference, p. 58. Copies are available from the ARRL, 225 Main St., Newington, CT 06111; Phone (orders only): (888) 277-5289 or (860) 594-0355; Fax: (860) 594-0303; Internet: <http://www.arrl.org>.

More information on building a sleeve/Bazooka balun can be found in the "Transmission Lines" chapter of the *ARRL Handbook*. In the 1997 edition, it's on Page 19.15. See above for ordering information.

More Really Cheap Antennas

If you enjoyed Kent's August column on cheap Yagis (and many of you did), you'll love this month's installment, with dimensions for "rolling your own" on 2 meters and 222 MHz.

We've been discussing how to make a high-performance Yagi antenna out of readily available materials and how to do it simply and cheaply. In the last column, we went over the background of these really cheap Yagis; this month, we'll talk about 144-MHz and 222-MHz versions of the Cheap Yagi.

Self-Matching Antennas

The simplified feed uses the structure of the antenna itself for impedance matching. So the design started with the driven element and the other elements were built around it. Impedance matching is accomplished through the loading effect of the other elements, so Gamma, Delta, T, and other impedance matching methods and their complex parts are not needed. Design compromises for the feed impedance, asymmetrical feed, simple measurements, wide bandwidth, the ability to grow with the same spacing, and trade offs for a very clean pattern cost about 1/2 dB of gain. But you can build these antennas for about $5! When it comes to dBs per dollar, you'll find these designs hard to beat!

The antennas were designed with YagiMax, tweaked in NEC, and the driven element experimentally determined on the antenna range. Typically, the three-element version measures 8 dBi gain with a little over 20-dB Front-to-Back ratio. The four-element Yagi measures 9 dBi with 30-dB Front-to-Back, and the six-element beam gives you 11 dBi gain with 35 dB Front-to-Back. These figures are the same for both the 2-meter and the 222-MHz versions.

You can go longer than six elements—W5UN has had good luck with 16-foot-long wood boom Yagis in the past—but I felt that a 6-foot-long, six-element version was about the limit for rover operations and 3/4-inch diameter booms.

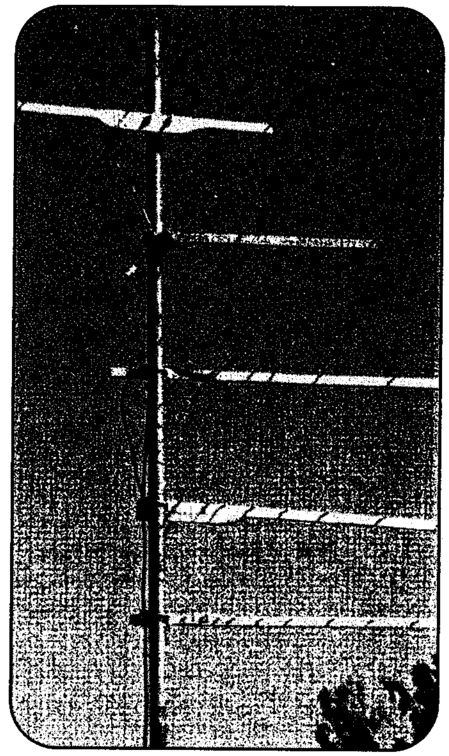
"Design compromises...cost about 1/2 dB of gain. But you can build these antennas for about $5! When it comes to dBs per dollar, you'll find these designs hard to beat!"

Building the Antennas

For the 2-meter and 222-MHz versions of the Cheap Yagi, I used a boom made from 3/4-inch square wood. A drop of Super Glue (or RTV) is used to hold the elements in place. Figure 1 provides the details of attaching your feedline to the driven element, and Figure 2 gives you the details on the 2-meter driven element. Other dimensions and element spacings for the 2-meter version are in Table 1. These measurements provide the best match in the single sideband portion of the band (around 144.200 MHz). To optimize the antenna for the FM portion of 2 meters, simply shorten each element .5 inches.

The dimensional details for 222 MHz are found in Figure 3 and Table 2. Like the 2-meter version, this antenna is peaked for SSB use at 222.1 MHz, but performance is barely changed at 223.5 MHz, the national FM simplex frequency. Actually, the gain is slightly higher at 223.5 MHz, but the pattern is not quite as clean.

My three- and four-element versions are end-mounted (see Photo) and I have two sets of holes drilled in the boom so I can mount the antenna either horizontally for SSB or vertically for FM.



Yes, you've seen this photo before...this time, though, we're interested in the top two antennas on the stack (144 and 222 MHz) instead of the middle one (432 MHz).

As I mentioned the last time, a coat of spar varnish or polyurethane will help these antennas last for years. After portable or rover use, I just store the antennas in the garage, and they still look fine after six years.

Other Materials

The question of using other materials for the boom has been asked by many

By Kent Britain, WA5VJB (<WA5VJB@cq.net>)

TEAR ALONG DOTTED LINE, FOLD OVER, AND TAPE

Table 1. 144 MHz

# of Elements		Reflector	Driven Element	Directors D1	D2	D3	D4
3	Length	41.0	*	37.0			
	Spacing	0	8.5	20.0			
4	Length	41.0	*	37.5	33.0		
	Spacing	0	8.5	19.25	40.5		
6	Length	40.5	*	37.5	36.5	36.5	32.75
	Spacing	0	7.5	16.5	34.0	52.0	70.0

*See Figure 2 for details on Driven Element (DE) dimensions

Table 1. Element dimensions and spacing for the 2-meter "Cheap Yagi." All dimensions are in inches. Spacings are all from zero; NOT *the closest element. Reflector and directors are made out of 3/16-inch diameter material. If you can't find 3/16-inch diameter material and want to use 1/8-inch material for the elements, you need to make the 1/8-inch elements .25 inch longer to compensate for the smaller element material.*

readers. Using PVC pipe for the boom has been a common question. Personally, I've had better luck keeping wood in the air for years than keeping PVC pipe in the air. But as long as you use smaller diameters (I don't recommend 3- or 4-inch pipe for the boom), it will work fine.

A few of you have asked about using metal booms. I'll be talking more about metal booms in future columns, but how the element is attached to the boom, the diameter of the boom, hardware, and even the plastic used in insulated elements, all affect the length of each element. So I've avoided metal boom antennas up to this point. They're more complicated and you have to be very careful to duplicate the design exactly.

Entrepreneurial Spirit

I was at a hamfest in Belton, Texas, a few months ago and there was an enterprising lad selling 450-MHz versions of my Simple Yagi for $25 each (at $25, I didn't feel Cheap Yagi was the proper name anymore). It looked like he did a pretty good business. I kind of asked him how he had the spunk to sell antennas that cost him $2 to make for $25. He just grinned. I don't think he ever figured out that he was chatting with the designer.

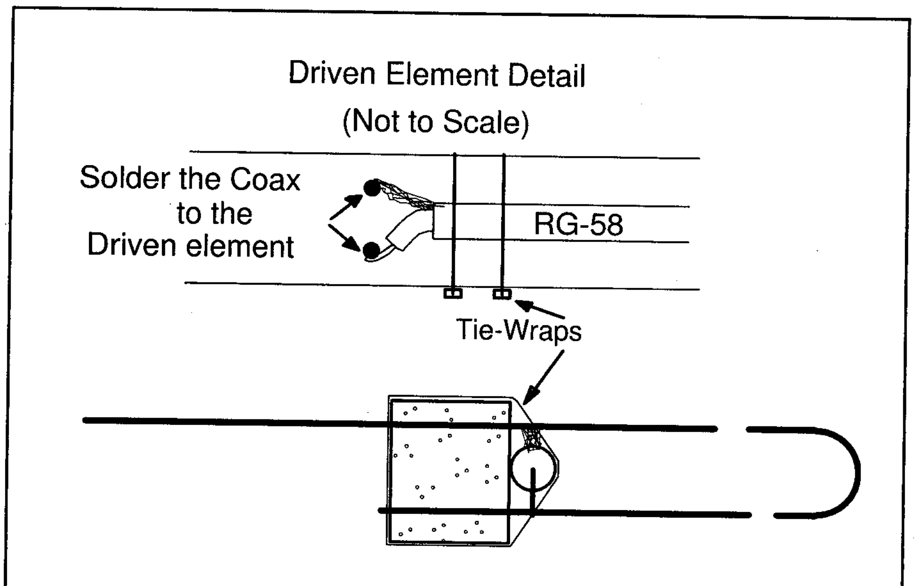


Figure 1. We're not going to repeat August's photo of attaching the coax to the driven element of the Cheap Yagi, so if you can't figure it out from this diagram, you'll have to go dig up your copy of the August issue. The article starts on page 57.

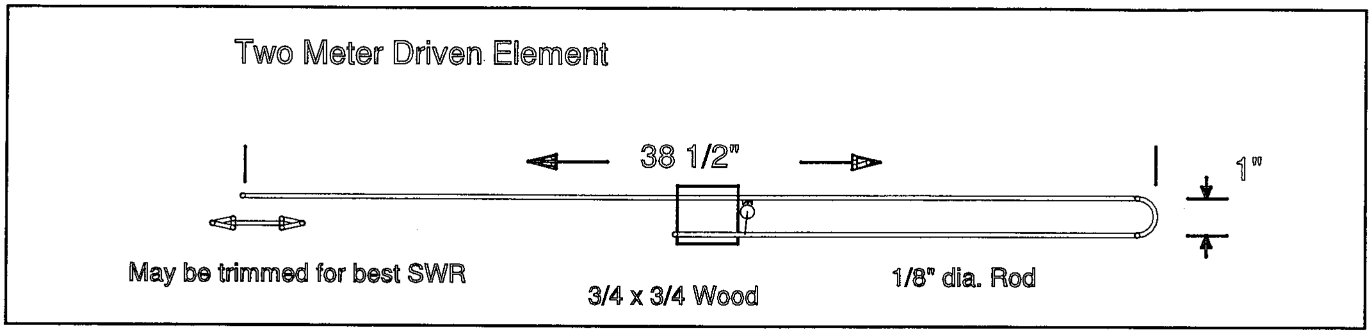


Figure 2. Details of the driven element for the 2-meter version of the Cheap Yagi. Use this in conjunction with the other dimensions in Table 1 to build your beam.

"Like the 2-meter version, [the 222] antenna is peaked for SSB use at 222.1 MHz, but performance is barely changed at 223.5 MHz, the national FM simplex frequency. Actually, the gain is slightly higher at 223.5 MHz, but the pattern is not quite as clean.

Table 2. 222 MHz

# of Elements		Reflector	Driven Element	D1	Directors D2	D3	D4
3	Length	26.0	*	23.75			
	Spacing	0	5.5	13.5			
4	Length	26.25	*	24.1	22.0		
	Spacing	0	5.0	11.75	23.5		
6	Length	26.25	*	24.1	23.5	23.5	21.0
	Spacing	0	5.0	10.75	22.0	33.75	45.5

*See Figure 3 for details on Driven Element (DE) dimensions

Table 2. Element dimensions and spacing for the 222-MHz "Cheap Yagi." As in the 2-meter version, all dimensions are in inches and the reflector and directors are made from 3/16-inch diameter material. Spacings are all from zero; NOT *the closest element. If you want to build this antenna using 1/8-inch material for the elements, simply make the Reflector and Directors .1 inch longer to compensate for the thinner element material.*

Next time we'll cover 900- and 1200-MHz versions of this antenna. The Houston Amateur Television Society, HATS, has built hundreds of them for ATV use. They also work well with 900-MHz spread-spectrum packet and 1200-MHz repeaters or L-Band satellites.

We Get Letters...

Interesting...my brief mention of a 6-meter version of the Cheap Yagi generated the most interest. Unfortunately, I have built only one 6-meter version—it didn't tune up the way it was supposed to. I used parts that are not readily available; and, well, it's not exactly duplicable. So, at least for now, there is only one 6-meter version of the Cheap Yagi; I'm using it, and even I couldn't build another one exactly like it. Maybe some day I'll get a few extra "round-to-its" and get back on that project.

There were also several letters asking about the software program, "YagiMax," by Lew Gordon, K4VX. A downloadable version of YagiMax 3.11 is available at <http://www.qrz.com/files/antenna>. The file name is Yagim311.ZIP. Everyone likes to just dive in and design the highest gain Yagi in the world—I know, I did too. But you'll find it takes a bit more work than that and I highly suggest you read Lew's excellent README.DOC before tackling any antenna designs.

Until next time, 73. ■

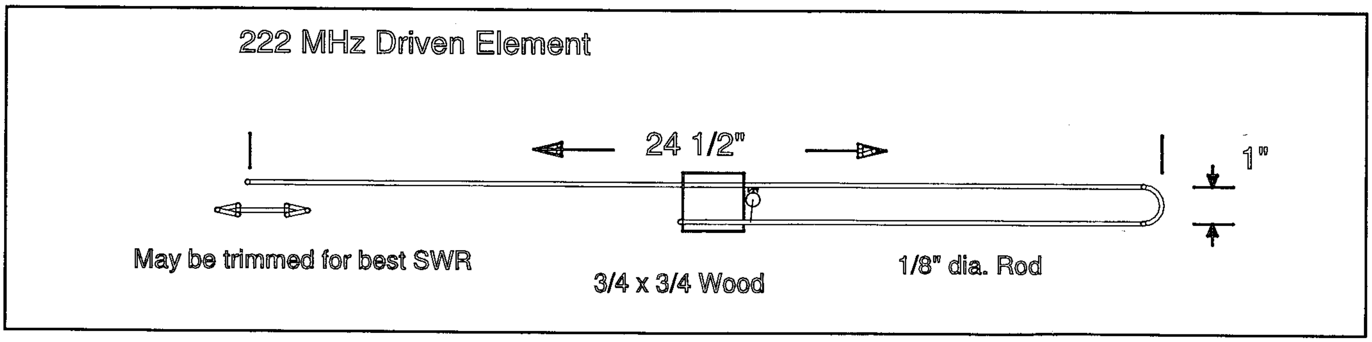


Figure 3. Driven element dimension details for the 222-MHz Cheap Yagi. You'll find the rest of the dimensions for the three-, four-, and six-element versions in Table 2.

More Cheap Yagis

WA5VJB's series on cheap Yagis has generated more "do-it-yourself" enthusiasm than anything else we've published to date. So here are more, this time for 902/903 and 1296 MHz.

If you've been following this column over the past few installments, you know that I first dubbed the antenna design I'm describing here as the "Simple Yagi," and when its low cost became as great a draw as its simplicity, I began calling it the "Cheap Yagi." Actually, its "official" name is the *Controlled Impedance Yagi* because of its wide bandwidth.

My first Controlled Impedance Yagi was made for 915-MHz spread-spectrum systems and used 75-ohm coax. A long-time friend was working for the phone company and had the job of chasing down "cloned" cellphones. He was having a heck of a time running around apartment complexes with his portable equipment and a rubber duck antenna. So I whipped up a short 840-MHz 50-ohm version for him to carry around and the Simple Yagi was born.

The challenge with spread-spectrum is that the antenna must have the same efficiency (for amateur use) from 902 to 928 MHz. Note that I didn't say the same *gain* across the entire band. By peaking the gain of the antenna at the top end of the band, but optimizing the matching section at the bottom of the band, the signals coming out are just about equal over the entire 902- to 928-MHz band. This can be quite important for wideband modes such as spread-spectrum packet and FM ATV (amateur television).

Photo A. A triple stack of Cheap Yagis. The top one is for 1296 MHz and the bottom two are for 902. See text and tables for details on dimensions.

The 33-Centimeter Cheap Yagi

Photo A shows three Cheap Yagis, the top one on 1296 MHz and the bottom two on 902 MHz (the bottom one's longer). You'll find the dimensions and construction details in Figure 1 and Tables 1 (915-MHz spread-spectrum) and 2 (902/3-MHz SSB/CW). The computer predicts only a .04-dB difference between 902 and 903 MHz, so this antenna works well on both calling frequencies (see "A Note on 902- vs. 903-MHz Activity" for discussion of SSB/CW calling frequencies on 33 centimeters). By the way, shortening each element on the 902/903 design by .1 inch will give good 50-ohm performance at 915 MHz.

Movin' on up... to 1296 MHz

A good story on this one: Back in 1994, I had been corresponding with Ed Krome,

Table 1. Measurements for 10-Element 915-MHz Spread-Spectrum Cheap Yagi

Element	R	DE	D1	D2	D3	D4	D5	D6	D7	D8
Length	6.1	*	5.6	5.5	5.4	5.3	5.2	5.1	5.0	5.0
Spacing	0	2.4	3.5	6.0	8.9	12.3	17.2	22.3	27.4	32.5

*Table 1. Element length and cumulative spacing dimensions (in inches) for a 10-element 915-MHz spread-spectrum Cheap Yagi. Element material: 3/16-inch diameter rod; if 1/8-inch material is used, make each element longer by .05 inch, or about 1/16 inch. Typical average performance: 14.3 dBi gain, 25 dB front-to-back ratio. *See Figure 1 for driven element dimensions.*

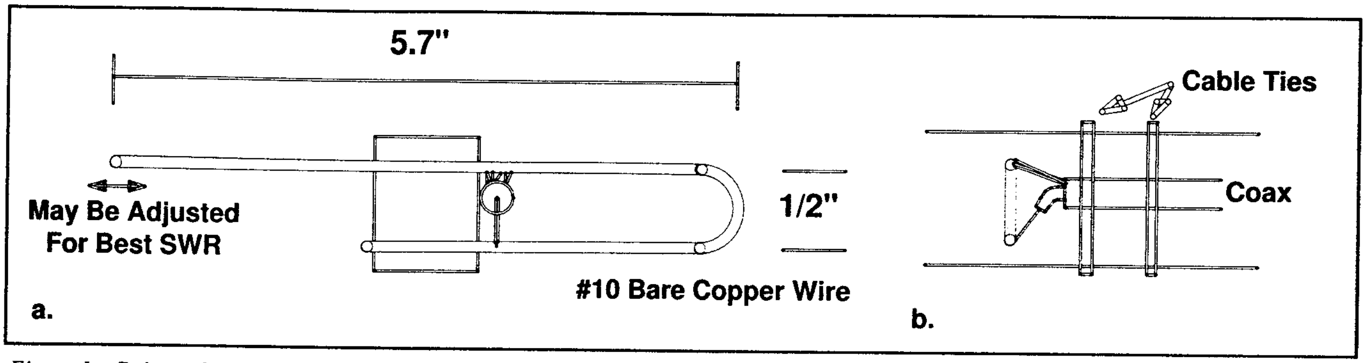


Figure 1a. Driven-element dimensions for all 900-MHz versions of the Cheap Yagi. See Table 1 for other element dimensions and spacings for 915 MHz and Table 2 for 902/903 MHz. Figure 1b. Detail of feedline connection to the 900-MHz Cheap Yagi.

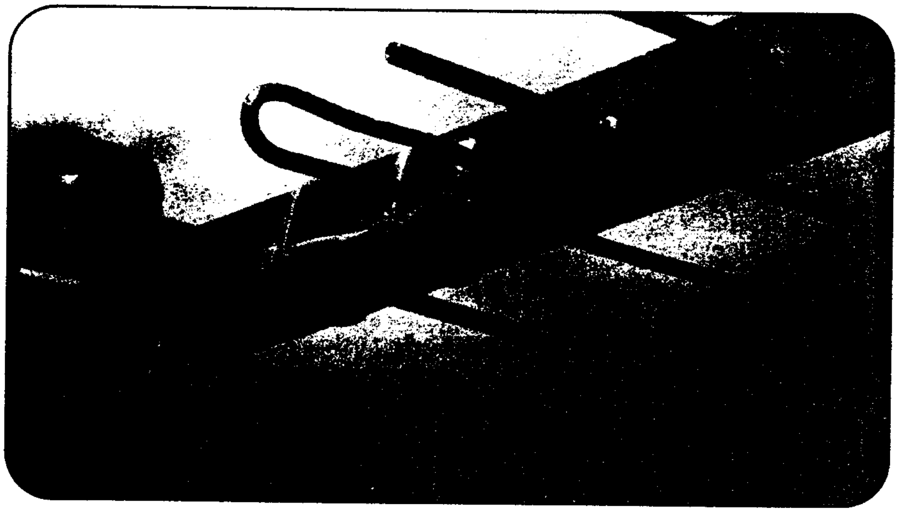


Photo B. Closeup of the feedpoint area of the 1296-MHz Cheap Yagi. I'm using semi-rigid coax as the feedline here, and I recommend it if you can get your hands on it. Can you find the "23 dB RL" notation in the photo? Guess what it means and then go find the discussion in the text to see if you're right.

K9EK, about the 1296-MHz Simple Yagi. Well, Ed also showed up at the Central States VHF Society antenna contest in Memphis, Tennessee, with a 1296-MHz Simple Yagi. He won the 1296 category, beating me by .2 dB *with my own design*!!! At least he proved the design was duplicable.

Figure 2 and Table 3 have all the numbers you'll need to build the 1296-MHz Cheap Yagi. And Photo B is a closeup of the area around the feedpoint. Those of you with sharp eyes will note "23 dB RL" written on the bottom of the boom. This stands for *return loss*. When measured on a network analyzer, the reflected power was 23 dB weaker than the forward power. Return loss is a more precise way of measuring SWR, especially when the values get very low. Twenty-three dB RL works out to about a 1.15:1 SWR. With a little tweaking and fancy test equipment, I've had many of these antennas show 40-dB return loss, or about a 1.02:1 SWR. Of course, the guy at the other end of the QSO is never going to hear this, but it's just fun sometimes to see how low you can go and for no other reason.

Back to Photo B—you may note that I used .141-inch semi-rigid coax. This stuff solders really well and makes an excellent RF connection. I recommend semi-rigid coax it you have it. I've also seen 1/4-inch hardline soldered to the driven element.

Watch That Boom

One problem did show up when the Houston ATV group (HATS) started building 1260-MHz versions. Someone substituted 1-inch square wood for the boom instead of 1/2 x 3/4-inch wood. This put nearly one-third of the element *inside* the wood—kind of like using a telephone pole as the boom for a 2-meter Yagi. This much wood did affect the antenna and shifted the frequency enough to just about kill it on the design frequency. So stay with 1/2-inch-wide wood.

My Secret Tuning Stick

In Photo C, you'll see one of my secret weapons for when I'm working with antennas. It's a stick with a 1-inch piece of element rod taped to one end, and a 2-inch piece of element material taped to the other end. When you place either end of the stick near an element, the coupling effects make the element electrically slightly longer.

When I think I've got an antenna working well on the antenna range, I just place

Table 2. Measurements for 10-Element 902/903-MHz Cheap Yagi with Direct Feed

Element	R	DE	D1	D2	D3	D4	D5	D6	D7	D8
Length	6.2	*	5.7	5.6	5.5	5.5	5.3	5.3	5.2	5.2
Spacing	0	2.4	4.0	5.75	9.0	12.5	17.5	22.5	27.75	33.0

*Table 2. Element length and spacing dimensions (in inches) for a 10-element 902/903-MHz Cheap Yagi with direct 50-ohm feed. Element material: 1/8-inch diameter (silicon bronze welding rod works well). Typical performance: 14.5 dBi gain, 40 dB front-to-back ratio. *See Figure 1 for driven element dimensions.*

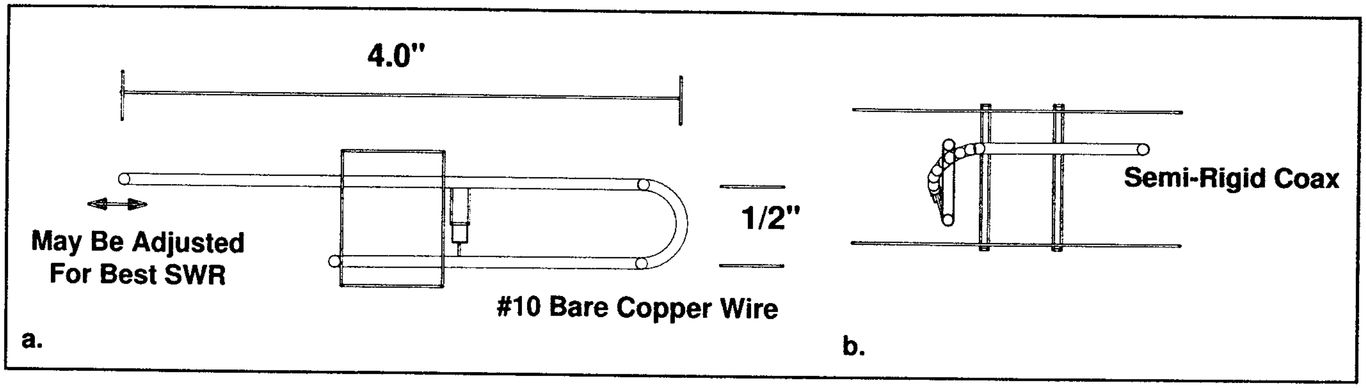


Figure 2a. Driven element dimensions for 1296-MHz versions of the Cheap Yagi. Figure 2b. Optional use of semi-rigid coax.

the tuning stick near each element (Photo D). In theory, detuning each element should make things worse. Well, sometimes (often), placing the tuning stick near the element *improves* gain. So I try again with that element slightly longer. On the other hand, if getting the tuning stick simply near the element instantly makes things worse, I trim off a little of that element and try again.

Table 3. Measurements for 10-Element 1296-MHz Cheap Yagi

Element	R	DE	D1	D2	D3	D4	D5	D6	D7	D8
Length	4.3	**	3.9	3.8	3.75	3.75	3.65	3.6	3.6	3.5
Spacing	0	1.7	2.8	4.0	6.3	8.7	12.2	15.6	19.3	23.0

*Table 3. Element length and spacing dimensions (in inches) for a 10-element 1296-MHz Cheap Yagi. Measured performance: 13.5 dBi gain, greater than 30 dB front-to-back ratio. Element material: 1/8-inch diameter rod. Making each element .1 inch longer will give good performance between 1260 and 1280 MHz for AMSAT, ATV systems, or for links. The F/B ratio will drop to 20 or 25 dB, but the gain will still be 13.5 dBi. **See Figure 2 for driven element dimensions.*

I never publish one of my designs unless it's been tested out on the antenna range. Computer programs are excellent design tools, but they only get you close to the final design. Computer modeling is valuable, but it's no substitute for testing full-size antennas. In a future article, we'll be covering how to use antenna design programs—and what to watch out for so you don't get burned by them.

We Get Letters...

In my last antenna column, I said that I make sure my projects are duplicable before I publish them. Duplicable means I take my early write-up and diagrams over to my friend Terry Turner, W5ETG,

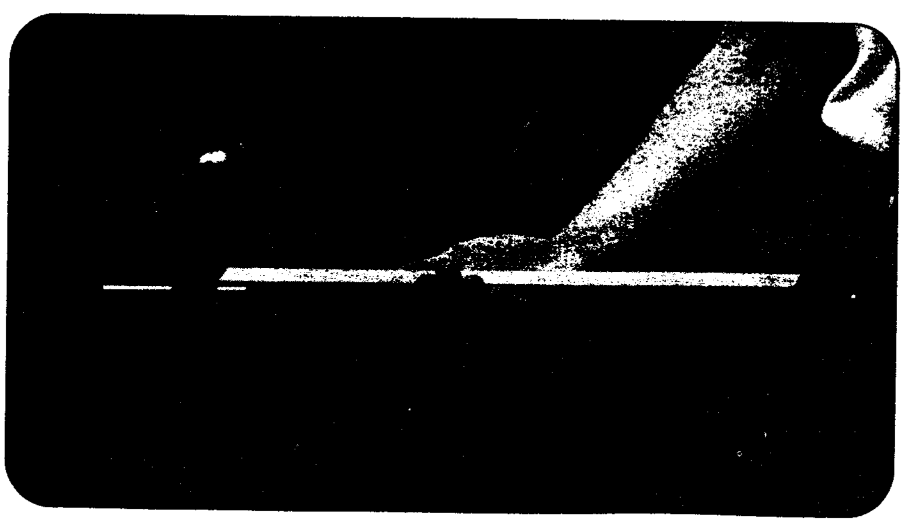


Photo C. One of my "secret weapons" for designing antennas: a "tuning stick" with a 1-inch piece of element material taped to one end and a 2-inch piece at the other end.

A Note on 902- vs. 903-MHz Activity

When 902 to 928 MHz was first opened for amateur use, many hams went for the traditional weak-signal frequency of 100 kHz above the bottom of the band. So, in the midwest and on the west coast, 902.100 MHz became the SSB/CW calling frequency. Up in the northeast, though, it was noted that 144 to *903* MHz converters could use commonly available oscillator crystals. So, much of the northeast activity is on 90*3*.100 MHz.

If you're building a new transverter for our 33-centimeter band, I'd like to put in a plug for 902.100 MHz for a couple of reasons. First, it's easy to tune your 2-meter rig from 144.100 to 145.100 MHz and work anyone using 903.100 MHz. (It's a bit more difficult to tune most rigs down to 143.100 MHz.) Finally, as more and more consumer products are sharing 902 to 928 MHz, the noise level is getting higher and higher. These products have very little filtering, yet are required by the FCC to have near zero output on 901.999 MHz. So the wireless modems, spread-spectrum cordless phones, security devices, etc. tend to avoid the very bottom of the band. In many metropolitan areas, 902.1 MHz is about a full S-unit quieter than 903.1 MHz.

and ask him to build one. Terry then gets back with me and we test it out. He usually has several suggestions on how I can make my instructions "clearer"! If his version works, I print it.

I know many of you are reading this column carefully. I made one tiny comment a few months ago about a 6-meter version of Cheap Yagi, and I received at least 15 inquiries for the dimensions. My 6-meter beam didn't tune up the way it should have, and I used some parts from my junk pile. So even I can't built another one just like it.

But even I can only take so much. I picked up a supply of aluminum tubing and promised a 50-MHz Cheap Yagi in the coming months. The "J" driven element doesn't scale well to 50 MHz, so I'm looking at several other designs. I only promise they'll be simple and cheap! For those of you who can't wait for my 6-meter beam, may I suggest the June '96 issue of *CQ VHF* and the three-element "Featherweight" 6-meter Yagi by K1BQT on page 24.

And finally, I realize some of you want the AMSAT 435-MHz versions *now*! I have a computer design and parts strewn about my workbench for a circularly polarized 435-MHz version to go along with that column. I just ask for the time to build a working model before publishing the plans. So *hold your horses*! Until next time, Happy Holidays and 73.

—WA5VJB

Photo D. The tuning stick in use. By holding it close to the elements of an antenna under test, I can get an idea of whether that element is resonant where it should be, or if it needs more work.

Cheap Circular Polarization? It CAN Be Done!

There are many ways to generate a circularly polarized signal, but you don't have to spend a whole bunch of bucks. The secret? Don't put all the elements on the same boom.

So you want to improve your performance on satellite contacts and you decide you're going to invest in a pair of circularly polarized antennas for the job. But then you look at the price tag, times two, and you think that this just might have to wait.

Have no fear! Cheap Yagi Man is here! Let's see how we can build you a circularly polarized antenna for 435 MHz. But first, let's talk about *why* you'd need a circularly polarized antenna to begin with.

Round & Round the Antenna Goes...

If you've been reading this magazine for more than a month or so, you'll know that the convention for hams on VHF is to use *vertically polarized* antennas for FM work and *horizontally polarized* antennas for SSB and code operating. This means that the antenna elements are vertical on an FM station and horizontal for an SSB antenna. We won't get into the reasons why now, except to point out that *cross-polarization*—in which one station is vertically polarized and the other is horizontal—can result in signal strength losses of as much as 20 dB (decibels). But what do you do when one station's antenna is slowly, but constantly, spinning between vertical and horizontal polarization?

Impossible, you say? Not if that antenna is mounted on a satellite, which spins to maintain its stability in orbit. When the polarization of a signal is constantly changing, your best bet is a *circularly*

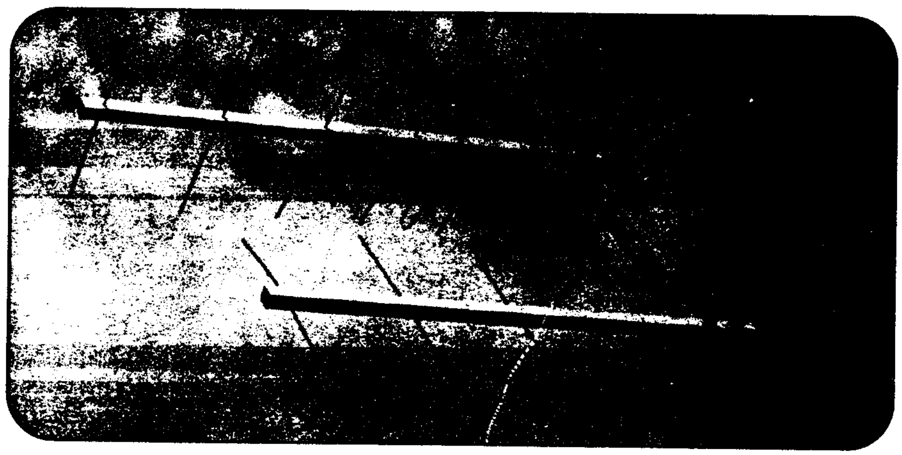


Photo A. Circularly polarized "Cheap Yagis." There's no need to have your circularly polarized satellite antennas on a single boom. Just build one quarter-wavelength ahead of the other, feed them through a phasing harness, and mount them 90 degrees apart.

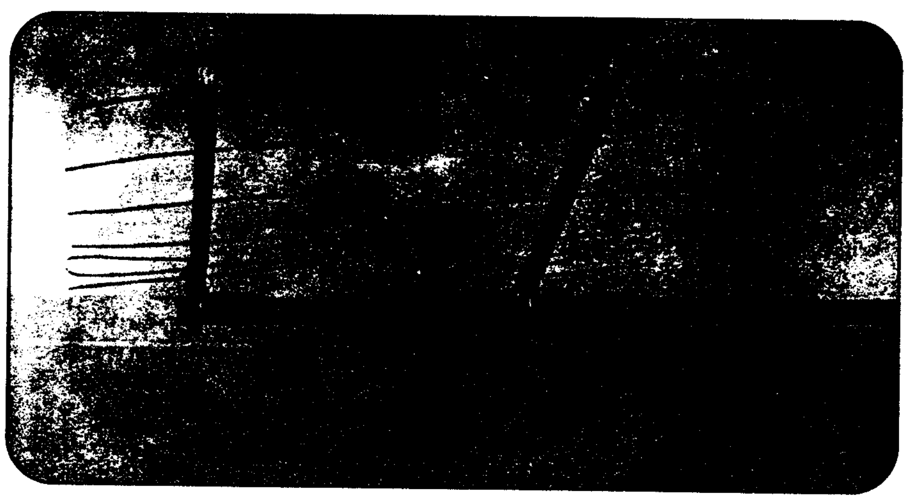


Photo B. Here we're using two antennas, mounted side by side like in Figure 1a. The antennas are in phase and give 3 dB more gain. This is the cheap ham's "stacked array" for terrestrial use. Mount the antennas as far apart as the phasing harness will comfortably allow. For vertical polarization, turn the page sideways.

By Kent Britain, WA5VJB (wa5vjb@cq-vhf.com)

"You can build three sets of these antennas for a fraction of the cost of the coaxial transfer relay that you need [to change polarization] with the single boom designs!"

polarized antenna. Here's how to build one—Cheap Yagi style.

The Cheap Yagi Approach

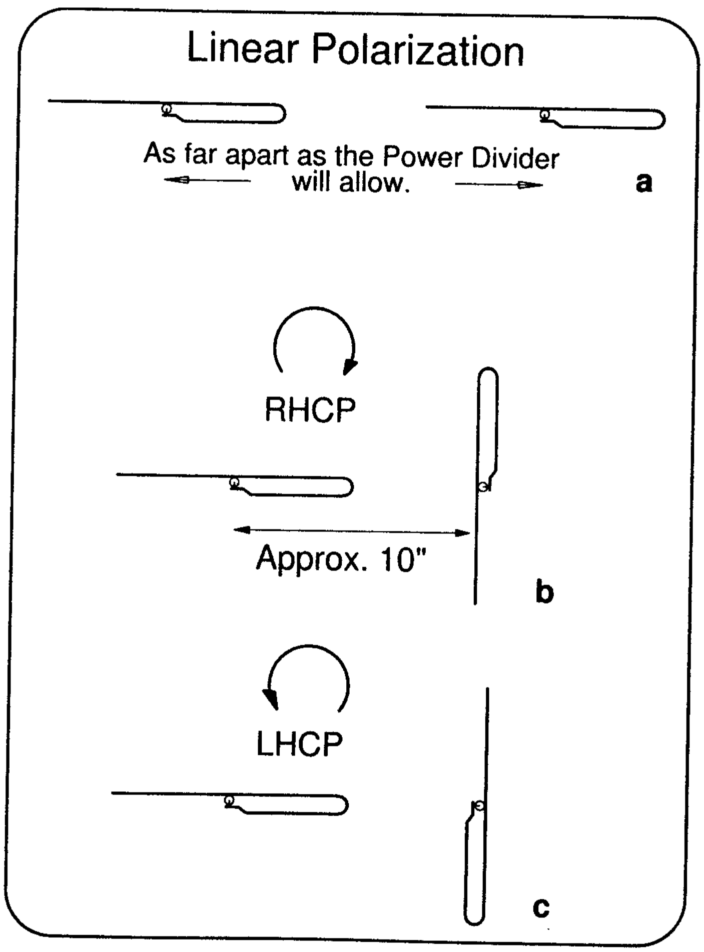
Most circularly polarized antennas consist either of a helically wound coil or of crossed vertical and horizontal Yagi elements fed through a *phasing harness*, a special cable designed to keep the signals in each antenna from canceling each other out! In most cases, all of the elements are on a single boom for ease of feeding and rotating to follow a satellite. *But they don't have to be!* (See Photo A.)

Mounting the horizontal and vertical elements on two different booms means you can use the tools and techniques described in past columns for building Cheap Yagis, and just build two for each of your uplink (transmit) and downlink (receive) bands. You can even "stack" them for terrestrial use. If you look at Photo B, and Figure 1a, you'll see two antennas, mounted side by side. These antennas are in phase and give 3 dB more gain than one antenna alone.

"But why didn't you build everything on one boom?" you might be asking.

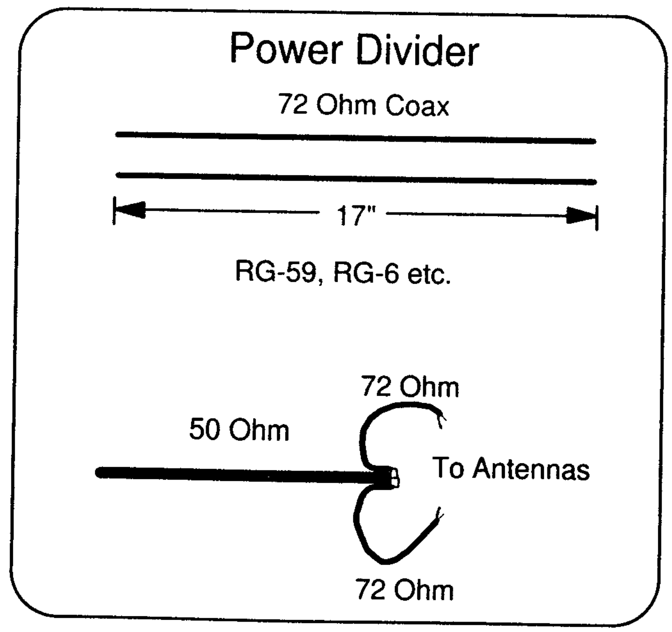
Well, to be able to change polarization, I would have had to use some of those fancy (read *expensive*) coaxial transfer relays. You can build three sets of these antennas for a fraction of the cost of the coaxial transfer relay that you need with the single boom designs! And parts like coaxial transfer relays are virtually unobtainable for satellite operators in third-world countries, and even some areas of the U.S. (If you're a true diehard for single boom circularly polarized antennas, the two antennas can be built on a single

Photo C. The coax splicing might not be up to "professional" specifications, but it works and it most likely presents less loss than using PL-259s. Feel free to use BNC or N connectors. And if you're using the antenna outdoors for extended periods, be sure to use waterproof sealant whether or not you use connectors.



←Figure 1. Arrangement of antennas for different polarizations. In Figure 1a, the elements are parallel for linear polarization and added gain. To achieve right-hand circular polarization (RHCP), as in Figure 1b, turn one antenna 90 degrees, with the folded portion of the driven element on top. Putting the folded portion on the bottom (Figure 1c) produces left-hand circular polarization (LHCP).

Figure 2. A power divider/phasing line is needed to feed two antennas with one signal. For the antennas described here, cut two 17-inch pieces of 72-ohm coax, connect one end of each to one antenna, then splice them both to the 50-ohm feedline from your radio.↓



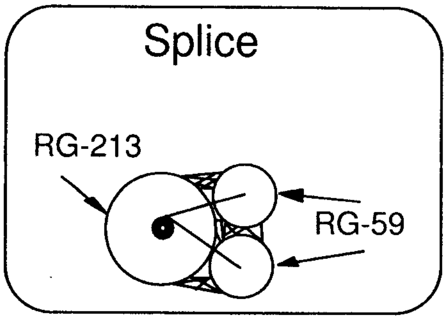


Figure 3. Detail of cable splicing between 50-ohm feedline (RG-213 in example) and the two lines of the phasing harness/power divider (RG-59 in example). BNC or N connectors may also be used.

boom. But there will be a few areas were the elements will be *real close together*. Just build one of the two antennas 6.5 inches farther along the boom than the other and use the same phasing harness as in Figure 2.)

I've included dimensions here for four different versions of this antenna: 6, 8, 10, and 11 elements (see Table). My NEC antenna modeling program predicts 11.2-dBi gain for the 6-element version; 12.6-dBi for the 8-element; 13.5-dBi for the 10-element; and 13.8-dBi for the 11-element versions. The 6-element has as 30-dB front-to-back (F/B) ratio and all the others should be over 40 dB F/B. The biggest field test of these designs was three years ago when N5EM made up an array for Field Day, using 16 of the 11-element versions. I understand they had a killer signal!

Building the Antennas

Please refer back to my previous columns on 70-centimeter Cheap Yagis for the basics of building these antennas. The original "Cheap Yagi" column in the August, 1998, *CQ VHF* is your best starting point, followed by this past February's issue (see "Resources" for information on ordering back issues). Everything is the same except for the element dimensions, which are listed here (see Table). Again, with all the Cheap Yagis, if you want to mount the antennas outside, a good coat of spar varnish, clear coat, or even house paint will greatly extend their operational life. Be sure to leave 4 inches on the back of the boom for the U-Bolt, and leave 6 $^1/_2$ inches more on the back of other boom.

Making the Phasing Harness

The phasing harness that lets you feed both antennas in phase requires a length of 72-ohm coax that is an odd quarter-wavelength long. I tried using a quarter-wavelength power divider, but the cable just wasn't long enough. A $^3/_4$-wave-length power divider worked out quite well. You need two pieces of coax, each 17 inches long. The 17 inches includes the inch or so you use at each end. I used two lengths of RG-59 (remember, the phasing harness is 72-ohm coax, not 52). RG-6 also works pretty well, but it's hard to find any RG-6 these days that's not using aluminum shielding. Copper-shielded RG-6 is OK, provided you can find it. Connect the center conductors of the two pieces of the phasing harness to your 50-ohm feedline, and connect all the shields together as well, but be careful to avoid shorting the shields and the center conductors.

My coax splicing in Photo C and Figure 3 may not be up to NASA specs, but it works. By all means, if you want to use BNC or N connectors feel free to use them; I just wanted to show that you don't actually have to use connectors. My splice job probably has less loss at 435 MHz than PL-259 connectors, which is why I try to avoid PL-259s anytime I can. A little RTV sealant and some electrical tape would be a good idea if you plan to use the antennas outside for an extended period of time. I also used a tie-wrap to keep everything in place once the connections were made.

The main 50-ohm feedline can be any length of coax. I used RG-213, but RG-214 or any other good grade of coax will work. I usually go out of my way to avoid

Table. 435 MHz Satellite Cheap Yagi

	Ref	DE	D1	D2	D3	D4	D5	D6	D7	D8	D9
6-Element											
Length	13.4	*	12.4	12.0	12.0	11.0					
Spacing	0	2.5	5.5	11.25	17.5	24.0					
8-Element											
Length	13.4	*	12.4	12.0	12.0	12.0	12.0	11.1			
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.5	37.75			
10-Element											
Length	13.4	*	12.4	12.0	12.0	12.0	12.0	11.75	11.75	11.1	
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.5	37.75	45.0	52.0	
11-Element											
Length	13.4	*	12.4	12.0	12.0	12.0	12.0	11.75	11.75	11.75	11.1
Spacing	0	2.5	5.5	11.25	17.5	24.0	30.5	37.75	45.0	52.0	59.5

* Driven Element for all versions; see Figure 4

Table. Element dimensions and spacing for 435-MHz Cheap Yagis. All dimensions are in inches, and the spacing uses the Reflector element as "0" inches. Build two of each, feed in phase, and mount 90 degrees apart to provide circular polarization. See text for details.

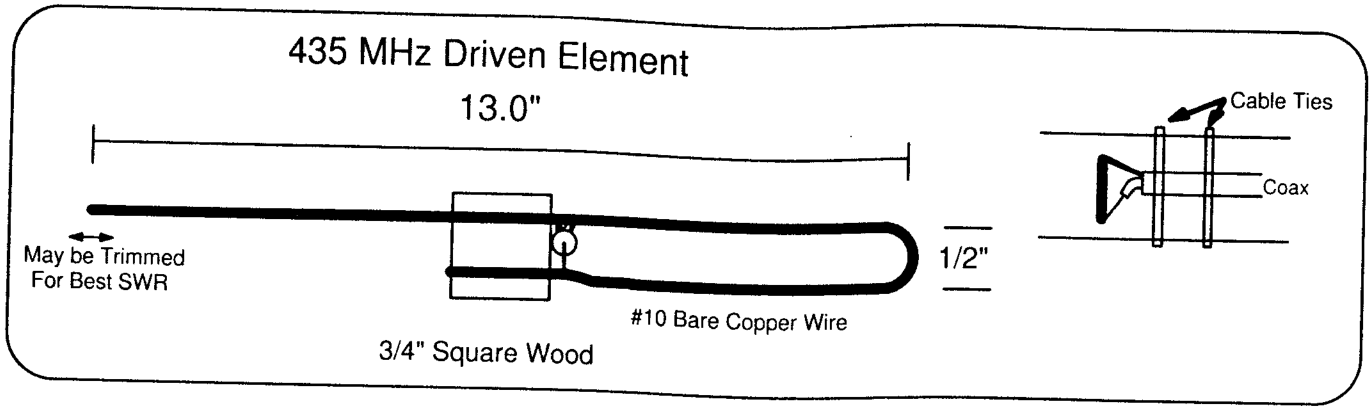


Figure 4. Detail of dimensions for driven element of all the antennas described in this month's column. See Table for dimensions and spacing of other elements.

RG-8 because most of that stuff gets very lossy after a few years. This will probably be a topic for a future article, but I only have one piece of RG-8 in my entire station. (It has terminal lugs on each end and is used to ground a roof top tower!)

Mounting Your Yagis

Mount the antennas as far apart as the phasing harness will comfortably allow. Another alternative is to mount one antenna a quarter wavelength, or 90 degrees (6 1/2 inches) in front of the other one and rotate its polarization 90 degrees (look closely at Photo A). By doing that, we generate a radio wave that appears to be spinning to the right. So the antennas in Figure 1b are *RHCP, Right Hand Circular Polarization.*

Next, we can flip one of the antennas over. This moves the antenna phasing 180 degrees, and presto, we have a radio wave that appears to be spinning *to the left*. So Figure 1c shows the *LHCP*, or *Left Hand Circular Polarization* set up.

Just by changing holes on a U-bolt (Photo D), we have the choice of linear (horizontal or vertical), LHCP, or RHCP polarizations. On Field Day and portable operations, these antennas lie down flat, taking up a whole bunch less space than the single boom CP designs.

Now for the technical guys who are good at picking flyspecks out of pepper: yes, the few inches of horizontal separation between the two antennas does mean that when looking 30 or 40 degrees off axis from the antenna, the antenna is elliptically polarized (sort of an egg-shaped circular polarization). But, hey, the whole idea is to point it where it works best.

What about 2 Meters? (And My Shop?)

Yes, I realize that most amateur satellites operate on two bands, with the most common combination being 435 MHz and 145 MHz (Mode B, Mode U/V, or Mode V/U, whatever your preference). When I started to build up this circularly polarized antenna, I looked around the shop and decided I'd better build the smaller one. Then the question came up, just how many antennas did I have in here? Well, a quick inventory counted 65 antennas in the shop. The depressing part was that was just the top layer! And that's not even counting the antennas out in the shed and the garage! Maybe it's time to do my spring cleaning, for 1985!

"Then the question came up, just how many antennas did I have in here? Well, a quick inventory counted 65 antennas in the shop. The depressing part was that was just the top layer!"

Want a 145-MHz circularly polarized version? Before I add #66 and #67 to the pile, perhaps one of our readers may want to give it a try. Just use the 144-MHz designs from October, 1998, *CQ VHF*. Mount one antenna 19 inches in front of the other. The 3/4-wavelength phasing harnesses would now be 48 inches long.

And before you ask, no, I haven't come up with a "Cheap Az-El Rotator" to help you track the satellites. You're on your own for that one! ■

Photo D. Two pairs of holes for the U-clamp allow the antenna to easily be rotated by 90 degrees to provide any type of polarization that you need (see text for details).

Resources

Back issues of *CQ VHF* are available for $4 each, postage included, to U.S. addresses. Write *CQ VHF* magazine, 25 Newbridge Rd., Hicksville, NY 11801; Phone: (516) 681-2922; Fax: (516) 681-2926. Be sure to indicate which issue(s) of which magazine you'd like, and include check, money order or credit card number and expiration date. We hope to have online ordering available very soon.