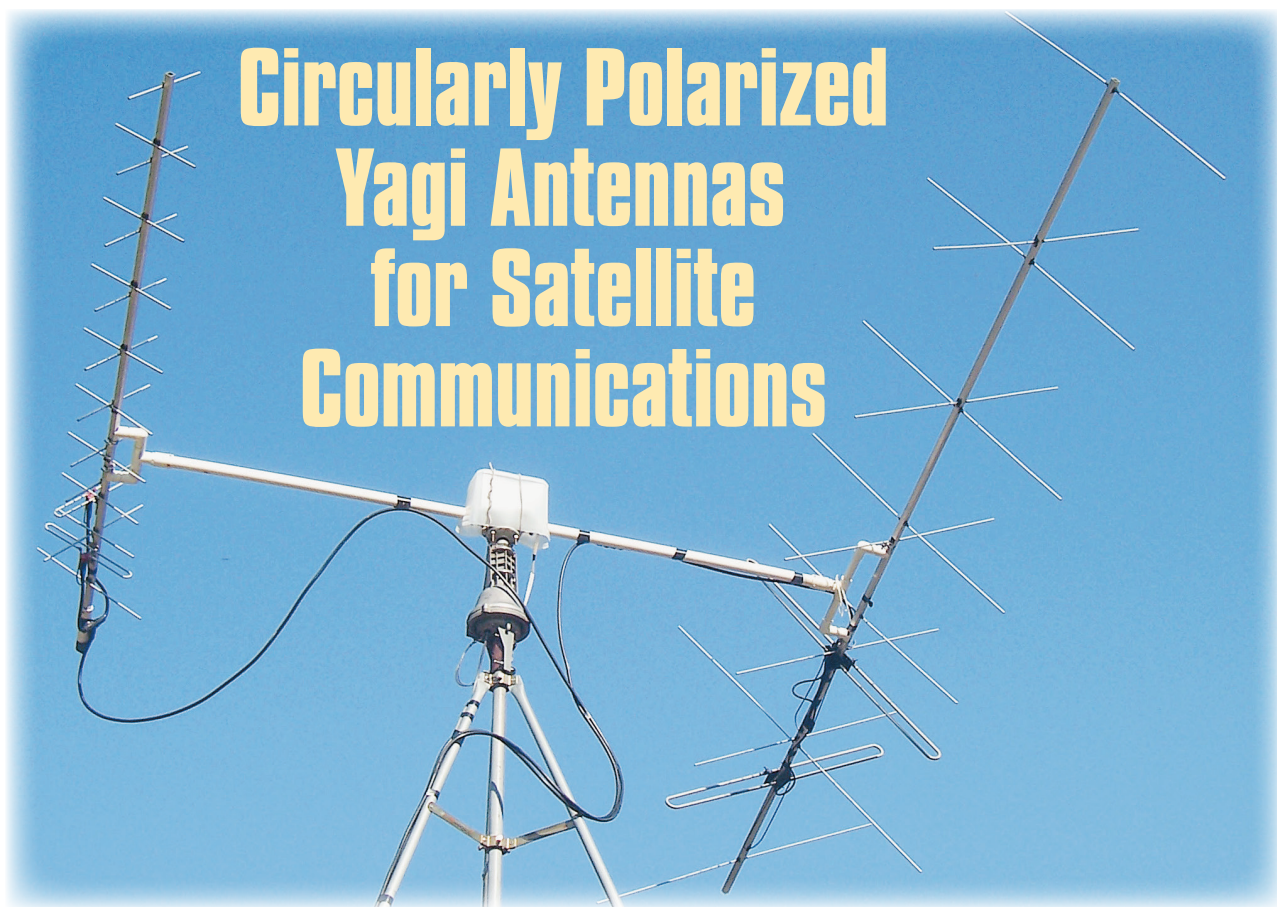


# Circularly Polarized Yagi Antennas for Satellite Communications



*Jim shows us how he makes satcom antennas on a semi shoestring budget.*

**Jim Kocsis, WA9PYH**

**B**ack in 1985 my big interest was VHF weather satellites. To get a really good, clear picture as the satellite neared the horizon you needed a circularly polarized (CP) Yagi antenna designed for a frequency of 137 MHz and pointed at the satellite. I built one and got rock crushing signals until the satellite went over the horizon — it worked great!

## **Amateur Satellites Appear on the Horizon**

Around 2000 my interest turned to VHF and UHF amateur satellites. After several years of mediocre performance from a single seven-element 2 meter Yagi, I decided to improve my antenna situation. I decided that I needed CP Yagis for 70 cm and 2 meters to get good signals from the SSB low earth orbit (LEO) satellites.

In this article I will show you how I built my own CP Yagis for much less than the cost of new antennas.

## **Why Circular Polarization?**

CP is very effective at eliminating signal fading both to and from the satellites. There are

two ways that CP eliminates signal fades:

- It mitigates fading due to spin modulation that occurs as the satellite turns.

- CP eliminates the effects of Faraday rotation as signals pass through the ionosphere.

If a linearly polarized antenna is used on the satellite and the ground station, the signal will fade as the satellite polarization rotates (vertical through to horizontal). I witnessed this firsthand years ago while trying to hear AO-10 with a single plane 2 meter Yagi. When the polarization of the signal matched my antenna, signals were strong. When the signal polarization rotated, the signal dropped out completely — only to return again in a few seconds. With a CP antenna there is much less fading because any rotation results in a constant signal level.

For a full explanation of each concept see *The Satellite Handbook*, page 4-2.<sup>1</sup>

## **System Design**

See Figure 1 for a view of the basic sys-

<sup>1</sup>Notes appear on page 6-16.

tem configuration of my CP Yagis. Note that I have elected to use a folded dipole as the driven element (DE). This has a feed point impedance of 200  $\Omega$ . A 4:1 balun (balanced to unbalanced transition) is used to transform the balanced 200  $\Omega$  impedance to 50  $\Omega$  unbalanced for a coax feed. This is done using a  $\frac{1}{2}$  wavelength section of 50  $\Omega$  coax connected as shown. Circular polarization is accomplished by adding a second Yagi to the boom at a right angle to the first and positioned back  $\frac{1}{4}$  wavelength behind the first Yagi.

The two antennas are then connected through multiple  $\frac{1}{4}$  wavelengths of 75  $\Omega$  coax to a T connector. The 75  $\Omega$  sections perform another impedance transformation. The lengths of the 75  $\Omega$  sections and the  $\frac{1}{4}$  wavelength spacing provide the proper phasing of the signals to generate a CP signal. The two 100  $\Omega$  feed points are connected in parallel at the T connector to result in a 50  $\Omega$  system impedance. It looks like a complex way to get to 50  $\Omega$  but it's simple and it works.

I used chapter 9 of *The ARRL UHF/Microwave Experimenter's Manual*, pages 9-3 through 9-8 to determine the element

lengths and spacing along with the dimensions of the DE for a 70 cm CP Yagi, with elements electrically connected to and side mounted on the boom.<sup>2</sup> If you use the same element diameter, boom size and mounting methods for each antenna you can use the dimensions shown in Tables 1 and 2.

## Materials Needed

There are no impossible to find parts in these designs. If you have a well-stocked junk box of mechanical parts, attend hamfests and have one or more local home improvement stores nearby, you can also build these antennas at low cost.

First things first. These antennas will be much easier to build if square tubing is used for the boom. It is very difficult to drill holes at an exact location on a curved surface unless

you have the needed mechanical skills and equipment.

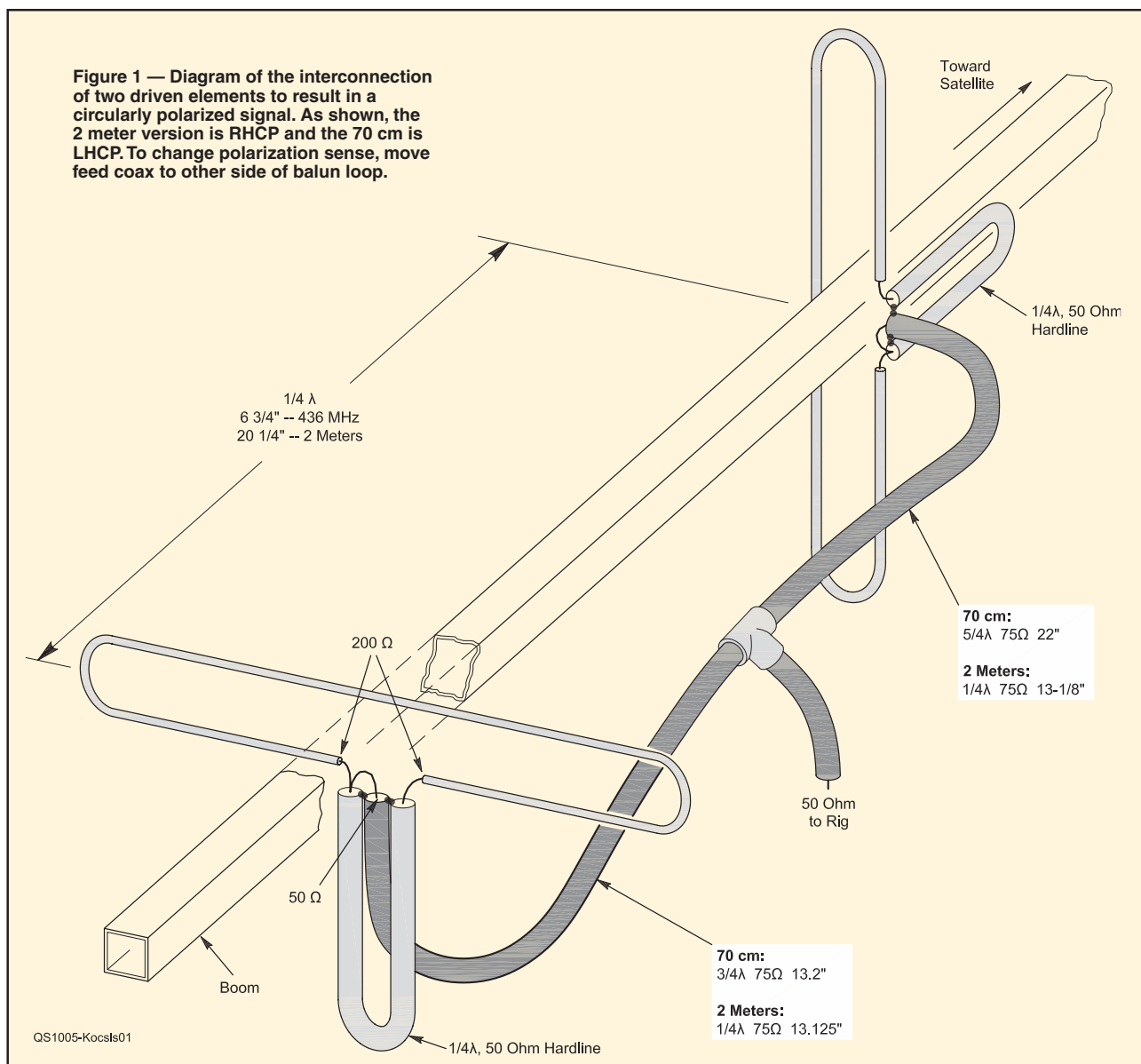
I used insulated through the boom construction for the 2 meter Yagi (see Figure 3) and on the boom construction on the 70 cm antenna (see Figure 4). The dimensions in Tables 1 and 2 reflect those methods using a  $\frac{3}{4}$  inch square boom. For the through the boom method, shoulder washers are needed to insulate the elements from the boom. Nylon shoulder washers are available at a very low price from MSC ([www.mscdirect.com](http://www.mscdirect.com)). Insulating washers made from Celcon are preferred as they withstand UV (sunlight) better, if you can find a source. Tubing in  $\frac{1}{4}$  inch size is available from [www.onlinemetals.com](http://www.onlinemetals.com). They also have  $\frac{1}{4}$  and  $\frac{3}{8}$  inch diameter round tubing available.

The DEs for 2 meters are built using  $\frac{3}{8}$  inch diameter aluminum tubing. The DEs

and all directors and reflectors for 70 cm, are built of  $\frac{1}{4}$  inch diameter aluminum tubing. One source I found is MSCDirect. I also found  $\frac{1}{4}$  inch tubing for my antennas available locally in 12 foot lengths. Check the classified directory in your area for suppliers of the aluminum tubing. Lowe's offers  $\frac{1}{4}$  inch solid aluminum rod in 36 inch lengths for \$3. This will work for a 70 cm antenna but will make it heavier. The solid rod elements will, however, resist bending much more than tubing.

The coaxial connectors, 75  $\Omega$  and hard line coax are available at many hamfests I've attended recently. The Type N bulkhead connectors must be able to accept solder. A silver finish is required. I've seen many at hamfests that are very shiny. The surface is not silver and the connectors may not work in this application since solder will not adhere

**Figure 1 — Diagram of the interconnection of two driven elements to result in a circularly polarized signal. As shown, the 2 meter version is RHCP and the 70 cm is LHCP. To change polarization sense, move feed coax to other side of balun loop.**





**Table 1**  
**2 Meter Seven Element Yagi**  
**Dimensions (inches)**

<i>Element</i>	<i>Length</i>	<i>Distance from Reflector</i>
Reflector	48 $\frac{5}{8}$	
Driven Element	38 $\frac{3}{8}$	15
Director 1	36 $\frac{1}{2}$	21 $\frac{5}{8}$
Director 2	36 $\frac{1}{8}$	35 $\frac{15}{16}$
Director 3	35 $\frac{3}{4}$	53 $\frac{3}{8}$
Director 4	35 $\frac{5}{16}$	73 $\frac{3}{4}$
Director 5	35 $\frac{1}{16}$	96 $\frac{1}{2}$

**Table 2**  
**70 cm 10 Element Yagi**  
**Dimensions (inches)**

<i>Element</i>	<i>Length</i>	<i>Distance from Reflector</i>
Reflector	16 $\frac{5}{8}$	
Driven Element	12 $\frac{3}{4}$	5
Director 1	12	7 $\frac{3}{16}$
Director 2	11 $\frac{7}{8}$	12
Director 3	11 $\frac{13}{16}$	17 $\frac{7}{8}$
Director 4	11 $\frac{11}{16}$	24 $\frac{11}{16}$
Director 5	11 $\frac{1}{2}$	32 $\frac{5}{16}$
Director 6	11 $\frac{7}{16}$	40 $\frac{1}{2}$
Director 7	11 $\frac{1}{4}$	49 $\frac{1}{8}$
Director 8	11 $\frac{1}{16}$	58 $\frac{1}{16}$

to them. Used silver connectors may be tarnished but they will work fine as long as there is no damage to the center pin, insulation or threads. I have listed a source on the QST In Depth Web page that provides non silver connectors that will accept solder.<sup>3</sup>

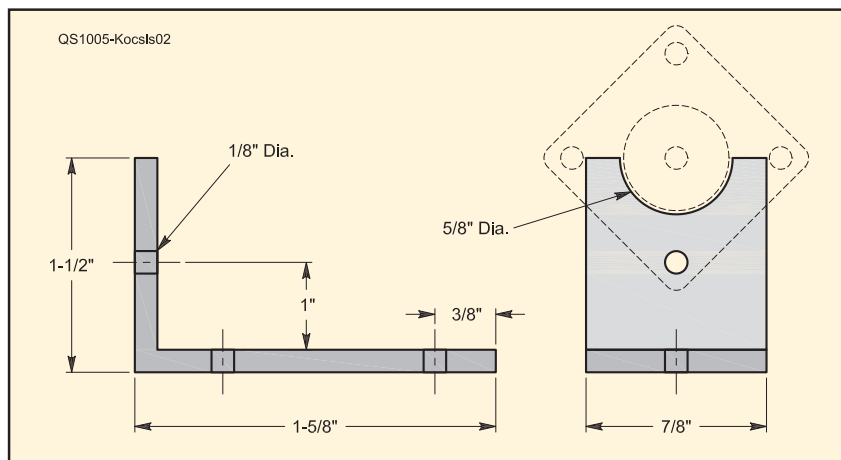
### Construction Steps

The assembly of the first plane is easy. Adding the second is a bit more difficult since the first plane of elements will get in your way. Drill all the holes for both planes before you begin assembly. Add the DE (minus the balun and connector) last as it has parts that can be damaged during installation. If at all possible, get a helping hand to hold the antenna while you're adding elements or suspend it from the ceiling inside your garage with rope at one end while providing support at the other end from underneath to position it at a comfortable working height.

With the offset between the antennas and the element spacing it is likely that there will be a conflict between an element in one plane and an element in the other plane with both needing to occupy the same location on the boom. Of course that's not possible, so the solution is to move one ahead a very small distance and the other back a small distance. There will not be a noticeable loss in performance with these small changes in position.

### Minimizing Waste and Securing Elements to the Boom

Once you've decided on a tubing source,



**Figure 2 — Fabrication details of the mounting brackets needed for the 70 cm antenna. Two are required.**



**Figure 3 — Elements mounted to boom of 2 meter antenna. The director with Celcon insulator and stud/rod detent washer are clearly visible, as is the driven element feed point with plastic plate.**

determine what reflector and director lengths can be cut from each length of tubing to minimize waste. Make a chart of the calculated lengths such as the one in Table 3 and switch things around until waste is minimized. Table 3 shows the lengths I cut from each 12 foot length of  $\frac{1}{4}$  inch tubing to minimize waste. Cut them to length and mark the center of each element clearly with a pencil or marking pen.

### Making the Driven Element

The folded dipole DE construction is the most difficult part of making this Yagi. Calculate the total length of tubing required (including the radius at each end) then add 4 to 5 inches. Mark the center point of the DE. Before making the first DE, practice bending some scrap pieces of tubing so that you will



**Figure 4 — Detail of a 70 cm director mounted to the boom showing clamps, washers and metal tapping screws.**

Table 3

## Minimizing Waste from 10 Foot Sections for 2 Meter Elements (inches)

Section 1		Section 2		Section 3		Section 4 (90°)	
35 $\frac{3}{4}$	Director 3	36 $\frac{1}{2}$	Director 1	48 $\frac{5}{8}$	Reflector	48 $\frac{5}{8}$	Reflector
35 $\frac{3}{4}$	Director 3	36 $\frac{1}{8}$	Director 2	35 $\frac{5}{16}$	Director 4	36 $\frac{1}{2}$	Director 1
35 $\frac{5}{16}$	Director 4	36 $\frac{1}{8}$	Director 2	35 $\frac{5}{16}$	Director 5		
13 waste		11 $\frac{1}{4}$ waste		1 waste		5 waste	

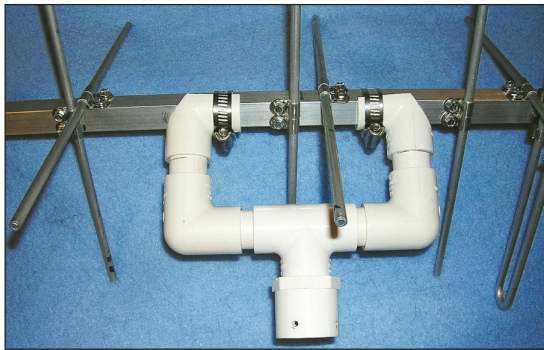


Figure 5 — View of the PVC support assembly for the 70 cm antenna.

know where to start the bend so the completed bend is located properly. Note how it slips through the bender and slightly changes the point at which the bend occurs compared to where you expected it.

This is a very important point. This slip-page will affect the final length of the DE after making the second bend. Allow a few extra inches of tubing at the end of the first bend then put the tubing in the bender for the second bend. Another very important point — make sure that the second bend is in the same plane as the first bend! If the second bend is out of the plane, the DE will be twisted and become scrap — not that I ever did that.

### The 4:1 Balun

The balun is constructed from RG-141, 50  $\Omega$  hardline, for 70 cm and RG-59/U for 2 meters. All junctions are coated with a sealer to keep out water and dust.

Notice that on the 70 cm antenna the feed line going to the coax T fitting exits the antenna at the rear and on the 2 meter antenna the feed line exits forward toward the support cross boom. I did this because the coax and T junctions are large compared to a wavelength at 70 cm but smaller (about  $\frac{1}{2}$  the size) at 2 meters. I routed the feed lines this way because I felt that the presence of a large object in the plane of the antenna could possibly distort the pattern at 70 cm but would be less of a problem at 2 meters. Fabrication details for the brackets needed to support the 70 cm balun are shown in Figure 2.

### Phasing Harness and Offset Spacing

This is probably the hardest part to explain, visualize and understand and so deserves some of your time to study and understand it. The purpose of the phasing harness and offset spacing is to feed the signal from the transmitter equally to both halves of the antenna, but phased so that the signal is launched in a circular pattern with the correct sense of rotation. I accom-

plished it by offsetting the two antennas  $\frac{1}{4}$  wavelength for LHCP then adding a  $\frac{1}{2}$  wavelength in one leg to reverse it to RHCP. Figure 1 shows the placement and orientation of all parts that affect polarization sense.

### Supporting the CP Yagi Antennas

I've read a few discussions about what happens to the performance of Yagi antennas when a metal cross-boom is used for support. The cross-boom (the long cross pipe that goes between the two antennas) can skew the pattern and will affect the circularity of the waveform of a CP antenna. One solution is to use fiberglass rod or tubing since it is not metal. A single 8 foot length costs over \$80 with shipping. A little more research on the Web led me to a site with an article written by Kent Britain, WA5VJB.<sup>4</sup>

Kent ran some experiments to determine the effects of placing a metal mast at various locations along the boom of a single plane Yagi. He also varied the angle between the plane of the antenna and the cross-boom. It is very interesting reading but the bottom line is that a properly placed metal pipe that reaches only the antenna boom (it doesn't go entirely "through" the antenna) and is positioned at 45° to the plane of the antenna will have very little effect on the gain or pattern.

A section of 1 $\frac{1}{4}$  inch outside diameter (OD), 1 inch ID, PVC tubing with  $\frac{7}{8}$  inch OD steel conduit inside for stiffness, is used to support each Yagi near the center of mass to eliminate any torque on the elevation rotator. The steel conduit doesn't extend all the way to the antenna boom — it's spaced a few inches back inside the PVC T fitting so the

effect on the antenna should be even slightly less than that shown on Kent's graphs.

I wanted to have a robust structure at the junction of the cross boom and each antenna's boom. Any metal in the field can affect the performance of the antenna so instead of the typical metal plate and four U bolts, I used several PVC 90° fittings, a PVC T fitting and short sections of PVC pipe jointed together with glue. The two 90° fittings at the antenna must be cut off along one side approximately half way so that the boom of the antenna can slip in place. A stainless steel hose clamp at each end grips the antenna boom tightly. Figure 5 shows the 70 cm antenna with this support.

### Performance

These antennas provide strong signals from the satellite as it travels all the way down to a few degrees above the horizon. They've been up for more than 4 years, have survived numerous wind gusts above 60 mph, show no sign of failure and work as well as the day they went up.

### Notes

<sup>1</sup>S. Ford, WB8IMY, *The ARRL Satellite Handbook*. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9857. Telephone 860-594-0355, or toll-free in the US 888-277-5289; [www.arrl.org/shop](http://www.arrl.org/shop); [pubsales@arrl.org](mailto:pubsales@arrl.org).

<sup>2</sup>Out of print, but available at [www.amazon.com](http://www.amazon.com).

<sup>3</sup>[www.arrl.org/qst-in-depth](http://www.arrl.org/qst-in-depth)

<sup>4</sup>[www.g6ivb.com/fibermetalboom.htm](http://www.g6ivb.com/fibermetalboom.htm)

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