70 cm RG-400 Colinear Repeater Antenna

By
John L Keith
W5BWC
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Introduction.

Searching for a commercial 70 cm repeater antenna led to fiberglass encased coax colinear as the practical choice. However, the price was not attractive, so a search for homebrew coaxial colinear antenna led to several articles listed in Reference Material.

Described here is a coaxial colinear antenna, that many Repeater Owners can build for themselves, which performs equal to, or better than, costly commercial products. Azimuth gain is 8.5 ± 0.25 dBd around 360° at 0° elevation angle. SWR is 1.45:1 at the design frequency for a 14.7 dB RL (return loss).

Built from RG-400 silver plated Teflon coax and housed in a fiberglass radome makes the antenna suitable for most locations. The feed-line is connected by way of a type-N female connector at the base of the radome. IMD (inter-modulation distortion) is minimized by the use of silver plated coax braid and solid copper conductors.

PLA (polylactic acid) spacers center the coaxial elements inside the fiberglass radome, as well as feed-point coax in the decoupling sleeve.

Those with basic knowledge of coax prep, soldering and use of VNA or network analyzer should be able to duplicate the antenna describe here easily. Some cautions, however; all dimension are critical, type-N connector is a must, as shown in Figure 1. and patience are required to assemble the coaxial elements.

Theory.

The antenna consists of eight λ/2 coax sections connected alternately center to shield as shown in Figure 1. Each element is also the feed-line for the next element. The λ/2 repeats the impedance seen at the input with a 180° phase shift. So in order to feed all elements in phase (as required by this design) the center conductor and braid of each coax connection are cross connected.

Each element is both a transmission line and radiator. This prevents the feed-line from interfering with the radiation pattern. The coax transports RF to the next element within

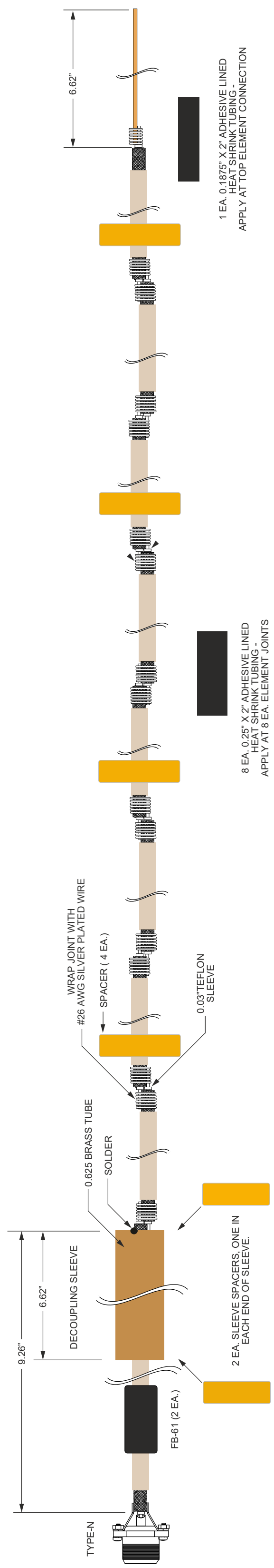

Figure 1. Coax sections, top radiator and decoupling sleeve.

the dielectric between the center conductor's outside diameter and the braid's inside diameter. The radiation takes place on the outside diameter of the braid. The coax element lengths are cut for λ/2 transmission lines - required to ensure 180° phase shift to feed the succeeding element.

This is critical to understand. Some comments on the web indicate that the VF (velocity factor) inside the coax dielectric and the outside braid are different and is a problem, which although they are, is **not**.

The fact is, the coax - as a transmission line must be λ/2 to ensure a 180° phase shift, end to end. This *does* mean the radiator, which is the coax braid, is short of a λ/2, but the only effect this really has is; to lower the radiation resistance slightly, add some reactive component to the feed-point and reduce the radiation efficiency slightly.

The insignificance of less than λ/2 radiators is substantiated by the fact that measured azimuth gain is 8.5 dBd vs 9 dBd theoretical; and includes all losses, including coax dielectric, conductor losses and imperfect phasing loss.

Speaking of phasing, this design has gain (well not really gain) but focusing of the RF field by compressing the otherwise vertical radiation pattern in the vertical plane. For repeater operation, the desired RF radiation pattern is out from the antenna toward the horizon. Radiation aimed above the horizon is mostly wasted.

A horizon looking pattern is achieved, in a vertical colinear, by feeding all elements in phase, such that their radiation patterns combine. The resultant effect is indeed to compress the vertical radiation pattern, again explaining why the coaxial elements must be cut to λ/2 based on the coax's VF, with no concern given to the radiator's fractional wavelength.

Being a balanced antenna, the decoupling sleeve (the brass tube) has two critical roles. First, it provides a return path for RF current in the radiated field. Secondly, it along with the braid of the feed-point coax, form an open-ended λ/4 transmission line. The open end reflects to the antenna feed-point as an RF short (at the frequency it is cut for).

This very low impedance point minimizes the RF that otherwise would be present on the remaining feed-line, headed back to the transmitter. Remember, the coax braid is the radiator on the eight elements. For additional isolation FB (ferrite beads) are added on the input side of the coaxial sleeve.

Element Design.

The design starts with the equation;

$$\lambda = \frac{300}{f} \quad (1),$$

which for a center frequency of $f = 446.3$ MHz is 67.22 cm. However, this is not the dimension to cut the half wave sections of coax.

RG-400 velocity factor (VF) is 0.695 to 0.700. So physical λ length is;

$$\lambda_{PHY} = 67.22\text{cm} \times 0.70, \text{ or } \lambda/2 = 46.71\text{cm},$$

and

$$\lambda/2_{PHY} = 23.36 \text{ cm or } 9.19",$$

and therefore the braid length for λ/2 at 446.3 MHz. Another 0.25" is added to each end to strip down to the center conductor for making the center conductor to braid connection.

Coax sections should be 9.69" stripped to the center conductor on each end by 0.25", with 0.25" braid exposed.

Check that no shield braid fragments are on the dielectric shorting to the center conductor. Figure 4. shows details of coax prep.

Design of the λ/4 stub.

Due to the constraint of having the decoupling sleeve (a λ/4 open ended stub) fit inside the 0.750" I.D. radome, the optimum spacing center to outer conductors is not met. However, a fairly low resistance short is presented at the shorted end of the sleeve, even with the 0.589" to 0.195" ratio of brass sleeve I.D to coax O.D..

Ideally the ratio D/d should be as large as practical to obtain the highest possible Q.

The sleeve needs to be a λ/4 at the operating frequency. The dielectric between the coax braid and the inside of the sleeve is mostly air, however, the outer protective layer of the coax is technically FEP (Fluorinated Ethylene Propylene), sitting directly over the double silver-plated copper outer braid.

This material has a negligible effect on the air dielectric VF because it is only 0.020" thick, compared to the air layer being 0.288" thick. The actual effect can be calculated by using the $\mathcal{E}_r$ of air and FEP along with the thickness of each. The calculation is not shown here, but the result showed the air VF = was lowered by a factor of 0.99. So the PFE effect is ignored.

Thus a simple matter to calculate the sleeve length as;

$$\lambda/4 = \frac{300}{4f} \qquad (2),$$

and,

$$\lambda/4 = 16.8 \text{ cm or } 6.62\text{''},$$

as can be seen in Figure 1. To ensure the air dielectric is the primary contributor to the line length and impedance, spacers are used at each end of the sleeve to center the coax inside the sleeve. Figure 2. shows the spacers for the sleeve.

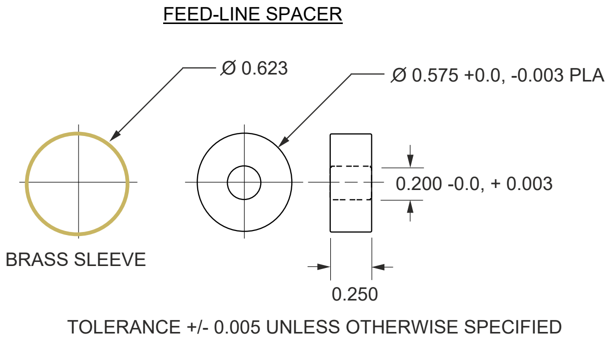

Figure 2. Decoupling sleeve spacers to center feed-point coax inside the sleeve.

The contribution of the spacer VF is not included above, but again due to the small area involved, it is ignored. The spacers fit tightly on the coax, but zip-ties may be used if need, to ensure the spacers stay in place.

The brass sleeve fits inside the fiberglass radome. The situation with inter and outer VF differences is reversed from the coax, with the decoupling sleeve, RF travels on the outside of the sleeve due to return RF current from the radiators.

The fiberglass radome has a small air gap, but in this case more fiberglass than air, so the λ/4 calculation for the open coaxial line makes the sleeve too long when acting as the counterpoise. Again, this is less important than the correct line length for the RF "choke", that is the open ended λ/4 coax line.

To assist in disconnecting the feed-line shield from the antenna, which is hot with RF, 2 ea. FB (ferrite beads) of 61 material are used between the decoupling sleeve and the type-N female connector. The beads are Fair-Rite Products 2631480102, 0.485" O.D, with 0.200" I.D. and 0.500" long.

Feed-point.

The feed-point is where the decoupling sleeve attaches to the coax braid, see Figure 1. A λ/2 length coax is fed through the sleeve which will replicate the actual feed-point impedance, although the reactive component sign will be reversed. Regardless, this is the point at which a matching network will be installed and designed to match this transformed impedance to 50Ω.

Do not expect this antenna, as built, to have a 50Ω feed-point impedance; so plan on a matching network. Once assembled, temporarily attach a female type-N connector to the prepared end of the λ/2 coax to measure the impedance at the desired center frequency. Then calculate a matching network to transform that impedance to 50Ω.

As shown latter in these notes, no matching network is required with the version built from this article.

Radome Spacers.

Radome spacers are used to center the coaxial elements inside the radome. Figure 1 shows the spacers are located on every other coaxial element. Install the spacers before stripping the coax. The spacers fit tightly and are more difficult to install after the coax is prepped. Figure 3 shows the the radome spacers, which are larger than the decoupling sleeve spacers.

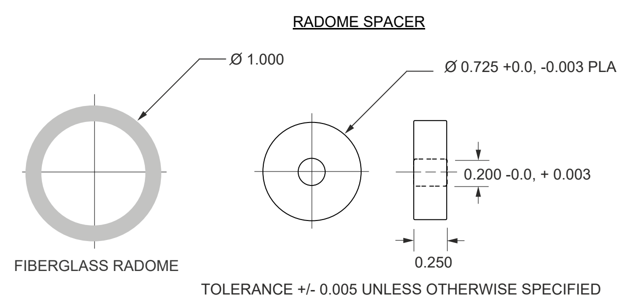

Figure 3. Radome spacers used to center coax inside the radome.

A prior build did not use spacers and resulted in undesirable effects on radiation pattern and decreased decoupling sleeve effectiveness.

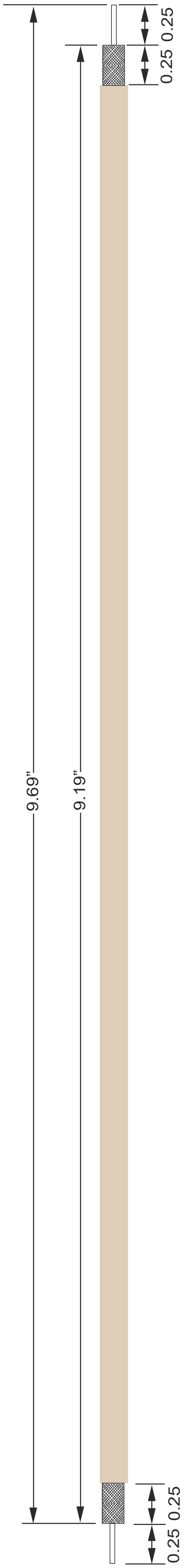

Figure 4. Details of coaxial elements.

Construction.

Now that the design has been discussed, we move on to the actual construction.

1. Refer Figure 4 to cut 8 ea. coaxial elements.

2. Cut the λ/2 feed-point coax per Figure 5.

3. Slide 1 ea. 0.725" spacers onto 4 ea. coax sections. Be sure to alternate these with non-spacer elements when interconnecting them.

4. Slide 2 ea. 0.575" spacers and the 2 ea. FT61 FB onto the feed-point coax.

5. Trim all coax sections to expose 0.25" of braid and 0.25" of center conductor.

Caution:
Inspect cut end of coax, before tinning center conductor ensuring no braid fragments are wrapped around the center conductor.

6. Tin center conductor and braid.

7. Cut a 6.62" top radiator out of bare or silver plated #14 AWG wire.

8. Cut 17 ea. 0.030" spacers from #18 AWG Teflon wire insulation. These provide the separation of the coax braids when interconnecting the elements. *A three bladed coax prep tool may be used in lieu of the spacers, if the blades can be set to 0.030" spacing.*

9. Cut 8 ea. 0.25" x 2" adhesive lined heat shrink tubing to cover the element connections. Note: must apply as elements are assembled, as the spacers prevent installation after assembly.

10. Cut 1 ea. 0.188" x 2" adhesive lined heat shrink tubing to cover the coax to λ/4 wire element.

11. Cut 6.62" length of 0.625" O.D, 0.018" wall, brass tube and de-burr the cut ends.

Figure 6 shows the kit ready to assemble. Take your time, mistakes are more difficult to fix than the effort required to carefully assemble the components.

When lap soldering the element's center conductor to shield, be sure to wrap the joint with #26 AWG silver plated solid wire and solder the entire connection. Do the same for the λ/4 top radiator. Install 0.030" Teflon spacers on center conductors.

Install adhesive lined heat shrink sleeving over each joint and ensure the radome spacers are in place.

Decoupling sleeve is soldered to the feed-point coax braid, see Figure 7. The tube may be crimped down to contact the sleeve, or as shown here, a 0.010" copper shim stock was soldered to the the sleeve and trimmed to fit the radome.

In order to measure feed-point impedance, a female type-N connector is installed on the feed-point coax, temporarily. A short 2mm RF transparent cord was tied around the bottom of the top spacer and pulled out the top of the radome to pull coaxial elements taught. A 2" length of 1" PVC conduit, with cap, is slipped on the top of the radome to hold the support cord tight.

Figure 8 shows the assembly ready to mount in fiberglass radome.

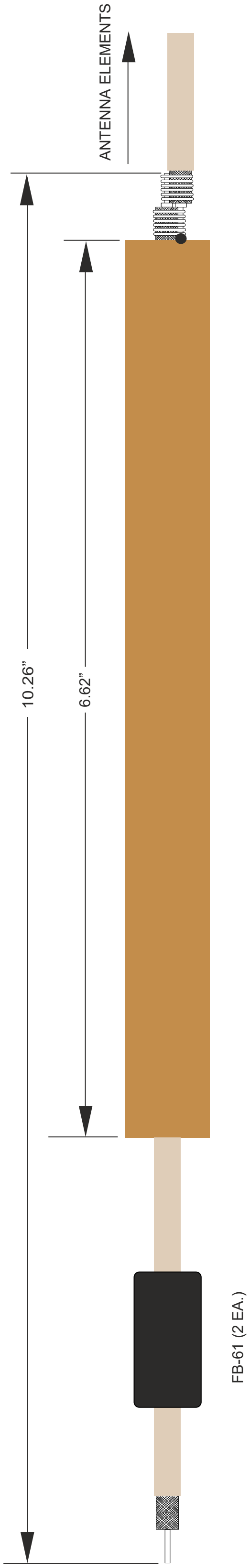

Figure 5. Details of feed-point and λ/4 decoupling sleeve.

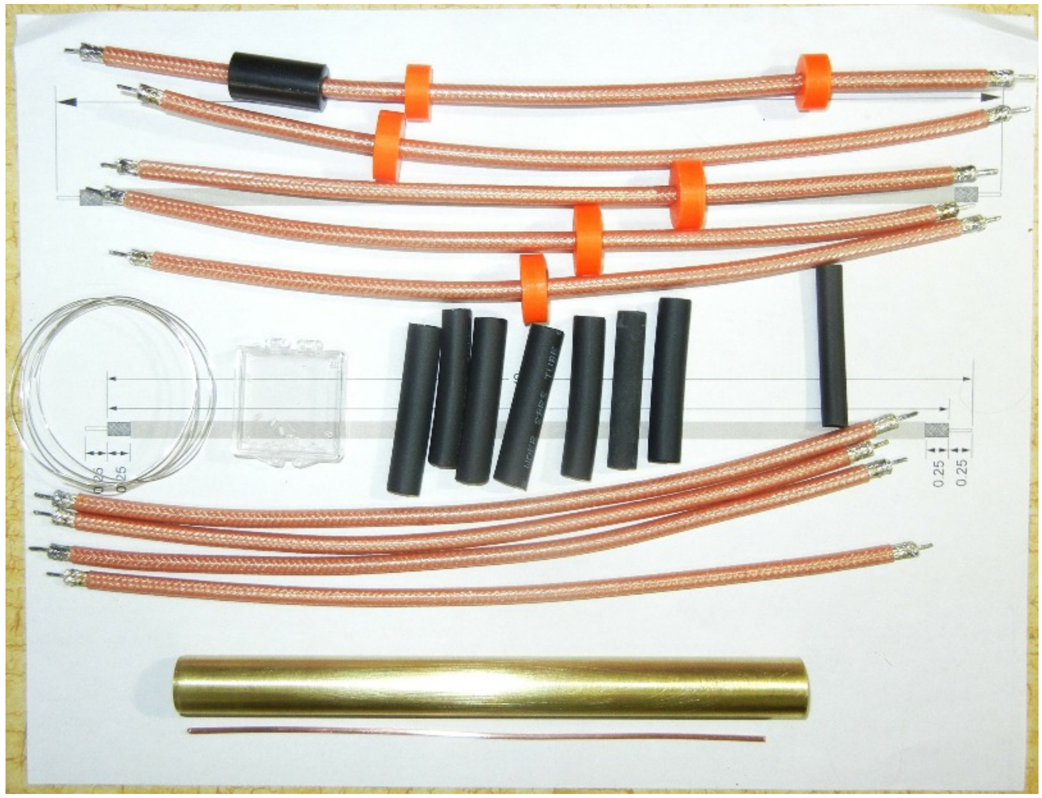

Figure 6. Kit ready to assemble. The small plastic box contains the 0.030” Teflon spacers - they can be a challenge to corral.

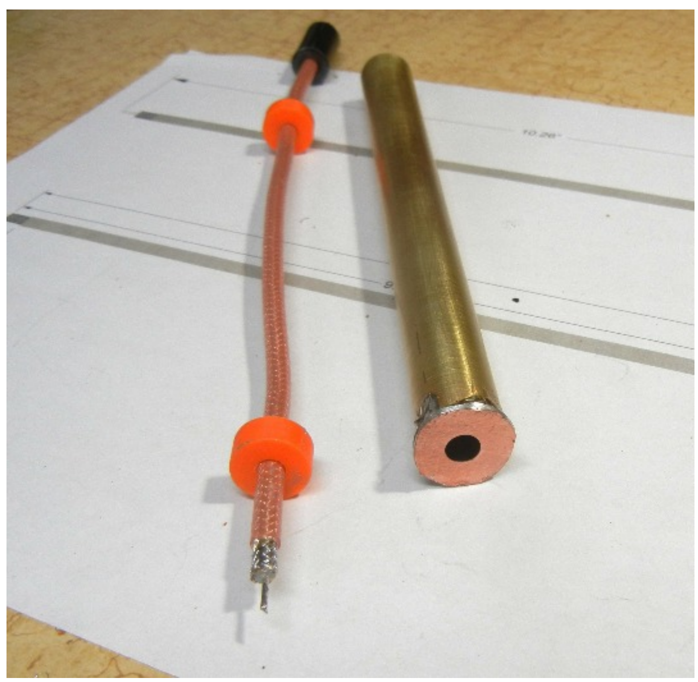

Figure 7. 0.010” copper shim stock used to make sleeve to coax braid connection.

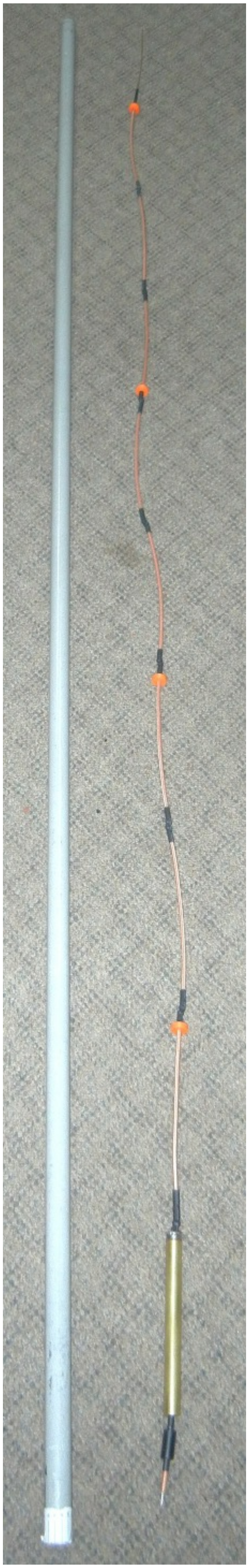

Figure 8. Assembled antenna ready to mount in radome and install type-N test connector.

Far-field RF measurements.

Before gain measurements are made, the SWR is measured for a few different conditions of the antenna. Table 1 lists the conditions and resulting values of SWR and impedance at the type-N feed-point.

Several measurements are made with some observed variations that yield an average SWR = 1.55 across the desired 443.800 to 448.8 MHz frequency range and a 1.45 SWR at center frequency of 446.300 MHz. Figure 9 shows a plot of SWR vs frequency.

Table 1. Antenna SWR and feed-point impedance, as built without matching network.

Condition	Freq.	VSWR	Z	R	X
In Office on chair	443.811	2.49	125.2	125.2	+*j*2.6
	448.811	2.16	79.2	66.8	-*j*42.7
As above w/ 4" PVC	443.811	2.26	113.0	113.2	+*j*2.0
	448.811	2.00	75.4	65.7	-*j*37.3
Re-test above	443.811	2.17	103.8	100.7	-*j*24.7
	448.811	1.98	63.2	52.3	-*j*35.4
Supports in Bay	443.800	1.74	87.1	87.1	+*j*2.9
	448.800	1.74	69.9	64.8	-*j*28.5
On Tower Arm	443.800	1.54	75.2	74.4	-*j*10.7
	448.800	1.49	56.6	54.8	-*j*20.9
Re-cal Re-test	443.800	1.60	78.9	78.4	-*j*9.4
	448.800	1.60	60.6	55.7	-*j*23.8
Resonance	441.70	1.65	82.3	82.3	*j*0.0
Re-cal Re-test	448.300	1.56	76.9	76.5	-*j*8.3
	448.800	1.52	60.7	56.9	-*j*21.2
Center f	446.300	1.45	67.2	65.5	-*j*15.0

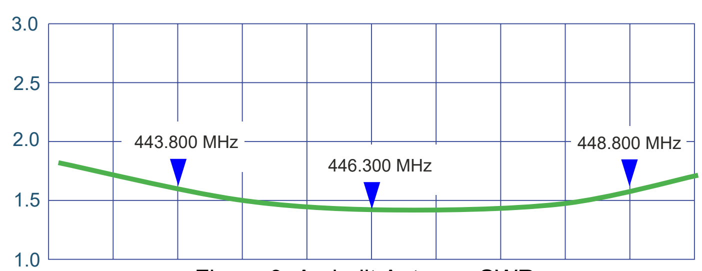

Figure 9. As-built Antenna SWR.

Gain measurements are made with respect to a λ/4 ground plane antenna mounted at 10 feet above ground and 8 feet from supporting tower. The reference antenna is a 5 element yagi mounted at three different elevations to provide -2, 0 +2 degree elevation measurements. Antenna Under Test (AUT) is located 155 feet from the measuring antenna tower, across open field.

Figure 10 shows the receiving, reference and AUT antennas. The λ/4 vertical establishes 0 dBd reference level, fed with a Rigol DSG815 RF generator set to 446.300 MHz and 0 dBm RF level.

All interconnecting coax cables are double shielded. Receive level measurements are made with a Rigol DSA815 spectrum analyzer.

Table 2 shows the measured values of RF level, gain and uncertainty (δ) for azimuth gain with an elevation angle of 0°. The gain uncertainty is a factor associated with atmospheric path level variations, with all other conditions

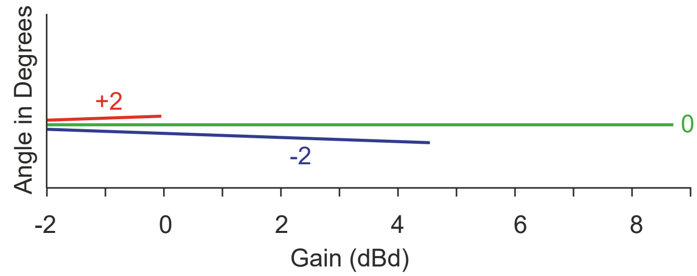

Figure 12. Far-field gain for ±2° elevation offsets.

Figure 10. Left to right; 5 element yagi receiving antenna, λ/4 reference antenna and AUT.

stable. The average azimuth gain at 0° elevation angle is +8.5 dBd. Figure 11 shows the azimuth gain plot. Figure 12 shows vertical gain measurements made at ±2°. The antenna definitely has vertical pattern compression and slight loss of gain in the downward elevation.

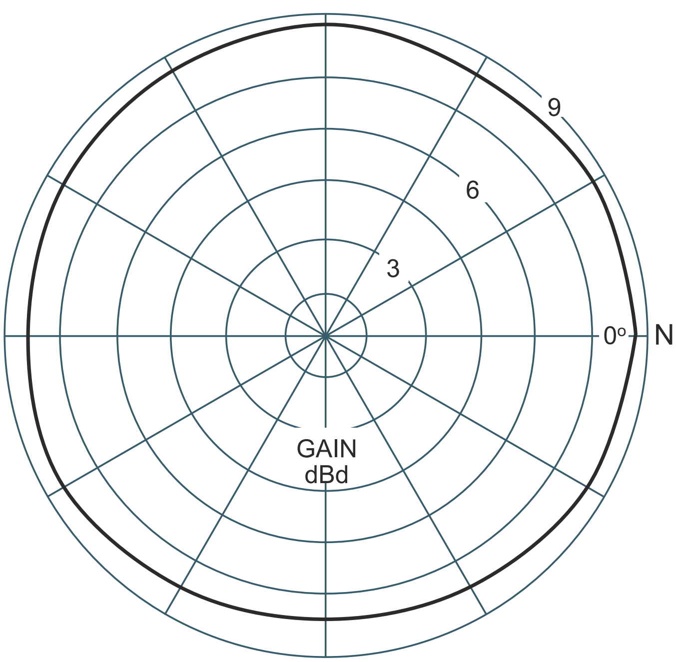

Figure 11. Far-field gain at 0° elevation angle.

Table 2. Azimuth Gain at Elevation Angle = 0°, Reference Antenna Level = -58.2 dBm.

Angle (°)	Level (dBm)	Gain (dB)	Gain ±δ = 0.25 dB(1)
0	-49.6	8.6	8.6
30	-49.4	8.8	8.7
60	-49.7	8.5	8.6
90	-49.4	8.8	8.7
120	-49.6	8.6	8.6
150	-49.7	8.5	8.6
180	-49.9	8.3	8.5
210	-49.7	8.5	8.6
240	-50.4	7.8	8.2
270	-50.4	7.8	8.2
300	-50.1	8.1	8.4
330	-50.4	7.8	8.2
0	-50.1	8.1	8.4

Measurement uncertainty (δ) = ±0.25 dB, data smoothed. Avg. gain = +8.5 ±0.25 dB.

Conclusion.

For general repeater use, this antenna is a cost efficient alternative to pricey commercial products and can be built by many Amateur Radio Operators. Take your time with this project, while easy enough to assemble, the process does require patience and careful work.

This article does not present a step-by-step build procedure, but rather a general overview of the construction project. I suggest the reader incorporate his/her own assembly process preferences.

A closing note, I did not present details of how the type-N connector is mounted to the fiberglass tube, but indeed it must be. Two of the four connector mounting holes were used, with short solder lugs, to connect to the feed-point coax. The other two connector mounting holes may be used to attach the connector to the fiberglass tube.

The reference material guides the reader to where I located the information I used for this project, not necessarily the specific documents.

Reference material and Credits.

1. Special thanks to Kevin Custer, W3KKC, owner of https://www.repeater-builder.com, for his valuable experience and knowledge, which he freely shared.

2. Thanks to James Stull, KB9VQQ for 3D printing radome and decoupling sleeve spacers.

3. https://www.repeater-builder.com

4. https://www.eham.net/

5. Generalized CoCo Antennas
Branislav M. Notaroš,1 Miroslav Djordjević,2 and Zoya Popović3

1Colorado State University, ECE Department, notaros@colostate.edu
2University of Massachusetts Dartmouth, ECE Department, miroslav@ieee.org
3University of Colorado at Boulder, ECE Department, zoya@colorado.edu