An Ultra-Light Yagi for Transatlantic and Other Extreme DX

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On Sunday, July 6, 2014 at 1341 UTC our experimental station VC1T in Pouch Cove, Newfoundland made the first ever transatlantic non-moonbounce 2 metre contact between North America and Europe. We were heard and recorded by John, G4SWX, in eastern England, 3,840 kilometres (2381 miles) east of VC1T! If you would like more information on, and pictures of, this expedition please visit http://www.brendanquest.org/.

Recent analysis by astrophysicist Joe Taylor, K1JT, of the solid digital signal (in WSJT mode FSK441) that John, G4SWX, received from us strongly suggests that its path was via bistatic reflection off the International Space Station (ISS), which happened to be in exactly the right spot – 422 kilometres over the mid-Atlantic – at the "magic moment"!

We – VC1T's members Roger, VE1SKY, Fred, VE1FA, Helen, VA1YL, Al, VO1NO, and Rich, VA1CHP – were disappointed that the contact wasn't by an "all-natural" path, but a transatlantic 2-metre contact via ISS reflection is also a first. In any case, we believe the antenna we used was key to our success. The following article provides the details of the novel homebrew 2-metre antenna that we used to "leap the pond".

THE "LADDER YAGI"

In the March 1995 issue of *QST* magazine Jim, N6JF, reported a 33-element, 2-metre "rope quagi" which used two lengths of rope in place of a rigid boom. In 1996, I put its dimensions into Roy, W7EL's antenna modeling program EZNEC 1.0 and tried to improve its gain.

The result of more than 100 runs (45 minutes each on a 386 computer!) was a 42-element "ladder yagi" with about 20 dBd forward gain. However, during an unsuccessful 2 metre transatlantic attempt from Glace Bay, Nova Scotia in 1996, we found that the big yagi had a problem.

In those strong winds off the North Atlantic, the two 3/8-inch polypropylene rope "booms" and 3/16-inch diameter welding rod directors were too heavy and presented too much wind area, causing substantial sag and skew (sideways movement) over the antenna's 100-foot length – it flapped in the breeze! This of course broadened the main radiation lobe and reduced forward gain by a large and continually varying amount.

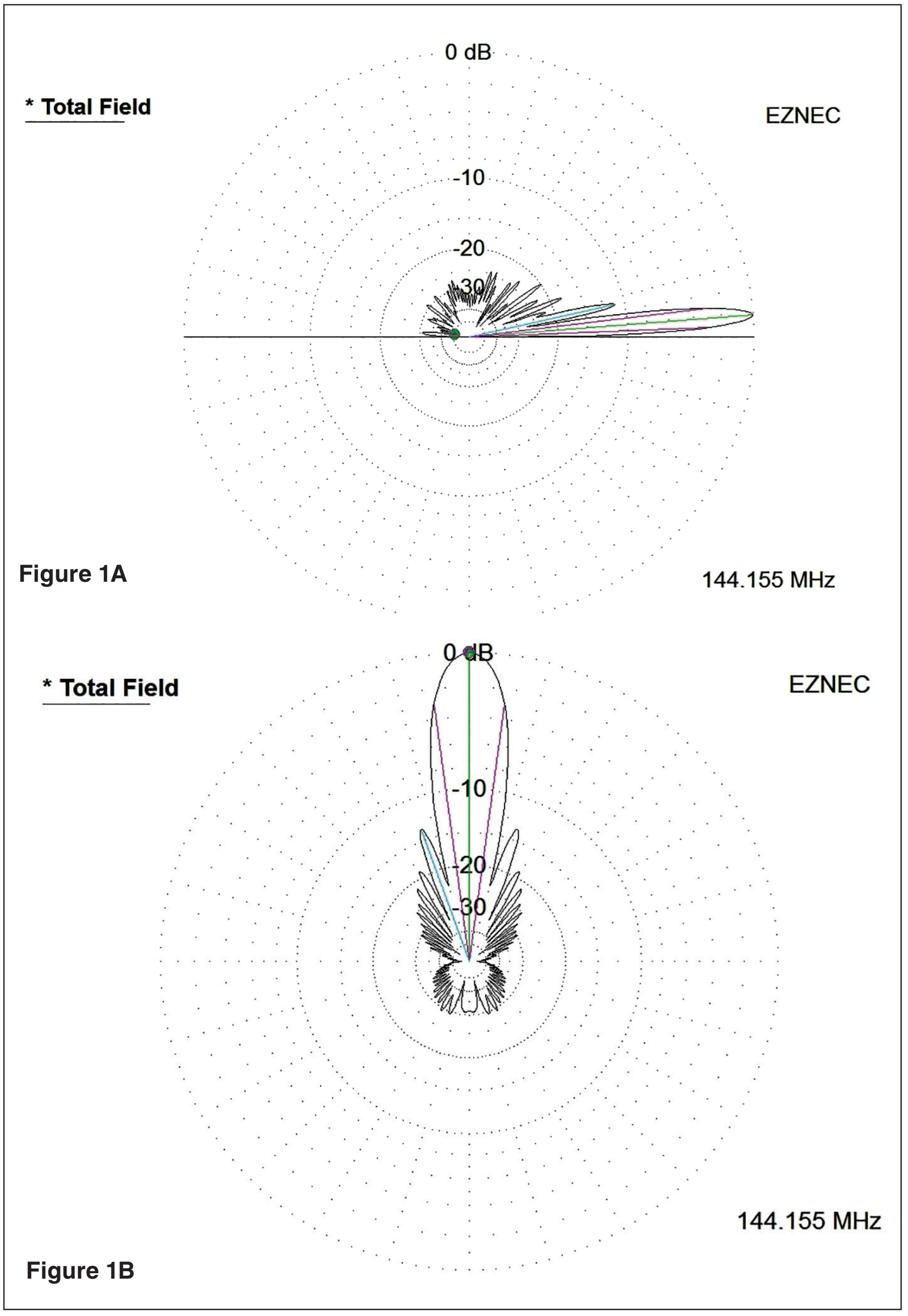

Figure 1: Elevation and Azimuth EZNEC 4.0 plots of the ultra-light yagi's radiation pattern at 144.155 MHz over very good ground. Elevation plot shown (Figure 1A) is at 90° to the major lobe, using a 0.5° step size and showing the 4.5° major lobe thickness at –3 dB points and 4° major lobe takeoff angle relative to ground at the antenna height of 20 feet. Azimuth plot (Figure 1B) is shown at 4° elevation, with the major lobe showing a 15.8° width at its –3 dB points and 26.05 dBi forward gain. All EZNEC calculations used 491 segments.

We also found that polypropylene rope booms are too stretchy for accurate inter-element spacing.

In 2013, Lionel, VE7BQH, posted the dimensions for a similar 43-element ladder yagi online at: http://www.bigskyspaces.com/w7gj/longyagi.htm

Lionel adjusted the lengths and spacing of directors 6-41 and got a better front-to-back ratio and a cleaner forward pattern than our 1996 antenna.

THE 2014 "POUCH COVE" LADDER YAGI

I put Lionel's antenna dimensions into EZNEC 4.0 and made a few further changes. The result is a very clean, high forward gain pattern with a thin, broad, chisel shape, taking off at a nice low "DX" angle (see Figure 1 and Table 1). It's ideal for any 2 metre extreme DX – unless you need to change your antenna's heading!

Table 1: Modeled Performance of the Ultra-Light 43-Element Yagi
Major beam takeoff angle (elevation view): 4.5° at –3 dB points at antenna height of 20 feet above ground
Beam width (azimuth view): 15.6° at –3 dB points
Beam thickness (elevation view): 4.6° at –3 dB points
Front-to-Back (F/B) ratio: 31.2 dB
Maximum forward gain at 4.5° takeoff angle: 26.0 dBi (23.9 dBd)
Frequency * = 144.155 MHz
Feedpoint impedance (Z) = 53.6 Ω +j 4.3 Ω; **SWR** = 1:1.15
EZNEC 4.0 Program settings **Ground:** real, high accuracy, 0.025 S/m; dielectric constant = 20 **Height above level ground:** 20 feet (6.1 metres); using 30 feet (9.1 metres) height gave nearly identical results. **Wire loss:** corrected for aluminum
* **Note:** Any frequency between 143.6 and 145.5 MHz gives similar performance. For example, this antenna used at 145.000 MHz has an F/B of 33.4 dB, a maximum gain of 26.0 dBi, and a takeoff angle of 4.6°. The SWR is nearly flat and below 1.2 between 144 and 146 MHz.

Devising a practical mechanical design that would consistently give us Figure 1's very nice radiation pattern and 26 dBi forward gain, on a shore or clifftop with strong winds and salty spray, was the real challenge.

To reduce antenna wind loading, stretch and weight, I replaced the 3/8-inch (9.53 mm) diameter polypropylene rope "booms" of our 1996 ladder yagi with 3/32-inch (2.38 mm) Kevlar cord, and the 3/16-inch (4.76 mm) diameter welding rod with less than 1/8-inch (3.14 mm) diameter #5356 aluminum alloy rod directors. Alloy #5356 rods are hard, springy and they resist bending fairly well. The entire 220 feet of Kevlar boom cord (see Figure 2) plus the 41 directors only weigh a total of 1.6 pounds (0.73 kilograms)!

CONSTRUCTION

We built the antenna at waist height in my backyard between two steel and wood 20-foot towers 105 feet apart using a pulley bar system and two parallel Kevlar cords (booms) 25 inches (63.5 cm) apart (see Figures 3, 4 and 5). The exact dimensions of this antenna can be found in an EZNEC file on the RAC website at http://wp.rac.ca/table-of-contents-march-april-2016-tca/.

The Kevlar cords were tensioned at 40 to 50 pounds.

All 41 directors were:

1) cut to the exact length

2) two red paint dots 12.5 inches (31.75 cm) each side of centre were added (where each director would cross the two Kevlar "booms")

3) dipped twice in UV-resistant exterior polyurethane varnish for electrical insulation and corrosion resistance

4) fastened onto the two booms with four black tie wraps each

5) Element spacing was carefully measured and adjusted (the tie wraps slide on the elements and Kevlar cord), and the directors were set to 90° with the cord using a carpenter's square

6) Elements were glued in place with polyurethane varnish

Every dimension was kept to +/- 1 mm and checked three times before the gluing. EZNEC modeling showed that element dimensions and geometry are critical, especially around the driven element. After the polyurethane dried, each of the 86 joints was glued again with a drop of "Plumber's Goop" and allowed to cure. No element ever broke loose from the Kevlar cord booms.

Figure 2: Helen, VA1YL, with 220 feet of Kevlar "boom" and the 41 directors. Total weight 1.6 pounds (730 grams).

Both reflector and driven elements were polished, capped 0.5-inch (12.7 mm) diameter copper water pipe. The driven element was also silver plated, with a plastic spacer/feedpoint (a standard CPVC plumbing tee with six inches of pipe for coaxial cable strain relief) in the middle, and brass element length adjustment screws and nuts soldered on the end caps.

When we actually set up the antenna on the cliff edge at Pouch Cove, we found that it had an SWR of 1.2 with these screws set at exactly the calculated active element length so the adjustments weren't needed, but they were cheap insurance! At 144 MHz the skin effect places nearly all the RF current in the surface 5 microns (5 µm) of the driven element so most of the current is in the silver plate, which minimizes RF resistive (I^2R) losses. A cleaned, polished copper surface (like the reflector) should work nearly as well.

Five Chilisin ZLF-110 ferrite chokes on the LMR-400 coaxial cable at the feedpoint gave about 675 Ω of reactance at 2 metres (see Figure 3) to keep RF off the exterior of the feedline. For insulation from wet, salty boom cord and to prevent surface oxidation, both driven and reflector elements were also polyurethane coated. These two heavier, bigger elements, plus the preamp, pulley bar and cables at the feedpoint, are supported and steadied by locking the antenna bar pulleys against the pulleys on the tower pulley support.

Boom tension adjustments are made at the light front (director) end of the antenna where the antenna pulley block is several feet from the wooden tower extension.

To minimize the effects of nearby metal and water on the yagi, the pulley bars were all polyurethane-sealed dry wood, as was the entire top five feet of the forward tower. Thus, by sliding the wood-attaching U-bolts up or down the steel tower legs, the front tower height can be easily adjusted to increase or decrease the main lobe takeoff angle, and to compensate for ground slope. This also removes nearly all metal from the path of the yagi's main radiation lobe.

Once the towers are guyed in place, the pulleys and halyards allow the antenna to be easily installed, raised, tensioned and lowered from the ground. The Kevlar booms are tied to long threaded eyebolts in the rear pulley bar. This allows fine adjustment of the angle of the Kevlar cord to elements to exactly 90°, and easy separation/connection of the antenna to the rear pulley bar for transport. All pulleys, U-bolts and eye-bolts were painted with anti-rust aluminum paint. Dismounted, the 97-foot long antenna rolls up on its front wood pulley bar and is easily transported in a 12" x 12" x 36" cardboard box.

During construction, a boom tension of about 40 pounds (18 kg) gave a sag of only five inches (12.7 cm) in an antenna length of 97 feet. Since the tension on the antenna when erected in Pouch Cove, Newfoundland was considerably higher (each 3/32-inch Kevlar cord has a breaking strength of 800 pounds or 364 kg), there was very little sag or skew. The Kevlar booms also have far less stretch than the old 3/8-inch polypropylene rope, keeping inter-element spacing correct.

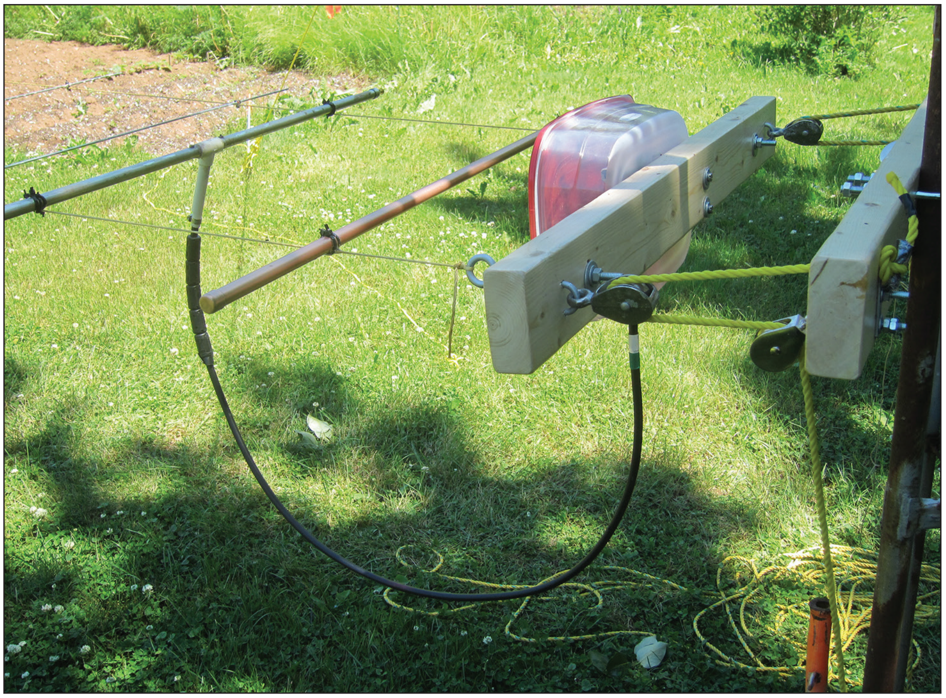

Figure 3: Feedpoint of just-completed yagi. The pulleys provide 2:1 mechanical advantage for tensioning. The plastic box contains the coaxial transmit-receive relay and GaAsFET receive preamplifier. Long eye-bolts through the pulley block allow adjustment of the Kevlar boom-to-element angle to 90°, and easy antenna breakdown for transport. The choke-type balun can be seen on the LMR-400 coaxial cable feeding the silver-plated driven element. The antenna is at waist height for convenience in construction.

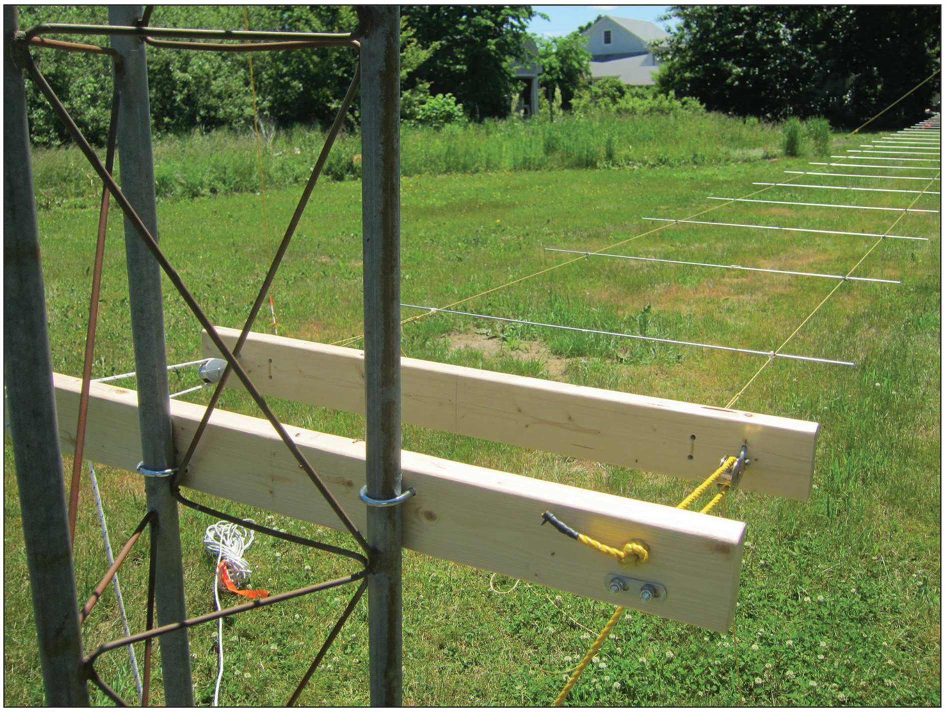

Figure 4: Front end of just-completed yagi, even tensioned to just 40 to 50 pounds. Notice the absence of sag in the 100-foot long antenna.

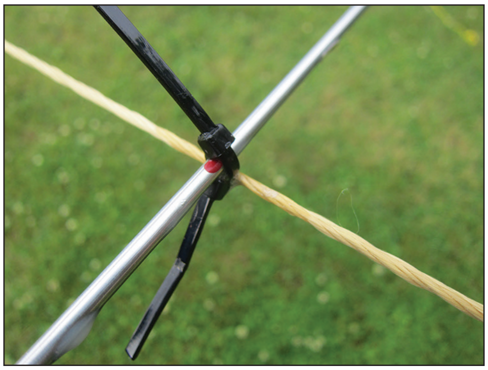

Figure 5: One of the 86 Kevlar boom-to-element joints The two tie-wraps are at right angles to and looped through each other, pulled tight and then coated with polyurethane varnish. Note the slight darkening of the Kevlar cord where it has soaked up the polyurethane to make a strong bond. Later, a drop of "Plumber's Goop" was applied (not shown).

At Pouch Cove in 30 to 40 knot winds, we compared a Cushcraft A-17B2 yagi (17 elements, 31-foot aluminum tubing boom on a guyed mast with a catenary support cord) to the nearby 43-element ladder yagi on its two 20 foot towers. The A-17B2 had far more sag and movement.

As you've probably concluded by now, this antenna is much less expensive and complex than a 40+ element multi-yagi commercial 2 metre array of comparable performance, and most of its components can be found at your local building supply and welding stores! The Kevlar yarn/cord was picked up on eBay for about $18 for 300 feet.

PERFORMANCE

During its week in the sun, rain, salt spray and strong winds of the Newfoundland coast, the antenna performed perfectly until the last day when the CPVC plumbing tee at the driven element feedpoint stretched and allowed the centre of the driven element to sag (see Figure 6). We splinted it with a piece of ABS pipe and polyethylene tie-wraps and resumed operating. Next time, we will use a heavier bit of ABS or Lexan plastic machined just for the feedpoint!

VC1T's experience and transatlantic success in the strong winds of Pouch Cove leads us to believe that, by solving the sag, stretch and skew problems of previous ladder yagi designs, and avoiding the swing and sway problems of conventional aluminum "boomer" yagis, this ultra-light yagi's real forward gain is probably quite close to the high 26.0 dBi given by the EZNEC 4.0 modeling program.

FINAL THOUGHTS

The major lobe (beam) takeoff angle giving maximum signal distance is likely to be the lowest angle clearing nearby obstructions (buildings, hills, dense forests, etc.). To lower this angle you can simply raise the antenna from 20 feet to 30 or 40 feet above the ground. This will also slightly decrease the EZNEC-calculated takeoff angle of this yagi.

At least in this yagi design, simply adding more directors to the 41 we used gives 0.1 dB or less improvement in forward gain per additional director, and the side and rear lobes begin to enlarge. That doesn't mean that a complete redesign with 50 or 60 directors might not be better, but of course the antenna would be much longer, and sag and sway would increase, and the area receiving its signal would decrease.

There are ways to use this antenna on more than one azimuth (bearing). First, remember that the beam is almost 16° wide so from Pouch Cove, Newfoundland it covered the entire United Kingdom, Ireland and parts of Holland at its –3 dB points. Placing one or two additional 20-foot forward towers and pulley block systems at desired bearings to the common rear tower, and using quick-disconnect carabiners in the front ends of the Kevlar booms and adjusting the halyards at both ends, would allow easy, rapid re-orientations of the yagi to cover 50° to 60° of azimuth with no climbing.

Regarding winning a Brendan Award (offered by the Irish Radio Transmitter's Society) for the first successful crossing of the North Atlantic on 2 metres by a "natural" path, we (the VC1T gang) feel that the key factor we lacked was time. One of these ladder yagis, in an automated beacon or beacon-like system that runs for months during the summer sporadic E and meteor shower seasons, probably has a good chance of doing it!

NOTES ON KEVLAR CORD

The 3/32-inch cord used for this ultra-light ladder yagi's booms has five major strands, each of which contains hundreds of extremely fine fibres, making it very supple.

The fine fibres have a high surface area, which the polyurethane varnish grips upon soaking into the cord and hardening; hence polyurethane's strong adhesion to Kevlar. By tensile strength to weight, Kevlar is five to eight times stronger than steel wire. For more information about its properties, search for Kevlar on the Dupont website (http://www.dupont.com) or on Wikipedia.

Many cords and ropes sold as "Kevlar" have Kevlar cores only, and may allow elements attached to their surfaces to move with the jacket and not with the core, so you should use 100% Kevlar cord for dimensional stability as well as for maximum strength

Figure 6: Ultra-light yagi operating in transatlantic service at Pouch Cove, Newfoundland. Notice the adjustable wood top section on the front tower, compensating for ground slope, and the use of five guys per tower to allow substantial tension to be applied to the Kevlar booms. The forward guy ropes on the front tower attach to the steel eye-bolts holding the tower pulley block in place, so the antenna exerts its pull on the eye-bolts and guys, not the wooden leg extensions. The rear tower's two forward legs are not exactly 90° to the yagi's long axis, easily compensated for by adjusting the right and left side antenna-tensioning halyards. The pulley pairs at the feedpoint are locked together so that the weight of the cables, preamplifier, driven element and so on won't cause sway or sag. Tension adjustments are made at the forward end, where there the two wood pulley blocks are several feet apart. We used "seasoned" steel TV towers from a Newfoundland forest, thanks to Joe, VO1NA!

with minimal wind area. As manufactured, pure Kevlar is yellow and darkens and weakens in solar ultraviolet rays over a period of many months to years. If you want a permanent ultra-light ladder yagi, you can dye the Kevlar with black water-based dyes which will block most of the ultraviolet rays, or find a source of dark dyed Kevlar. Online sites sell many varieties of Kevlar cord and rope.

ACKNOWLEDGEMENTS

Special thanks go to Barry, VE1QY, Phil, VE1WT and Kurt, VE1TT (SK) for their help in constructing the antenna in my backyard; and especially to the rest of the VC1T team: Al, VO1NO, Rich, VA1CHP, Roger, VE1SKY and XYL Helen, VA1YL, for making the Pouch Cove expedition a success!

Fred, VE1FA, is a retired research scientist and professor of microbiology at McGill University and the Pulp and Paper Research Institute of Canada. He received his first call sign VE2SEI in 1988 and enjoys DXpeditions, DXing, ragchewing, restoring old radios and introducing "newbies" to our great hobby!