Square Four Aerials

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Yagi-Uda antennas with driven and parasitic wire elements come in many shapes and sizes. Historically, radio amateurs focused on maximum gain that would fit the space and budget, until they began aiming their antennas into cold space and discovered that receive noise floor was often limited by terrestrial noise sources in the side and back lobes. In the 21st century, gain and clean pattern are the criteria. The set of compact antennas described here is small, lightweight, easily taken apart and reassembled, and a convenient size for strapping to a backpack for hiking in to portable locations. Gain is modest and the radiation pattern exceptionally clean. In addition, they embrace an aesthetic that appeals to the technical senses, as did the Ariel Square Four.*

The local 21st century noise environment, dominated by a plethora of digital devices and their switching power supplies, makes urban residential VHF-UHF operation an exercise in frustration. A drive out of town and hike up some hill with a view offers relief from both the cares of daily life and the awful EM noise environment in which we live. Events like Summits on the Air (SOTA) encourage lightweight portable VHF operation, and a younger generation is discovering the joys of the oldest radio experiment: “can you hear me now?” Often no, when the antenna is a rubber duck on an FT-817.

The ubiquitous rubber duck an exceptionally modest antenna that receives equally well in all directions, and local hills tend to be line-of-site to another hill with a forest of high power transmitting facilities. So a clean pattern may be as necessary for portable work as EME. The initial “Square Four” yagi was developed years ago for 2m. It has four elements, and the boom length is equal to the reflector length. It fits in a square. The three parasitic elements poke through a lightweight wooden boom, held by friction, and the driven element was a design puzzle.

A clean pattern, and indeed antenna performance in general, requires decoupling from the feedline. The simplicity of J driven elements is appealing for impedance matching, but appalling from an electromagnetic point of view. I confess to have used them, but my antenna professor D. K. Reynolds literally gagged at the concept.

*The 1952 Vincent Black Lighning represents a pinnacle of engineering, immortalized by Richard Thompson in a song describing an all-too-mortal young man who is carried away by “Angels on Ariels,” leaving young Molly his Vincent to ride. The Ariels ridden by the angels are Ariel Square Fours, a true engineering marvel and evidence that the arts, creativity, and engineering were perhaps more closely entwined in the mid-20th century. The Johnson Ranger front panel...Clegg color schemes...I rest my case.

A half-wave dipole in free space presents an impedance near 70 ohms in the center. Parasitic elements nearby couple electromagnetically, and the arrangement of elements becomes an array with all the far-field radiation from each element adding in phase in some directions and cancelling in others. Since the parasitic elements take energy from the driven element, the drive point impedance goes down. Historically, small yagi antennas have been designed for a drive point impedance near 12.5 ohms, and that is stepped up to 50 with a folded dipole. This is good practice. The resulting currents in the driven element and parasitic elements are symmetrical, and if the feedline follows a right angle path away from the driven element, no antenna currents are induced. A few ferrite beads may be slipped over the coax as a balun, but careful measurements have shown that they are not necessary. Symmetry does the job.

Electromagnetically, coax feedline has two paths: a TEM travelling wave inside, that carries the signal, and the outside of the outer conductor, electromagnetically separate, just a length of wire. That's why you can grab the outer conductor of aluminum hard line with a kilowatt inside and not feel a thing. When the outer conductor of a coax line is in an assymetrical EM field, for example if it leads away from a yagi parallel with the elements or if the yagi antenna currents are assymetrical, the coax becomes part of the antenna. A simple test for feedline decoupling is to tune in a weak signal and grab the outside of the coax a small distance away from the antenna. Nothing should change. If it does, then the coax is an unintentional antenna element. The effects can be quite dramatic with J poles and J driven element yagi antennas.

Folded dipole driven elements are elegant and work well, but present two challenges to the builder of a few antennas: they are hard to mount, and they are impossible to tune. The mounting becomes even more of a challenge when the antenna needs to be easily assembled and disassembled for portable work. The photos show the present solution for the antenna experiments at KK7B. This remains a work in progress. A PC board center insulator clamps to the boom with a screw. U shaped folded dipole halves are soldered in place, and the length trimmed by desoldering and making fine adjustments. The feedline is soldered in place as in photo 1, or attached with screws and nuts.

A feature of Yagi-Uda antenna design is that the parasitic element lengths and spacing from the driven element set the pattern. The amplitude and phase of the current in each parasitic element is relative to the driven element, so you can adjust the length of the driven element last, and it has no effect on the pattern. The traditional approach to yagi design is to adjust the elements for pattern, and then adjust the driven element and its feed network for 50 ohms. A transmatch needs two knobs, because the Smith Chart is a target with a bullseye around the center, and not a line. A simple folded dipole has a length adjustment, but that's it. Fortunately, EZNEC permits getting the real part close to 50 ohms by adjusting parasitic lengths and spacings, and then tuning out reactance by adjusting the folded dipole length.

In practice, the antennas are designed using EZNEC with the constraint that the boom length is nearly equal to the reflector length. Lengths of the elements are adjusted for pattern and a real part of the drive impedance near 50 ohms. With only four elements and a fixed boom length, only the driven element and first director positions are variable and manual optimization of the E and H patterns while watching the drive impedance goes quickly.

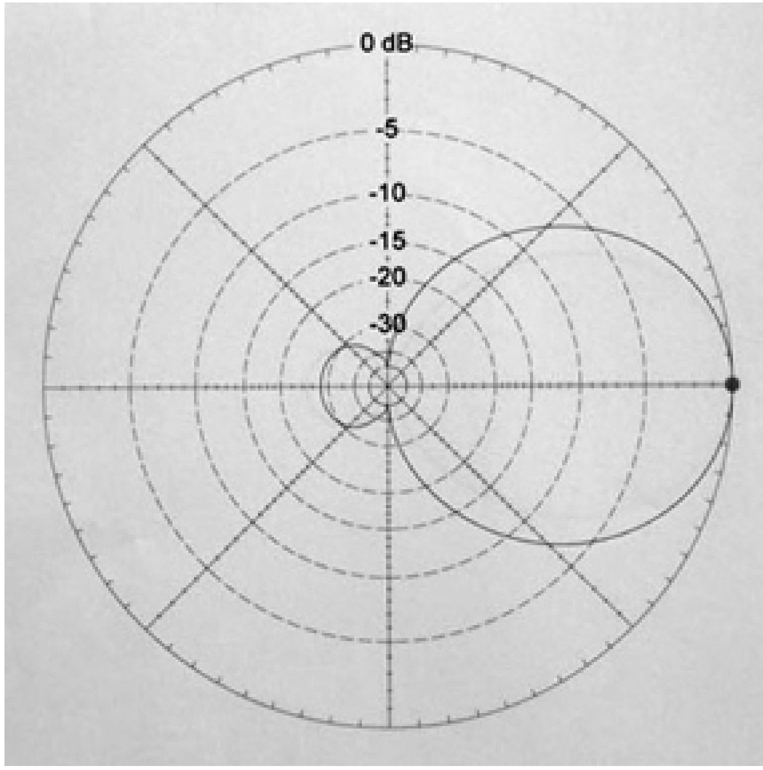
EZNEC is now mature enough that the simulated antenna may be constructed with as much care as possible. The software allows easy exploration of a 1/16" error in the first director length, for example. These antennas all use wood booms, so the conducting boom effect is zero. For different parasitic element diameters, change the diameter in the simulator, observe the pattern, and then change the design frequency up and down until the pattern looks good again. For example, if the original design was optimized at 144 MHz and with a new element diameter it looks better at 142 MHz, then the lengths are a bit long--by about 1.5%. Trim the element lengths by 1.5% and check the pattern again. The design will need to be tweaked a bit more to simulate an impedance near 50 +j0 ohms, but after a few designs with the limited number of variables in a four element square yagi, your design intuition starts to kick in. EZNEC is the best video game ever, and time spent at the basic levels pays of with longer yagi designs.

The 4 element yagi is useful on its own, but it is also a good starting point as the launch for a long yagi or as the feed for a shallow dish. They may be combined in arrays, but one more element on a significantly longer boom achieves nearly 2 dB more gain.

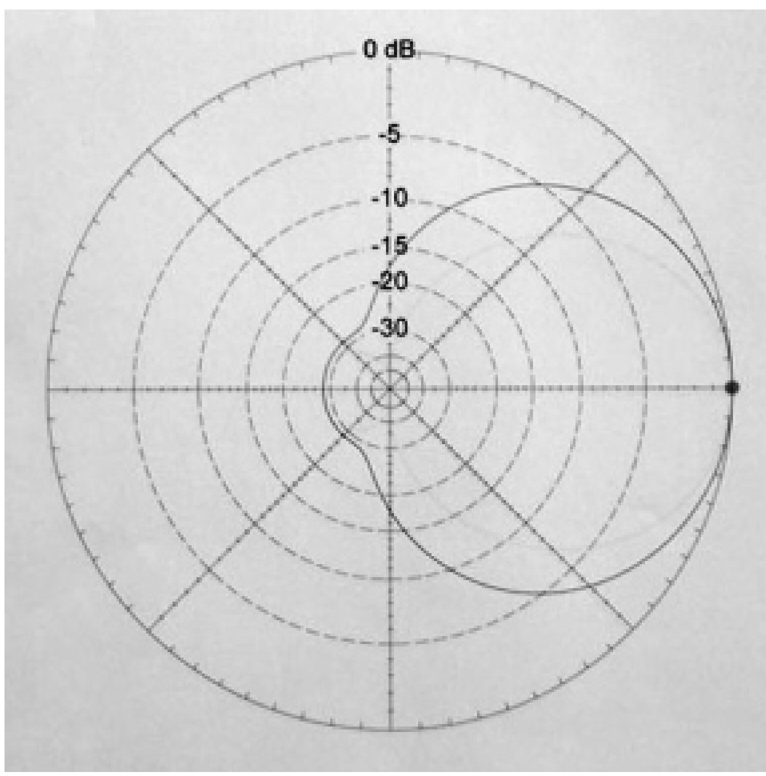
The three 4 element yagi examples at 144, 222 and 432 MHz may be constructed using the dimensions in the table without further adjustments or simulation. Experiments with insulated #12 house wire instead of bare #12 copper wire for the folded dipoles suggest that insulated elements need to be about 1% shorter than bare elements, nearly 1/2" at 144 MHz. The dimensions in the table are for bare #12 copper wire folded dipoles.

If you have a convenient way to measure SWR or return loss at the weak signal calling frequency, it is useful to attach the folded dipole driven element to the boom with a cable tie so it may be slid back and forth a bit on the boom. If sliding it toward the 1st director improves the match, then the driven element needs to be shorter, and vice versa.

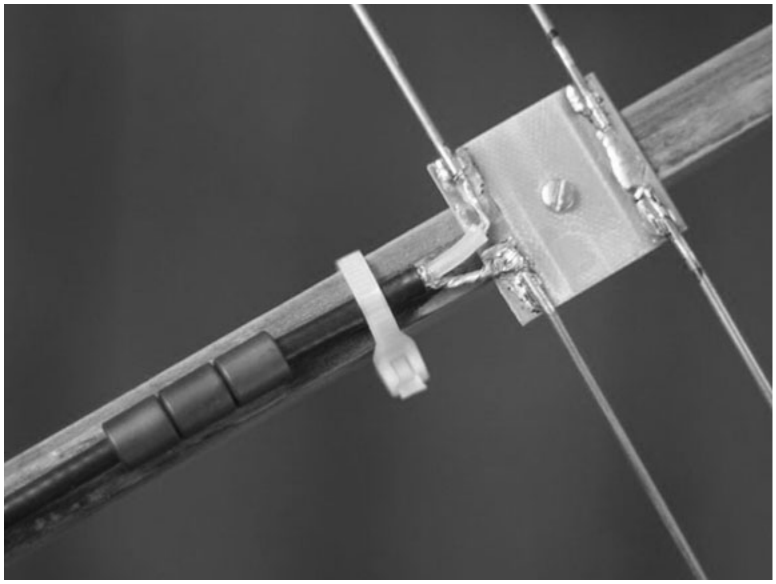
Since sliding the folded dipole back and forth on the boom is much easier than trimming it to length, it is useful to know what happens to the antenna pattern when the return loss it adjusted by moving the folded dipole rather than adjusting its length. The table has dimensions adjusted for an E plane pattern with low and equal side and back side lobes, typically 28 dB below the main lobe. Moving the folded dipole back toward the reflector typically nulls the back lobe, but the back side lobes increase. Moving toward the 1st director increases the back lobe. Neither has much impact on forward gain. Most of the change is in the imaginary part of the drive impedance, so adjusting the length of the folded dipole will achieve the same result without changing the clean E and H patterns shown on the next page. All three antennas have nearly the same patterns.



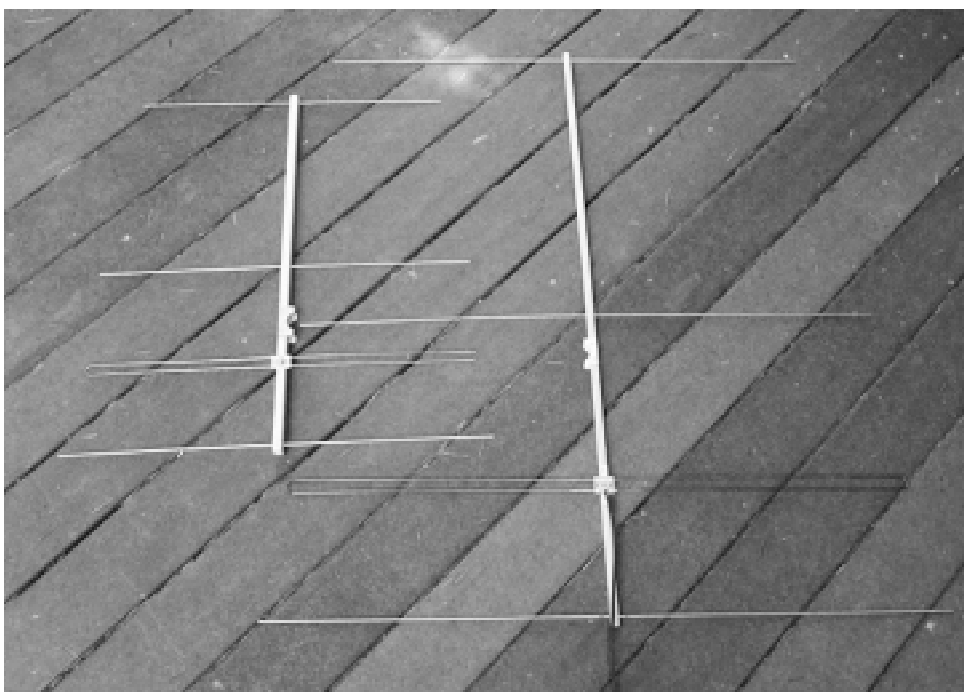
EZNEC Simulated Square Yagi E plane Azimuth Far Field Pattern



EZNEC Simulated Square Yagi H plane Elevation Far Field Pattern



Detail of Prototype 2m Square Yagi folded dipole feed, showing how length is adjusted by unsoldering half sections of the folded dipole and trimming. After the optimum length is determined, a one piece folded dipole is cut to length so that this adjustable feed may be used for the next prototype.



222.1 MHz and 144.2 MHz Optimized Square Yagi antennas. Construction is ultra light, with 1/8" parasitic elements, #12 copper wire folded dipoles, and wood booms. The 222.1 MHz boom is 3/4" clear fir, and the 144.2 MHz boom is 5/8" laminated from two pieces of fir, glued with Titebond III.

Table of Element Lengths and spacing along boom, with the reflector position as the 0.000” reference point. These dimentions taken directly from EZNEC simulations, which explains the number of significant digits. In the simulations, 1/32” change in element length makes a difference at 144. MHz, so careful cutting is expected. The numbers for the driven element “Distance Along Boom” are for the two sides of the folded dipole in the simulation. “Distances along boom” are less critical. Experiments in EZNEC are encouraged, with these lengths and positions as a starting point.

144.2 MHz	Distance Along Boom	0.000″	7.500″ 8.500″	20.000″	42.000″
	Length	41.000″	38.250″	38.125″	35.000″
222.1 MHz	Distance Along Boom	0.000″	5.250″ 5.875″	13.000″	27.250″
	Length	26.625″	24.750″	24.5625″	21.500″
432.1 MHz	Distance Along Boom	0.000″	2.6833″ 2.9833″	6.666″	14.000″
	Length	13.666″	12.750″	12.440″	11.000″

Table of 4 Element Square Yagi dimensions for 144 MHz, 222 MHz and 432 MHz

144 MHz Square 4 Aerial tied to lightweight mast with a sailor knot. The mast and all the elements disassemble quickly and all slip inside the thin hollow fiberglass mast for transport. The mast is in 4 telescoping sections less than 4’ long.