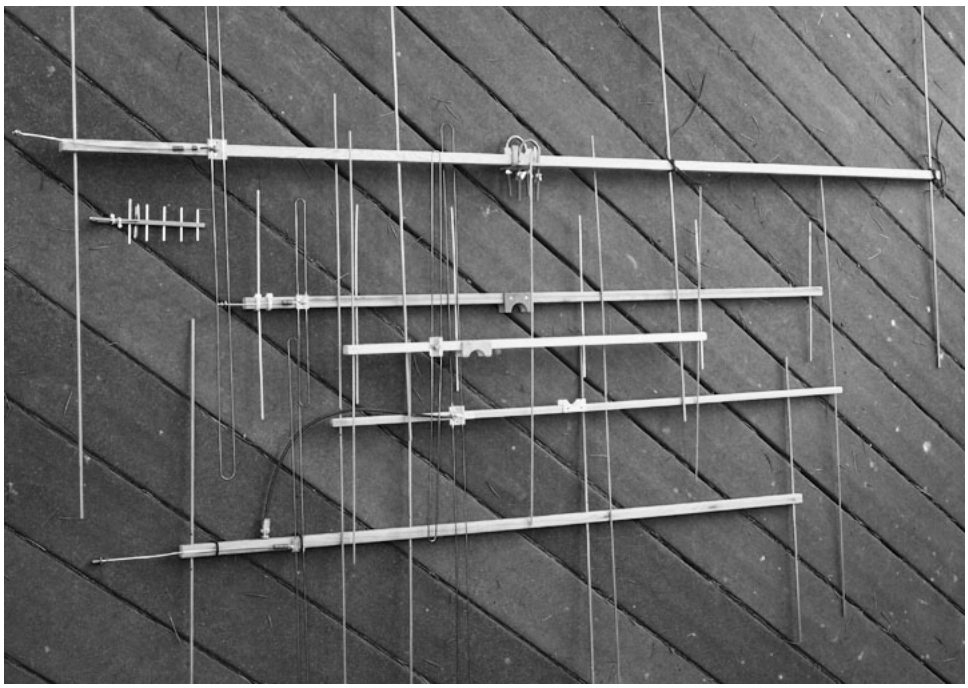
High Performance Lightweight Portable Yagi Antennas for VHF-UHF

Rick Campbell KK7B
Portland State University
May 2017

A yagi with a reflector, folded dipole driven element, close spaced director and a second dirctor may be optimized for a very clean pattern and good return loss with a bit more than 9 dBi gain on a half wavelength boom. The reflector is just over a half wavelength long, so a half wavelength boom results in an antenna that fits in a square, just over a half wavelength on a side. This makes it easy to visualize the size of the antenna when deciding whether it is attractive for a particular application on a particular band.

For a quiver of backpack portable antennas on the VHF-UHF bands 2m and up, the "square" 144 MHz antenna: 42" boom and 41" reflector will most likely be disassembled and carried in a bundle strapped to the side of the backpack. That same boom length works for 5 or 6 elements on 222 MHz and 7 or 8 elements on 432 MHz. The 222 MHz version will most likely be disassembled for hiking into an off-grid location, but the 12" long 432 MHz elements are not too inconvenient for strapping the assembled antenna to a backpack. On 1296 MHz and 2304, a 4' boom is technically a "long yagi," perhaps fussier to design. Shorter antennas on the back of the transverter eliminate feedline loss, which is significant with feedlines that are convenient to hike up an Oregon hilltop.



A stack of lightweight yagi antennas from 144 MHz to 2304 MHz on the back deck at KK7B

As with other antenna designs in this series, a prototype antenna is designed, built, measured and evolved on one band, and the optimized design is then scaled to other bands. EZNEC simulations of the 2m version show a bit more than 9 dBi forward gain, an E plane beamwidth of 60 degrees, H plane beamwidth of 86 degrees, and a single back lobe at -28 dB. That is a delightfully clean pattern, and the 144 MHz square yagi has become a favorite for a number of applications in the Pacific Northwest. Adding one more element at 222 MHz has nearly as clean a pattern, and 11 dBi gain. A 5 element 144 MHz lightweight yagi was scaled from the 222 MHz version, on a 6' boom. That's long for backpacking and inconvenient in the car trunk, but useful in some applications.

Design Notes

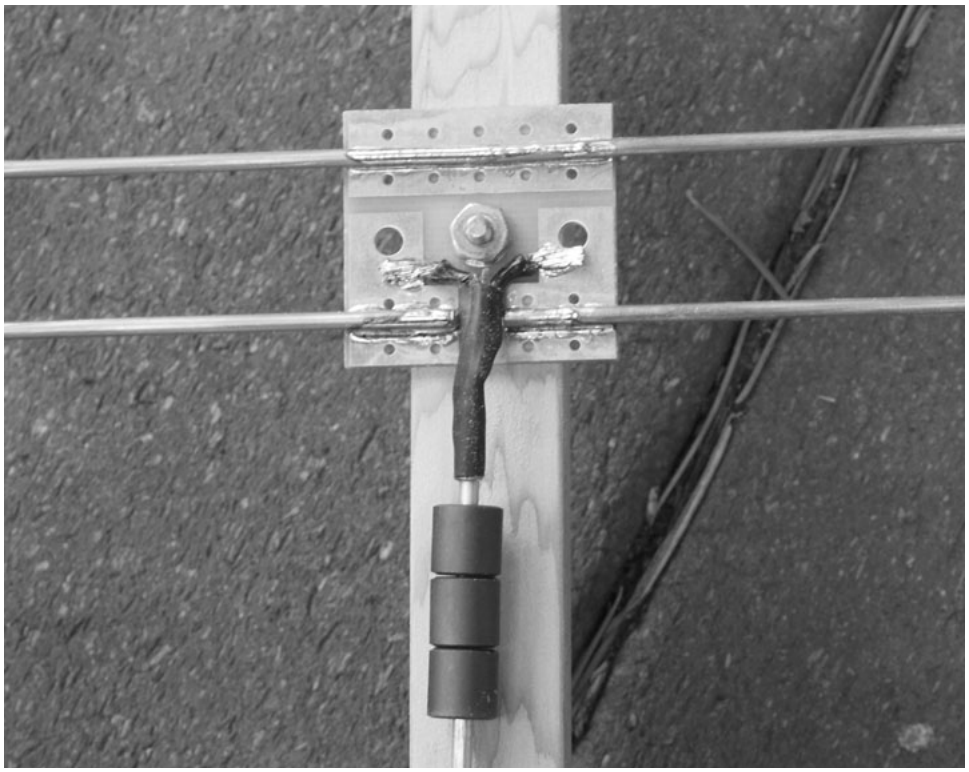
The reflector, folded dipole, and close-spaced first director are the "launch," and work together to launch a wave in the desired direction with 50 ohms at the drive. Generally the reflector and director are somewhat less than a quarter wavelength apart, and the driven element about halfway between. Reflector length and spacing are less critical, and may be set for a clean pattern with a small back lobe. The length of the folded dipole driven element and the spacing to the first director are more critical, and may be adjusted to achieve a 50 ohm drive impedance. Note that driven element length doesn't impact the antenna pattern, so after a clean pattern is achieved in EZNEC simulations, the driven element length is adjusted to tune out the imaginary part of the load. Make the folded dipole longer if it is -jX and shorter if it is +jX.

The mathematics is challenging, but the Far-Field pattern of an array of field sources is an Angle-Space Fourier Transform. Sidelobes are related to the currents in elements at the extreme ends. Yagi antennas that sacrifice a little gain for a very clean pattern often have a notably short last director as seen in the table...the Gibbs Phenomenon.

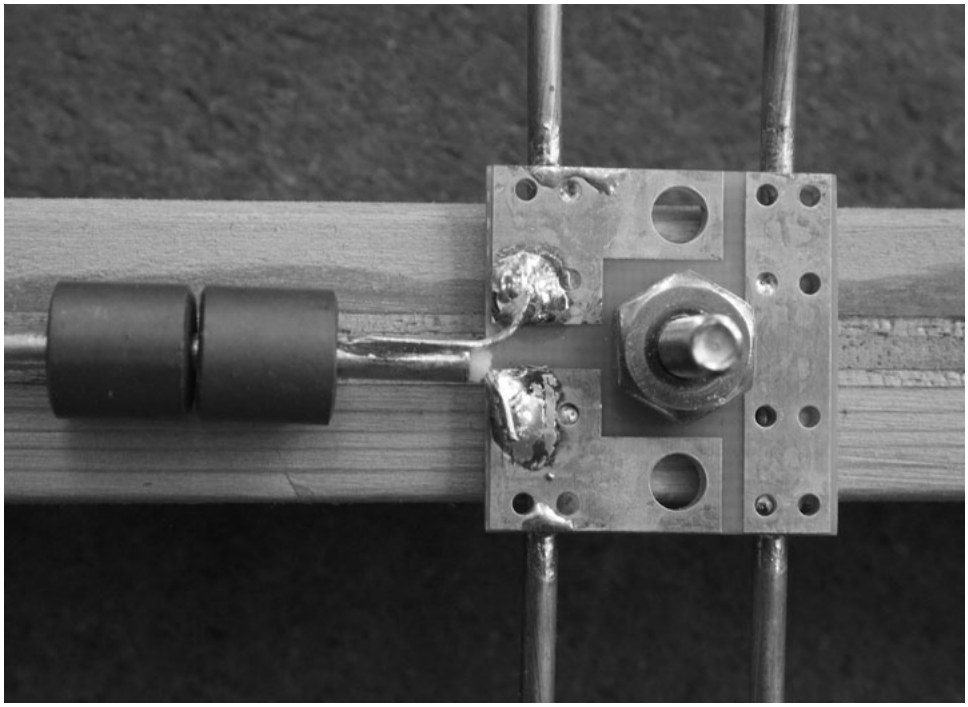
Adjusting the folded dipole length

Historically, antenna engineers have jumped through every conceivable hoop to avoid trimming the lengths of folded dipole driven elements on VHF-UHF yagis. The most common ploy is to use some other driven element configuration. But folded dipoles have profound advantages when they are the right length: they are fat so they are less critical; they don't have high E fields on sharp ends that may be detuned by a raindrop or insect; and most importantly, they are a low loss 4:1 impedance step-up transformer. A dipole in free space has an impedance near 72 ohms, and when we start adding loads (parasitic elements) in parallel, that impedance drops. With a folded dipole driven element, we design the yagi for a dipole feedpoint impedance of 12.5 ohms and use the 4:1 folded dipole to step that up to 50 ohms. Then we can directly connect our 50 ohm transmission line at right angles to the EM fields, and have a nearly perfect feed.

A folded dipole driven with 50 ohm feedline has another major advantage for hilltop and urban operation. The folded dipole is a short circuited small loop at lower frequencies, which acts as a first line of defense against the forest of FM broadcast stations on the next hilltop over. These antennas are both signal arrival angle and frequency filters.

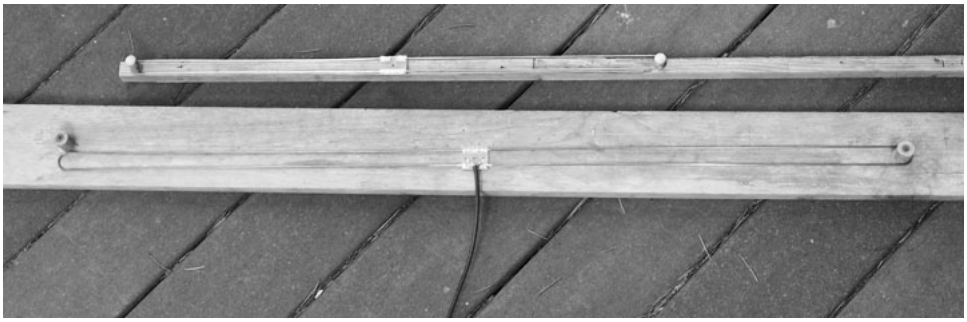


The ExpressPC center insulator on an experimental 144 MHz yagi. The circuit board is double sided with plated through holes, and several options for feedline attach. The ferrite bead sleeve balun is optional in practice, but is used for measurements.

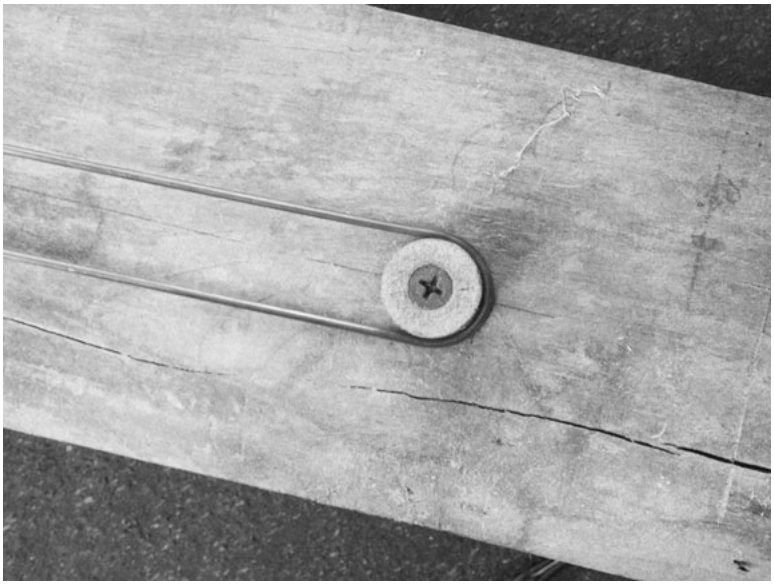


A smaller center insulator on the 432 lightweight yagi. In this case the elements are on the back side, in grooves cut in the laminated lightweight boom.

Once you get over the fact that trimming the length of folded dipoles is a bit of a chore, it's not that bad. It is particularly not bad after you've spent hours working on a clean EZNEC pattern and bear in mind that any length adjustments on any of the parasitic elements will mess up all your good work. After a few months of experiments, a center insulator PC board was designed in different sizes for VHF and UHF antennas, and a set of three boards was ordered from ExpressPC. The three boards were cut up into lots of center insulators, total cost $52. It now takes about ten minutes to try a longer or shorter folded dipole, and in a half hour of experiments with a reflected power meter, return loss greater than 20 dB is common.



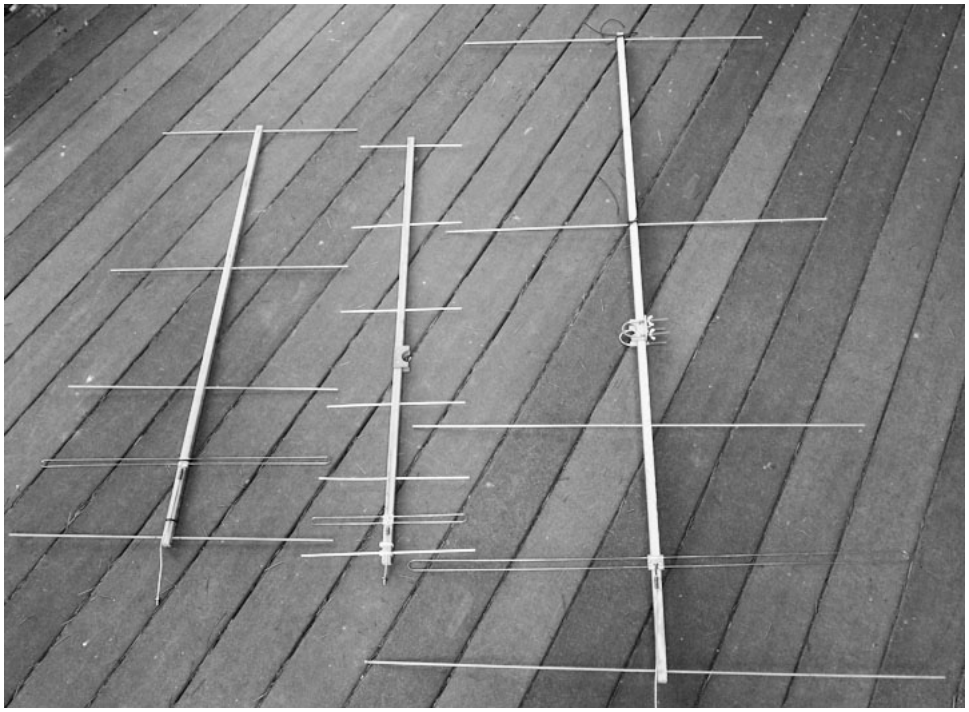
A bending jig makes it easy to duplicate folded dipole elements. The #12 bare copper wire is first straightened by clamping one end and stretching, twisting, and untwisting with a hand drill. The jigs are for 144 MHz and 222 MHz.



Detail of an end of the bending jig. A pair of 3/4" dowel sections screwed into a board, at the right distance apart for making neat folded dipoles. To change length, just move the dowel.

A family of lightweight yagi antennas

These antennas have been designed and built from the EZNEC dimensions in the table. Element lengths are critical, and the director lengths will change if a different element diameter is used. The reflector is less sensitive, but if a different wire diameter is used for the elements, a new set of EZNEC simulations is encouraged. Note that 3/16” solid aluminum rod weighs more than twice as much and is twice as expensive as 1/8” rod, so for backpack portable use it isn’t the best choice. As of this writing, 1/8” 6061 Al rod in 72” lengths is available by mail from MSC Direct for $2.23. Three pieces will provide the reflector and directors for a 2m and 222 yagi, with some leftovers for 432 directors. After cutting to length with a fine hobby hacksaw blade, the ends are filed square and then rounded with a hand file. If you need an excuse to acquire a lathe, the old 10” Logan in the KK7B garage works wonderfully for holding and trimming elements. 6160 Aluminum rod is delightful to work with--far less expense than driving around looking for a hardware store with 1/8” aluminum clothesline wire in stock. The folded dipole driven elements are #14 bare copper house wire, stripped out of a three conductor roll. They are a little flimsy on 2m, but stiff enough for 222 and 432. A small stripper was built to cut the white and black plastic insulation.



222 MHz 11 dBi, 432 MHz 13 dBi, and the longer 144 MHz 11 dBi lightweight yagis.

The lightweight 4 element 144 MHz yagi quickly disassembles and the pieces are tied with a little tarred marline with constrictor knots, and slipped into the telescoping mast.

The quickly assembled 2m 4 element yagi is tied to the lightweight mast with a short piece of line and a modified constrictor knot.

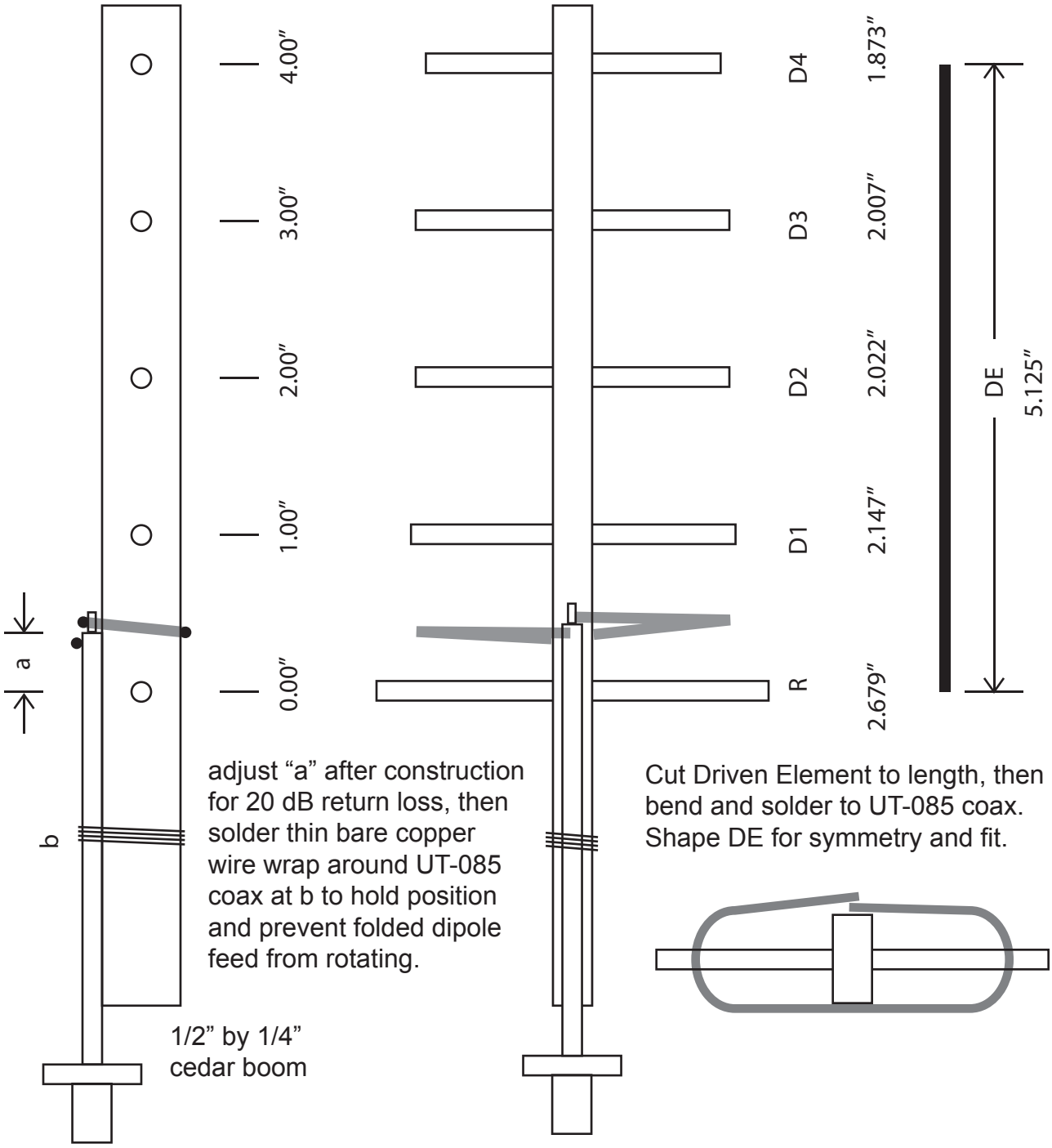
Element diameter		Reflector	Driven Element	First Director	Second Director	Third Director	Fourth Director	Fifth Director
144.2 MHz 0.125″	Distance Along Boom	0.000″	7.500″ 8.500″	20.000″	42.000″			
	Length	41.000″	38.250″	38.125″	35.000″			
144.2 MHz 0.187″	Distance Along Boom	0.000″	7.500″ 8.500″	20.000″	42.000″	70.000″		
	Length	42.250″	38.500″	38.0625″	37.000″	34.250″		
222.1 MHz 0.125″	Distance Along Boom	0.000″	5.250″ 5.875″	13.000″	27.250″			
	Length	26.625″	24.750″	24.5625″	21.500″			
222.1 MHz 0.187″	Distance Along Boom	0.000″	6.000″ 7.000″	14.000″	27.500″	46.500″		
	Length	27.000″	24.750″	24.600″	23.650″	21.500″		
432.1 MHz 0.125″	Distance Along Boom	0.000″	2.6833″ 2.9833″	6.666″	14.000″			
	Length	13.666″	12.750″	12.440″	11.000″			
432.1 MHz 0.100″	Distance Along Boom	0.000″	3.500″ 4.000″	8.000″	17.000″	26.000″	36.000″	46.000″
	Length	14.000″	12.700″	12.450″	12.250″	12.000″	11.750″	11.250″

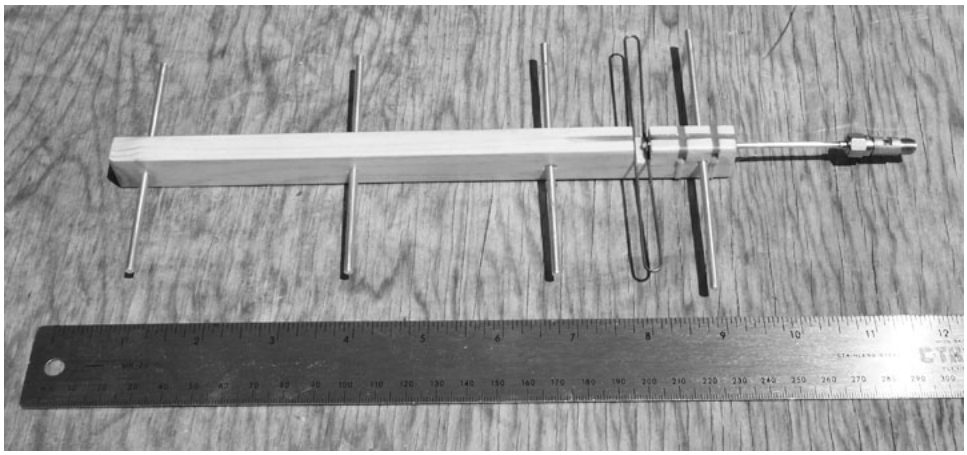
Dimension Table for construction of Lightweight Portable Yagi Antennas. The significant digits in the dimensions are from EZNEC, and are useful to study the impact of errors.

The table has the EZNEC dimensions of a set of antennas that have been carefully built to appropriate tolerances: significantly less than 1mm error on element length. Careful construction results in antennas that achieve the gain and pattern predicted by EZNEC, and impedance near 50 +j0 ohms by adjusting the length of the driven element. Feed impedance is probably good enough for most applications without any adjustments.

If you plan to duplicate this work, it is highly recommended that you experiment with these designs in EZNEC, starting with the dimensions in the table. In a week's work you can develop a stack of optimized designs that would take years to build.

Some of the first antennas in this series, and the ones with the most careful gain and pattern measurements, were designed and built for 1296 and 2304 MHz. This page has the 2304 short yagi seen in the family photograph, with enough information to build. A number of these have been built, and they work better than some designs floating around the maker community on the web. Element lengths are ridiculously critical.





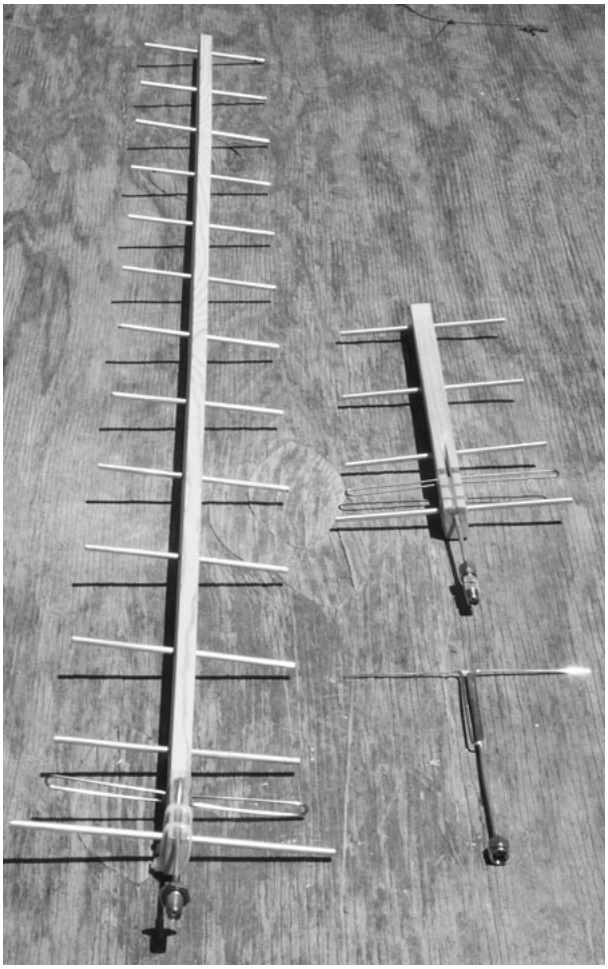
1296 compact high performance lightweight yagi, a First-Pass design that worked well enough to encourage further experiments.

1296 yagi antennas were designed, built and carefully measured for return loss at the KK7B backyard range, and for pattern, gain, and feedline isolation at the more serious range of Bob Larkin, W7PUA.

These antennas were early in the study, and have much fussier folded dipole driven element attachments. As is always the case, we learned a tremendous amount that we didn't even know we didn't know when this antenna study was started, and the next set of 1296 designs at KK7B will make use of that knowledge. These first pass dimensions are left in my notebooks.

Your simulations and experiments are highly encouraged. One important thing we learned is that with wood booms and carefully trimmed elements of the same diameter as in the simulator, EZNEC may be trusted to design yagi antennas up throught at least 2304 MHz.

An acknowledgement list would be as long as this paper, but thanks are at least due to Kent Brittain WA5VJB, whose cheap yagi designs inspired this work.



Family of 1296 antennas including a dipole