Inverted V Wire Yagi with Switchable Pattern Rotation for 14 MHz

A two element rotary beam antenna without moving parts.

Ashraf Abuelhaija and Klaus Solbach, DK3BA

Yagi or quad, beam antennas are well established antenna types for improved directivity and gain compared to a single dipole antenna.[1] Using an electromechanical rotator, these antennas can be turned toward the desired direction in ±180° of azimuth. Due to the considerable inertia involved in most practical beam antennas, however, rotation is fairly slow. This makes it difficult under typical short wave propagation conditions, for example, to switch between two different directions while listening to an ongoing conversation, or to find the direction of a station that makes short transmissions.

An alternative is offered by phased array antennas, in which the beam can be rotated by the switching of feed networks. With different phase excitations of the elements of the array, different beam patterns can be provided. The popular *four square* array of four vertical ground mounted monopole antennas with about quarter wave spacing and that provide four beam directions with 90° separation in azimuth is an example of such a system.[2]

A comparable alternative with horizontal polarization has not been available, to the knowledge of the authors. A phased array of four horizontal dipoles arranged in a square is not a good idea because of the orientation and coupling of the dipoles arranged under an angle of 90°. Also, this array would require four poles to carry the dipoles high above the ground.

A simpler configuration was found that requires only one support pole and that uses inverted V wire dipoles to create a two element Yagi antenna that can be remotely switched in its beam direction in steps of 60° in azimuth. The result is shown in Figure 1.

Figure 1 — Inverted V wire switched beam array antenna on the roof platform. The dipole wires have been colored for better visibility.

The Inverted V Wire Yagi

This two element inverted V based wire Yagi requires four wires of exactly the same length, each sloping from the top of a support pole or tower. Each is oriented with the same 30° elevation angle (measured from the horizontal) and spaced 60° and 120° apart in azimuth. Two wires are combined to form the driven element and the other two wires are combined to form a director element. Each pair combines two wires at an angle of 120° and both pairs are separated by an angle of 60°. Simulations were performed using *EZNEC5+* and the azimuth and elevation patterns are shown in Figures 2 and 3, respectively.

The combination of wires #2 and #4 driven by the RF source while the combination of wires #1 and #5 is center loaded by a series capacitance to electrically shorten the element to form a director. Mutual coupling between the two dipoles is strong in this configuration due to the short distance between the elements. Thus, we can adjust the phase, and also the amplitude to some extent, of the parasitic element current by choosing a frequency slightly above or below the half-wavelength resonance in combination with the choice of a series reactance load.

Our design employs a wire length of about 0.26 wavelengths and a series capacitor load to create a director element. The design and the realized radiation patterns look similar to the inverted V wire Yagi described by VE7CA in *The ARRL Antenna Book.*[3] Our antenna, however, uses equal length wires and reactive loading and wires radially extending from the apex while the referenced design uses parallel wires with reflector and driven elements of different length.

We tested the theoretical design by building a model for 1 GHz and measuring the reflection coefficient and the radiation patterns in our anechoic chamber. Results were quite satisfactory and this allowed us to proceed in building a full size version for 14 MHz.

Peak gain and the elevation angle of the peak critically depend on the height over ground. In the simulation, a height of 40 feet was assumed as an example. The pattern shows a half-power beamwidth in azimuth of about 65°, broad sidelobes and a relatively low front to back ratio between 10 and 15 dB, depending on elevation angle.

Although this certainly is not the perfect pattern of a two element Yagi, the antenna concept is useful since it can be extended into an antenna design with switch selectable beam directions.

[1] Notes appear on page 37.

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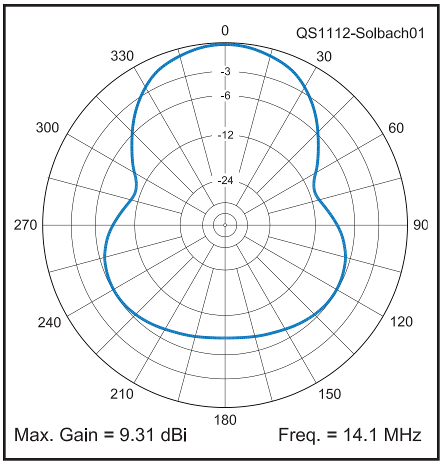

Figure 2 — *EZNEC5+* azimuth pattern of the two element inverted V wire Yagi at a height of 40 feet over typical ground (conductivity 0.005 S/M, relative dielectric constant 13). Wires 2 and 4 are driven, wires 1 and 5 form the director.

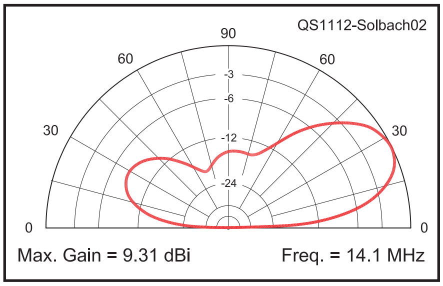

Figure 3 — Elevation pattern under the same conditions as in Figure 2.

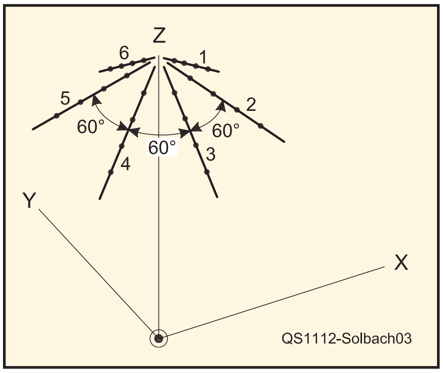

Figure 4 — Six wire arrangement of the switched beam array.

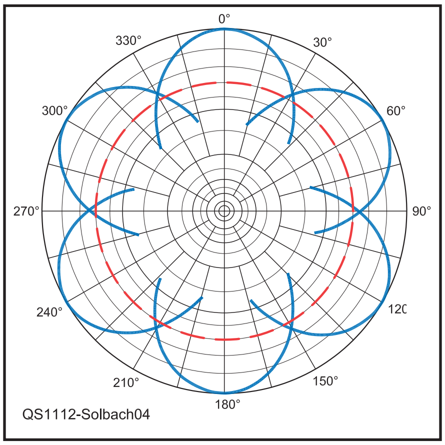

Figure 5 — Sketch of principal patterns created by six selections of wires for the two element inverted V wire Yagi array.

Hamspeak

dBi — Decibels with a reference to an ideal isotrpic antenna. A way of indicating antenna gain in comparison to an antenna with uniform radiation in all directions.

EZNEC — Antenna modeling software that provides a user friendly interface to the powerful *Numerical Electromagnetic Code* (NEC) calculating engine. Several versions of *EZNEC* antenna modeling software are available from developer Roy Lewallen, W7EL, at **www.eznec.com**.

Inverted V — Common name for a center fed dipole antenna in which the center is supported at a higher point than the ends, giving the appearance of an inverted letter V. Such antennas operate in a manner similar to a horizontal dipole at a height about ⅔ as high.

Monopole — Single vertical antenna element, typically a quarter or more wavelengths long. Often used as a transmit and receive antenna, singly or in combination with other similar antennas.

Quad — Multielement directional antenna array in which the elements are made of square, rectangular or round loops approximately 1 wavelength in circumference.

Transceiver — Radio transmitter and receiver combined in one unit. In many cases some circuitry is shared between the two functions.

Yagi — The name of a multielement narrowband directive antenna array using multiple parallel dipole type elements. It is more properly called a Yagi-Uda array, named after its inventors.

The Switched Beam Antenna

Our switched beam antenna is comprised of six wires spaced equally by 60° in azimuth as shown in Figure 4. Using remotely activated switches, we select one pair of wires for the driven inverted V dipole and one pair for the director inverted V dipole. The four selected wires represent the two operating elements, with the two unused wires sitting exactly on the symmetry axis of the driven and the parasitic dipoles. Thus there is no net mutual coupling to the unused wires and they are virtually invisible to the operating elements. We can cyclically interchange the selection of wires to create six different combinations which produce six different patterns rotated in azimuth by steps of 60°. See Figure 5.

It is seen that the six beam positions cover the 360° azimuth range and that the beam cross-over level is slightly above –3 dB; thus, while scanning the antenna around, the worst case pointing loss for any direction is less than 3 dB.

The switching in and out of dipole wires has to be accomplished at the center of the array where the wires are fastened and electrically connected and from where the six wires stretch out radially. Figure 6 shows one of six routing configurations for the connection of two wires to the coaxial feed for the driven dipole and two wires to the reactive load for the director dipole.

For this switch unit we use electromechanical relay switches of SPDT type (Takamisawa SY-12W-K) and DPDT type (Omron G5V-2) arranged on a circular 12 cm diameter circuit board (Rogers RO4003, 0.5 mm thickness) with 50 Ω microstrip lines connecting the wires, relay terminals, capacitor, coaxial cable and the five wire control lines as shown in Figure 7. The relays are conventional miniature sealed signal relays with low capacitance (about 1 pF) between contacts and voltage handling of several hundred volts and load current up to 1 A. Power handling has been tested with 100 W of carrier power in short transmit periods, but high duty-cycle power handling and higher peak power have not been tested.

The six dipole wires are electrically connected and mechanically fixed to the board by eyes at the periphery while the RF coaxial cable and the five wire control cable thread through openings in the middle. With the switch unit and dipole wires in place at the top of our tower, the control cable and the coaxial cable run downward from the board — the RF transmission line with a cable choke balun just below the board. At the other end of the cables, the relays are actuated by a rotary switch with six positions controlling a digital encoding and interface circuit as shown in Figure 8.

Our antenna is mounted on a 23 foot mast placed centrally on the roof platform of our building (see Figure 1): The tower also carries a microwave dish antenna below the top. Other VHF, UHF and microwave antennas also are present on the platform and a three element Yagi is placed at a distance of 40 feet from the tower. The switch unit is mounted on a short PVC tube just above the top of the metal tower and an inverted plastic salad bowl is used as a top cover to protect the unit from rain (see Figure 9).

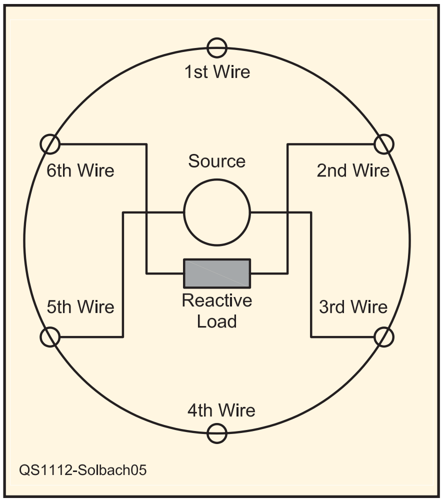

Figure 6 — Routing configuration of the switch unit for a beam pointing to 90° azimuth.

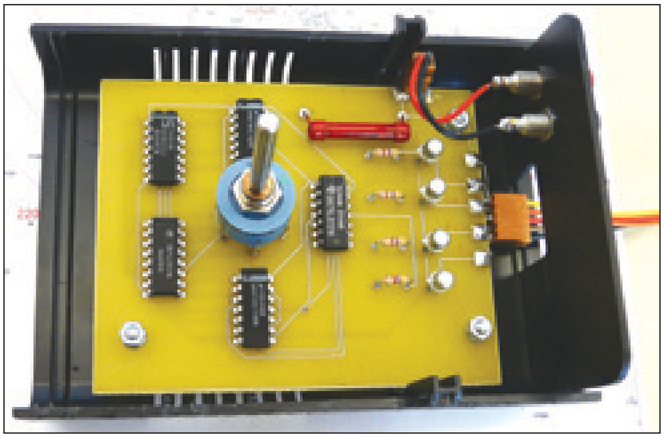

Figure 8 — Relay digital control unit with rotary switch.

Figure 9 — Switch unit with dipole wires and weather protection cover placed on top of the supporting mast.

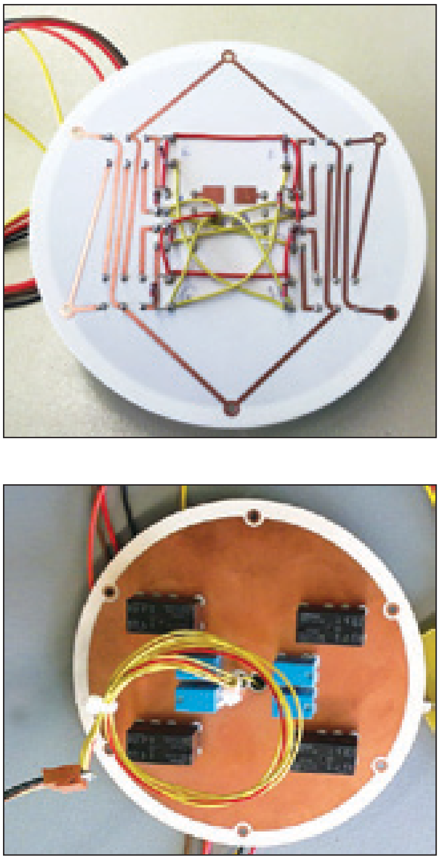

Figure 7 — Switch unit with eight relays to switch six dipole wires at their periphery. At the top is a view of the wiring side showing the use of microstrip lines for the RF connections. At the bottom is the relay side.

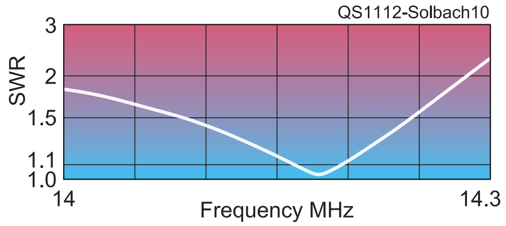

Figure 10 — *EZNEC* SWR plot of the two element Yagi.

To keep the weight low, we used thin insulated copper stranded wire of 0.42 mm diameter [approximately #26 AWG—*Ed.*] for the dipole arms (expected conductor loss of about 1 dB) and supported the open ends at an equal height of 14 feet by ½ inch PVC pipes which were fastened to the railings of the platform. Some wires had to be extended by Nylon string to reach their supports.

From simulation with *EZNEC5+*, an optimum wire length of 18.4 feet was calculated with the director loaded by 120 pF. The model assumed an infinite conducting ground and projected a maximum gain of 7.44 dBi under 45° elevation.

Since the roof of our 13 story concrete building is about 165 feet above ground, the ground plane assumption is much too pessimistic as it applies to the far-field pattern and we can expect higher gain at lower elevation angles. The antenna feed-point impedance was as predicted, after we cut the dipole wires by about a foot to adjust the resonant frequency (Figure 10). Within a bandwidth of about 200 kHz, the SWR is below 2:1 and the pattern has acceptable variation in gain and beam shape over the range.

Operating Experience

The antenna was operated using an FT-101 transceiver from our University club station, DL0UD. While we observed the signal strength indicator we rotated the pattern by turning the switch through all six positions within a few seconds or fast toggling between two positions in order to find the maximum indication for CW stations in the 20 meter band. Although the antenna patterns indicate only a moderate front-to-back ratio, a clear maximum position was found in most cases and also a clear minimum position at the opposite beam direction. Correspondence of antenna beam direction and theoretical azimuth could also be verified in most cases.

We compared the switched beam antenna to our rotatable three element Yagi by quickly switching between the two antennas. This tended to be frustrating because often the rotatable beam took more time to move to the optimum direction than the duration of transmission of the observed amateur station. Unfortunately, the comparison can give only a very rough indication of the actual antenna gain, since we are not sure about the gain of the rotatable Yagi.

The rotatable beam is operated under inferior conditions compared to our switched beam antenna as it is situated 40 feet west of the tower at the edge of our roof platform only 10 feet above the platform level. Including additional cable loss, this should reduce the gain by about 2 dB. Nevertheless, comparisons using signals from the Eastern Hemisphere tended to give one-half up to one S-meter unit advantage for the switched antenna while signals from the Western Hemisphere tended to give equal signal strength with both antennas. The difference may be explained by the mutual coupling and diffraction effects when the Yagi radiation has to pass through the switched beam and vice versa. As a rough estimate of the gain from these results, we conclude that the switched beam antenna would come close within a few dB of the traditional Yagi if both were in the same position.

Conclusion

The six wire switched beam antenna has been found to be a useful antenna for shortwave operation due to its inertialess beam rotation and simple construction based on the inverted V design. A four wire version has also been investigated but this presents only four beam directions while an eight wire version promises more interesting features with eight beam directions based on six wires selection to create a three element Yagi array rotatable through eight directions. The presented concept could be expanded to multiple bands operation be using wires with traps and multiple capacitors.

Additional construction details are provided on the QST-in-Depth website.[4]

Klaus Solbach, DK3BA, started in Amateur Radio as SWL in 1965 at the age of 14 years, and received his full license 4 years later. His amateur work led him to study electrical engineering, which he finished with Dipl-Ing and Dr-Ing degrees. He worked for 17 years as an engineer at the Radar Systems department of EADS, responsible for RF Systems and Antenna development. In 1997, he became the chair of RF and Microwave Engineering at the University of Duisburg.

His university research group supports contest station DF0UD, repeaters, some Amateur Radio beacons and the university FM broadcast station (see **hft.uni-duisburg-essen.de/amateurfunk/amateurfunk_en.shtml***). You can reach Klaus at University Duisburg-Essen, Bismarckstrasse 81, 47048 Duisburg, Germany or at* **klaus.solbach@uni-due.de***.*

Coauthor Ashraf Abuelhaija is from Jordan. He received the BSc in Communications and Electronics Engineering in 2002 at the Applied Science University in Amman, Jordan and worked 6 months as a Laboratory Technician and Supervisor at the Department of Electronics and Computer Engineering at the same university. He came to Germany to receive his MSc in Electrical and Electronics Engineering (Communication Engineering) at Duisburg-Essen University.

This article is based on his Master's thesis, "Development of a Novel Switched Beam Antenna for Communications," selected from the Amateur Radio projects offered by the department and through this had his first ham radio experience.

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Notes

[1] R. D. Straw, Editor, *The ARRL Antenna Book,* 22nd Edition, Chapters 11 and 12. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9876. Tel 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[2] See Note 1, "A "Four Square Array," p 8-27.

[3] See Note 1, "40-Meter Wire Yagis," p 15-18.

[4] **www.arrl.org/qst-in-depth**

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