Six-Beam Reconfigurable Wire Antenna
Ashraf Abuelhaija and Klaus Solbach

1Hochfrequenztechnik, Universität Kassel, 2Hochfrequenztechnik, Universität Duisburg-Essen, Germany

Abstract—A novel concept of a beam reconfigurable antenna is presented which rotates the beam of a 2-element Yagi antenna without mechanical rotation. The antenna is based on an arrangement of six wires extending radially from the apex of a support. A switch circuit is used to combine two wires into the driven dipole and two wires into the parasitic dipole. The paper presents the basic Yagi antenna using Inverted-V dipoles with verification of simulations by an experimental model at 1 GHz. A fully configurable array was built for operation at 14 MHz to serve in a short-wave direction finding system. Based on simulation, the antenna provides a gain of about 8 dBi and a front-to-back ratio of 10 to 15 dB. Improvements are expected from the use of horizontal dipoles or folded dipoles and additional radiator types can be configured, like single-dipole or vertical top-loaded radiator antennas. Realizations of the concept may provide diversity gain in communication systems.

Index Terms—Wire antennas, array antennas, beam scanning, reconfigurable antennas.

I. INTRODUCTION

Many applications in communications, Radar or navigation require beam scanning antennas for the coverage of 360° in azimuth. For a direction finding system, we were looking for such an antenna for 14 MHz short-wave operation which should be simple and inexpensive.

One traditional realization is based on a motorized mechanism which rotates a high-gain antenna; large antennas (low frequencies) tend to create large inertia which limits the agility of the scanning system. For high agility, an alternative is offered by phased array antennas, where the beam can be rotated by inertialless switching of individual phase shifters at the elements or by switching of feed networks in such a way that different phase excitations for the elements of the array are created leading to different beam patterns. One simple and inexpensive example is the “Four Square” array, where four vertical antennas are placed on the ground with about quarter-wave spacing, providing four beam directions with 90° separation in azimuth [1], [2]. Another example for a simple realization is the Electrically Steerable Passive Array Radiator (ESPAR) antenna which employs one active element plus a number of parasitic elements with switchable loading [3].

A comparable solution with horizontal polarization has not been available to the knowledge of the authors – at least, a phased array of four horizontal dipoles arranged in a square is not a good idea because of the polarization mismatch of dipoles which are arranged under an angle of 90°. Also, this array would require four poles to carry the dipoles high above the ground.

However, a simpler configuration was found which can be remotely switched in its beam direction in steps of 60° in azimuth. This antenna requires only one support pole and uses inverted-V wire dipoles to create a 2-element Yagi antenna. This is achieved by selecting two pairs of wires from an arrangement of six wires.

In the following, first, the basic two-element Yagi configuration is discussed which uses four wires and this is followed by a presentation of the concept of a switched beam antenna which uses six wires.

II. BASIC INVERTED-V WIRE YAGI ANTENNA

Our basic 2-element inverted-V wire antenna requires four wires of exactly the same length and sloping from the top of a support pole or tower under the same elevation angle (30°) and spaced under 60° and 120° in azimuth. Two wires are combined to form the driven element and two wires are combined with a reactive load to form a director element.

Fig. 1. Four wires combined in a 2-element Inverted-V Yagi antenna shown with current distributions and overlaid azimuth pattern.

Each pair combines two wires under an angle of 120° and both pairs are separated by an angle of 60°. Simulations were done with EZNEC5+ and the geometry of the antenna and a typical azimuth pattern are shown in Fig.1:

We see the combination of wires #1 and #2 driven by the RF source while the combination of wires #3 and #4 is loaded by a series reactance to realize a parasitic element. Mutual coupling between the two dipoles is strong in this configuration due to the short distance between the elements and we can adjust the phase, and also the amplitude to some
extent, of the parasitic element current by choosing the 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 0.256 wavelengths and a series capacitor load to create a director element. Note that, while conventional designs of Yagi antennas use parallel wires with reflector and driven element of different lengths with their centers displaced along a boom, e.g. [4], our antenna uses equal length wires and reactive loading and the wires extend radially from the apex with a down-tilt. This geometry seems to degrade the achievable bandwidth of our Yagi array to 2% (for 10 dB match and F/B ratio) as well as it increases the sidelobe level over the standard Yagi design.

The theoretical design was tested by building a model for 1 GHz, Fig.2, and measuring the reflection coefficient and the radiation patterns in our anechoic chamber. Results, Fig.3, were quite satisfactory, showing an impedance and radiation pattern close to the prediction. In particular, the radiation pattern exhibits a beam width in azimuth of about 65°, broad sidelobes (the pattern looks like “Mickey Mouse”) and a relatively low front-to-back ratio between 10 and 15 dB and a gain around 5 dBi.

III. THE SIX-WIRE SWITCHED BEAM ANTENNA

Our switched beam antenna comprises six wires spaced equally by 60° in azimuth, Fig.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 original configuration of Fig.1, with the two unused wires sitting exactly on the symmetry axis of the driven and the parasitic dipoles, thus without mutual coupling and basically decoupled. The switching in and out of dipole wires is accomplished in switching circuit at the center of the array where the wires are fastened and electrically connected and from where the six wires stretch out radially. Fig.5 shows the schematics for the
connection of the four wires to the feed and to the reactive load providing a beam directed to 90° Az.

The schematics shown in Fig.5 is one of six routing configurations for the connection of two wires to the feed line for the driven dipole and two wires to the reactive load for the director dipole. In our 14 MHz antenna realization, we use a relay switch board for the selection of the six configurations, Fig.7. It employs three SPST signal relays per wire plus an impedance transformer for the driven element and also provides the capacitive reactive load.

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°, Fig.6. It is seen that the six beam positions cover the 360° azimuth range and that the beam cross-over level is slightly above -3dB; thus, when scanning the antenna around, the worst case pointing loss for any direction is less than 3dB.

The relay switching unit, together with a relay control board, sits at the top of a mast under a weather cover. Six wires are connected to the eyes at the periphery of the relay switch board from where the wires slope down to supporting poles, Fig.8.

This realization provided an impedance match close to the simulation after a correction of the lengths of the wires, Fig. 9. Pattern measurements are planned to be performed using an aircraft circling the antenna in different elevations. At present time only approximate information about the radiation patterns of the realized antenna is available from using the antenna in direction finding of radio signals in the 14 MHz amateur band: This was done by tuning to a large number of different amateur radio stations transmitting mainly from European countries. While these stations were received (mostly short passes with duration of several ten seconds only), the selection switch of the antenna control circuit was used to find the best suited position providing highest signal strength; this position then was compared to the direction...
under which the station was expected due to its geographical position (which can be deduced from a station’s call sign).

In most cases, the forward-to-backward pattern ratio was found on the order of 10 dB and the direction found was correct. However, in about 5 cases out of 30 tests, the direction found based on the best antenna beam differed considerably from the expected direction; also, in several cases very low front-to-back ratio was seen. These observations may be explained by large differences in the elevation angle of incidence of the short-wave signals which mostly arrive at the receiving antenna after reflections at the ionosphere in different levels above the ground. In particular, signals incident under high and very low elevation angle may suffer from an antenna pattern which exhibits degraded front-to-back ratio.

A second approximate information on the antenna pattern performance was derived from a comparison of the strength of received signals while the receiver was switched between the switched beam antenna with optimum beam position and a mechanically rotatable 3-element Yagi antenna also present at the roof platform. This comparison mostly was slightly in favor of the switched beam antenna. However, the 3-element antenna was mounted at a less appropriate position on the roof platform and at less height above the platform, such that effective gain of the 3-element antenna certainly was lowered by several dBs. The comparison, therefore, only allows us to conclude that the gain of the switched beam antenna was not far from the predicted 8 dBi.

Fig. 9. Measured and simulated reflection coefficient of the Inverted-V wire switched beam antenna for 14 MHz on the roof platform.

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Fig. 10. Improved antenna configuration using folded wire dipoles.

IV. CONCLUSIONS

A novel concept for a configurable wire antenna was presented which allows scanning of the beam through six positions in azimuth. In the most simple and inexpensive version designed for operation at 14 MHz, the antenna employs inverted-V dipoles as the radiators and uses signal relays in a switch network for selecting the beam positions. Present redesign aims at increased gain and improved front-to-back ratio and lower sidelobes which can be achieved by horizontally extending wire dipoles or folded wire dipoles, Fig.10, at the cost of a mechanical support structure (spreaders). Also, using additional wires for resonance at other frequencies, multi-band operation will be realized. By fully exploiting the freedom in the configuration of the switches, even additional antenna modes will be switch selectable, i.e., six selectable single dipoles and a top-loaded vertical radiator mode.

The concept of a reconfigurable wire antenna was presented in a realization for 14 MHz operation. However, scaling of the antenna design to the lower microwave frequency range appears feasible, using planar structures. Limitations in the upper frequency limit are expected due to the limited size reduction potential of the switching circuits which should be less than 5% of wavelength in size as a rough estimate; e.g., at UHF frequencies, surface mount switch devices (MEMS) may be used to reduce the switch “board” size to below 20 mm. This opens the door to applications in mobile communications, where a beam reconfigurable antenna may provide diversity gain [5].

REFERENCES