Uniform Current Dipoles and Loops
Part 2 – Practical Realization

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Abstract – Practical means of constructing uniform current distribution dipoles and loops are discussed. Non-reactive cable made from parallel transmission line is introduced. Examples of a W8JK dipole array and a 50 Ω square loop are presented.

I. Introduction

Part 1 of this paper covered the theory of uniform current dipoles and loops. Here, in Part 2, we discuss practical means of realizing such antennas and their benefits. The criterion for obtaining uniform current is identified in Section II as element resonance (zero reactance). Section III introduces zero reactance resonant cable as a practical easy-to-realize antenna material. Section IV details construction of a one-wavelength W8JK dipole array, while Section V discusses a 50 Ω square loop. Concluding remarks comprise Section VI.

II. Uniform Current (Uni-Phase) Condition

Normal dipoles (of any length) with open ends ($\Gamma = 1$) will display a sinusoidal current distribution with all points on the dipole <u>in-phase</u>. This is a consequence of an outward traveling wave, from the feed point, and unity reflection coefficient at the dipole open ends.

Here we wish to consider an in-phase constant amplitude current distribution. This may be achieved at a given frequency $\omega = 2\pi f$ by canceling the wire series inductive reactance with uniformly spaced capacitive reactance. Then, at the design frequency, an extended wire becomes a series network of inductive reactance X_L and capacitive reactance X_C with $X_L = - X_C$. The length of the antenna, even for many λ, becomes unimportant as there is no net reactance and the current is in-phase everywhere. There will be only a net resistance due to radiation loss.

Although the "uni-phase" condition at first seems aphysical, we may imagine such a case by considering a plane wave in space traveling to the right. In the plane perpendicular to the direction of propagation, the wavefront is everywhere in-phase and of uniform amplitude. Placing a uniform current distribution dipole parallel to the electric field will result in maximum coupling to the field.

In the past, antenna structures have been made to have a uniform current uni-phase distribution by severing the wire periodically and inserting appropriate capacitive reactance. This is effective but tedious. Section III describes a much simpler technique.

III. RESONANT CABLE

A uniform current distribution, as noted in Section II, may be achieved by introducing periodic capacitive loading (*-j X*) to counteract (cancel) the inductive reactance of a wire element (*+j X*). At the resonant frequency, such loading produces a wire element with zero net reactance, as shown in Figure 1.

Here we accomplish this task by modifying 300 Ω parallel (ribbon) transmission line. The equivalent-circuit model of such line is shown in Figure 2a, consisting of series inductors and shunt capacitors. We can easily make resonant cable by cutting the cable (on opposite sides) to produce resonant sections with 50% overlap between sections. This is shown schematically in Figure 2b, and in the diagram in Figure 2c. Figure 2d is a photograph of such a modified line. The Appendix demonstrates mathematically that cable sections are actually $0.1125\, v_f\, \lambda$ in overall length for ribbon cable with a velocity factor of v_f.

Since the cable consists of short staggered resonators, the current distribution will be as in Figure 3, consisting of overlapping truncated sinusoids which are nearly triangular. The currents are in phase, so that at the resonant frequency the net cable current is the algebraic sum of the currents in the individual wires, as shown by the top curve of Figure 3. Although the net cable current is not precisely uniform, it varies from a uniform distribution by only $\pm 4\%$.

IV. W8JK Dipole Array

The W8JK "flat top" beam dates back to 1937 [1,2]. Historically, the W8JK beam consists of two closely spaced half-wave dipoles fed 180° out-of-phase. With the dipoles "bucking" each other, the result is two (opposite polarity) gain lobes of 6 dBi each. An additional result is a very low feed impedance – less than 8 ohms. The low feedpoint impedance has always limited the practical applications of this antenna.

Here we present a W8JK wire beam for 50 MHz with a novel twist:

i. The dipoles are made to have a uniform current distribution, since a wire element will always develop the highest radiation resistance and gain for this condition.

ii. The dipoles are a full wavelength long, further enhancing the radiation resistance and gain.

iii. The dipoles are placed "in series" to provide a single feedpoint resistance of 50 Ω.

Since the current on the beam is uniform throughout the structure, we are at complete liberty to feed the beam wherever we choose for convenience. With this in mind, the present beam is fed at one end of the wire elements, where the feedline may be taken directly into the operating room.

Tests on Radio Shack *NEXTECH* super low-loss foam core twinlead show the proper length for the resonant sections is 0.1223 λ. Accordingly, for a frequency of 50.2 MHz the resonant length is 0.730 m. We use 18 sections for a total length of 2.20 λ, which yields two 1 λ dipoles with short end sections for connecting the two dipoles together.

Before making the array, EZNEC modeling is performed. The most convenient means to model resonant cable on EZNEC is to use periodic capacitive loading as in Figure 1. The W8JK array is modeled with wire elements (#12 gauge to represent two #18 wires in parallel) one wavelength long and a spacing between the elements of 0.07 wavelength. The 1 λ elements are divided into 72 segments, while the wires connecting the elements at the ends are divided into 7 segments. The wire model is shown in Figure 4. There are 9 equally spaced capacitive reactances in each 1 λ element with a value of –289 jΩ a piece.

The voltage source is placed at the center of one of the end wires, in the center of one of the resonant sections. The modeled currents are also shown in Figure 4. There is a very minor ripple on the current distribution amounting to ±4 %. This is not just a modeling artifact, but actually occurs as mentioned earlier. It is of no consequence.

In free space, there are two oppositely directed 6.14 dBi lobes as in Figure 5. When the same antenna is placed half a wavelength above real earth[♦], the two gain lobes increase to 10.15 dBi at a takeoff angle of 24.0°, as in Figure 6 and 7. There are no minor lobes. The source impedance for the model above real ground is 50.7 Ω real with 0.07 λ spacing.

Figure 8a-e is a collage of photographs detailing construction of the array. Since the antenna is entirely balanced, there is equal current entering on one feed wire and leaving by the other. That is, there is no opportunity for feedline sheath currents and a balun is ***not*** required.

[♦] High accuracy ground, conductivity = 0.005 S/m, relative permittivity = 13.

The W8JK array has a feed impedance which is a rapid function of the element spacing, with closer spacing resulting in lower impedance. A spacing of 42 cm is very close to 50 Ω, although in practice minor variation can be made to obtain exactly 50 Ω. The actual center frequency is 50.230 MHz, with an SWR of 1.07:1. The experimental SWR curve is shown in Figure 9.

V. 50 Ω Square Loop

A 50 Ω square loop for 21 MHz is now presented. The actual desired frequency is 21.200 MHz, for a wavelength of $\lambda = 14.141$ m. Since the loop will develop an inductive reactance due to its geometry, the resonant cable sections must cancel the inductance of the cable as well as that of the loop. Several test loops (of 7 sections) were constructed to determine the resonant section length, with the result of 0.1100 λ (1.555 meter for the frequency desired).

Part 1, Figure 4, indicates a 50 Ω square loop would have a normalized perimeter of 0.8 λ, or 7.3 resonant sections. We build the loop with 7 resonant sections.

Figure 10 shows the loop gain modeled on EZNEC with the loop mounted horizontally one-quarter wave above real earth[♠] for a circumference of 0.8 λ. The main lobe of the loop is +4.9 dBi at a takeoff angle of 37.0°.

Figure 11 is a photograph of the completed 21.200 MHz loop.

Figure 12 is a plot of the experimentally measured SWR, with the best SWR of 1.10:1 at 21.200 MHz.

♠ High accuracy ground, conductivity = 0.005 S/m, relative permittivity = 13.

VI. Concluding Remarks

Uniform current dipoles and loops have been presented in a simple, physical manner. Zero reactance resonant cable made from parallel transmission line is introduced and used to realize a W8JK dipole array and a 50 Ω square loop. The performance of these antennas would be difficult (or impossible) to match with sinusoidal distribution antennas of similar complexity. It is hoped that this series of papers will change uniform current antennas from a theoretical topic to one of widespread utility.

References

1 John D. Kraus, "A Small but Effective Flat Top Beam Antenna", *Radio*, no.213, 56-58, March 1937 and no. 216, 10-16, June 1937.

2 John D. Kraus, "The W8JK Antenna", *QST*, **66**, 11-14, June 1982.

APPENDIX

Consider the cable in Figure A1 with:

Wire radius = a
Wire separation = d
Cable severed every length h (on opposite sides)

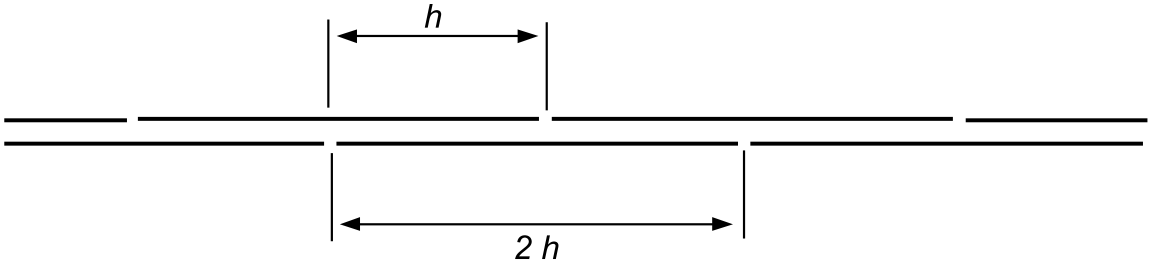


Figure A1

If the inductance per unit length is L_o, and the capacitance per unit length is C_o, then

$$\text{Inductance per section} = L = 2hL_o \int_0^{2h} \frac{I(x)}{I_{\max}}\, dx = 2hL_o(1/2) = hL_o \quad \text{(A1)}$$

$$\text{Capacitance per section} = C = hC_o \quad \text{(A2)}$$

The integral in equation (A1) is the mean current over the length 2h. That is, inductive reactance is developed only in accordance with the relative current over 2h. Then the resonant frequency of the wire is

$$F_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{hL_o\,hC_o}} = \frac{1}{2\pi h\sqrt{L_o C_o}} \quad \text{(A3)}$$

The inductance per unit length for 1 wire of a 2 wire system is

$$L_o = \frac{2\mu_o}{\pi}\ln\left[\frac{d}{a}+\sqrt{\left(\frac{d}{a}\right)^2-1}\right] \quad \text{H/m} \quad \text{(A4)}$$

The capacitance per unit length of a 2 wire system is

$$C_o = \pi\,\varepsilon_r\,\varepsilon_o \frac{1}{\ln\left[\frac{d}{a}+\sqrt{\left(\frac{d}{a}\right)^2-1}\right]} \quad \text{F/m} \quad \text{(A5)}$$

Therefore,

$$L_o C_o = 2\,\varepsilon_r\,\varepsilon_o\,\mu_o \tag{A6}$$

where

$$\varepsilon_o\,\mu_o = \frac{1}{c^2} \tag{A7}$$

The resonant frequency is

$$F_o = \frac{c}{2\pi\sqrt{2\,\varepsilon_r}\,h} = \frac{v_f\,c}{2\pi\sqrt{2}\;h} = \frac{c}{\lambda} \tag{A8}$$

where the velocity factor v_f is $1/\sqrt{\varepsilon_r}$. Finally,

$$\lambda = \frac{2\,\pi\sqrt{2}\,h}{v_f} \tag{A9}$$

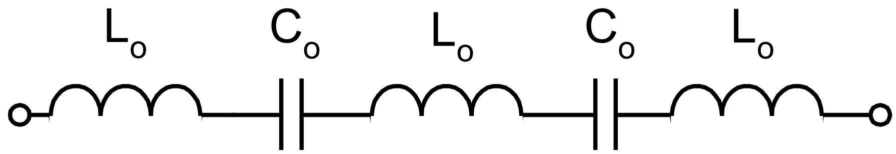


Figure 1 – Wire with periodic capacitive loading so as to cancel the inductive reactance of the wire at a given frequency $F = 1/2\pi\sqrt{L_o C_o}$.

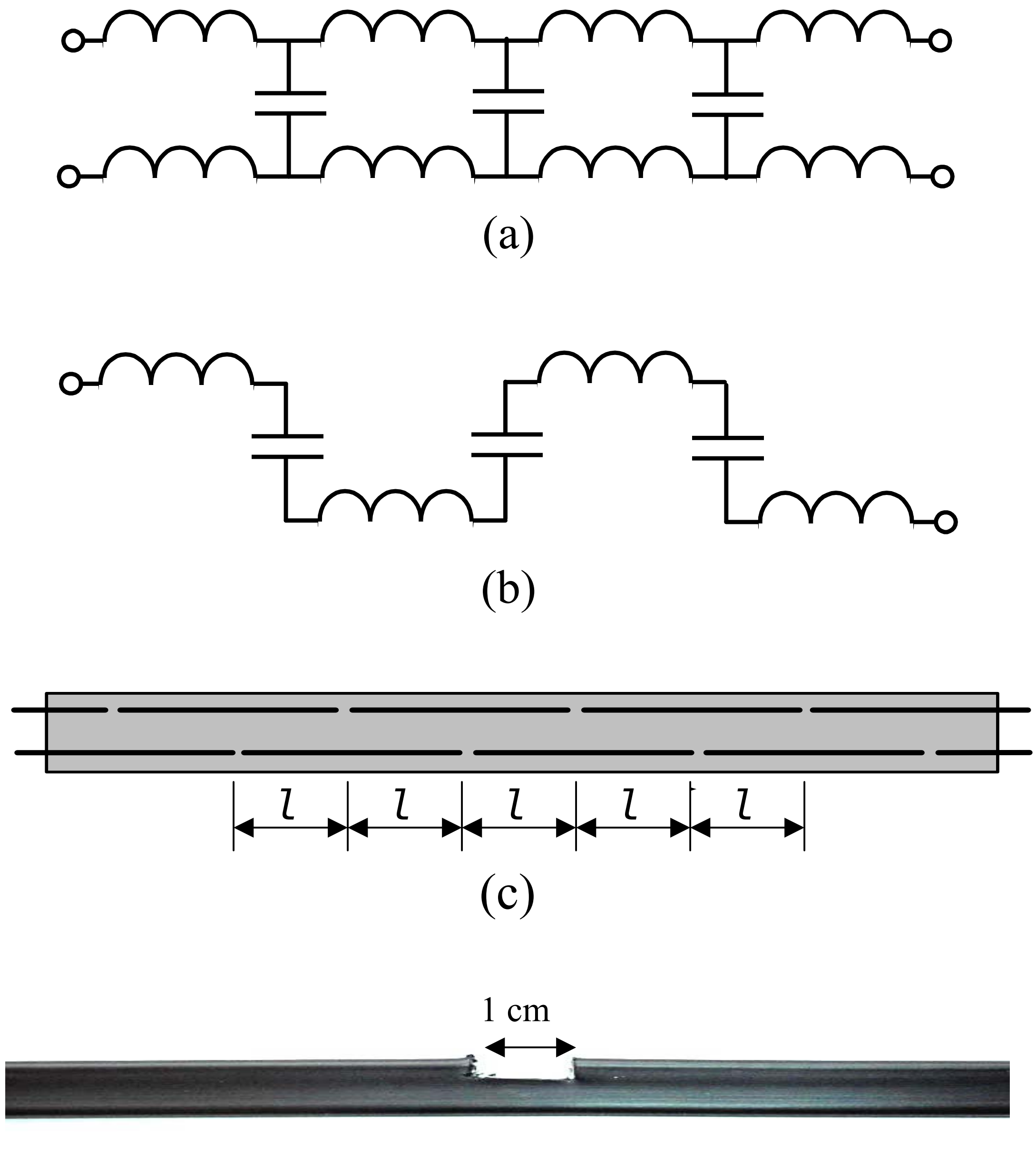


Figure 2 (a) Ladder network representation of balanced transmission line (ribbon cable). (b) Network representation of transmission line modified by cutting opposite conductors every length ℓ. (c) Pictorial view of modified line. (d) Photograph of a modified line, where one wire of the twin-lead has been severed.

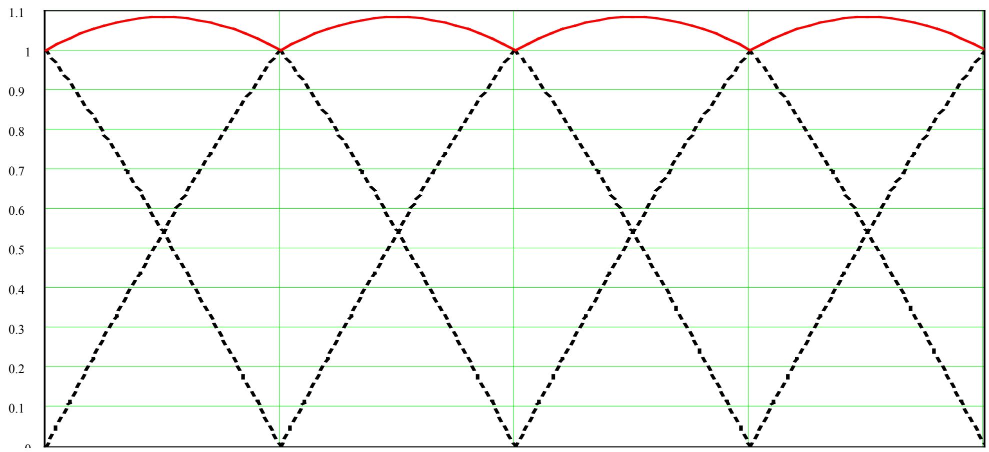


Figure 3 – The dashed curves show the truncated sinusoidal current distribution on the two parallel wires in resonant cable, repeating every $\lambda/8$ (approximately). The solid curve at top shows the algebraic sum of the currents in the two parallel wires, resulting in a nearly uniform current distribution ($\pm 4\%$).

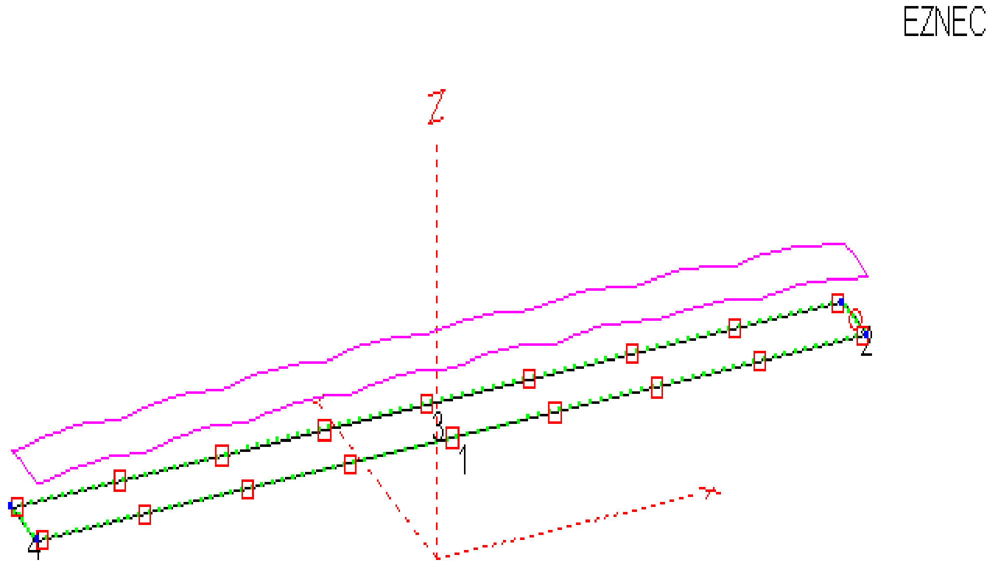


Figure 4 – EZNEC 3.0 four wire model of W8JK array. There are 9 capacitive loads on each 1 λ element, equally spaced. The feedpoint is on the far right end. There is a minor current ripple of ±4%.

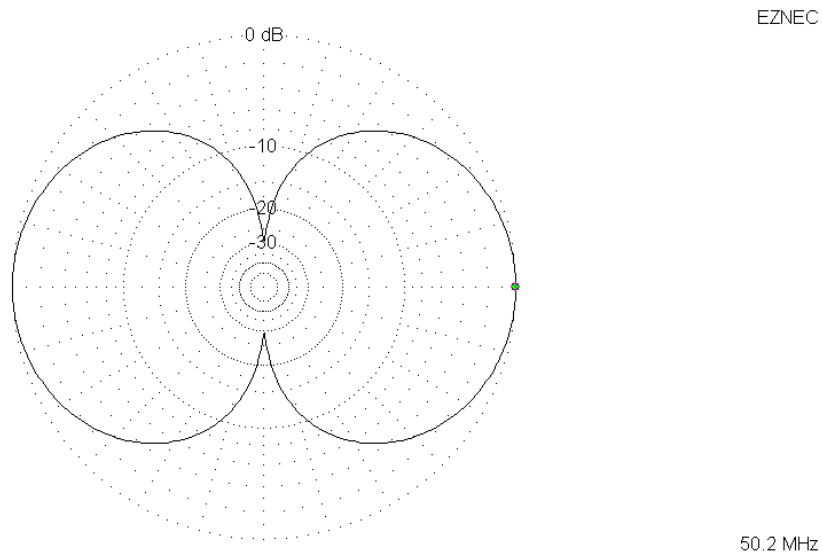


Figure 5 - Modeled free space gain lobes of 6.14 dBi, oppositely directed.

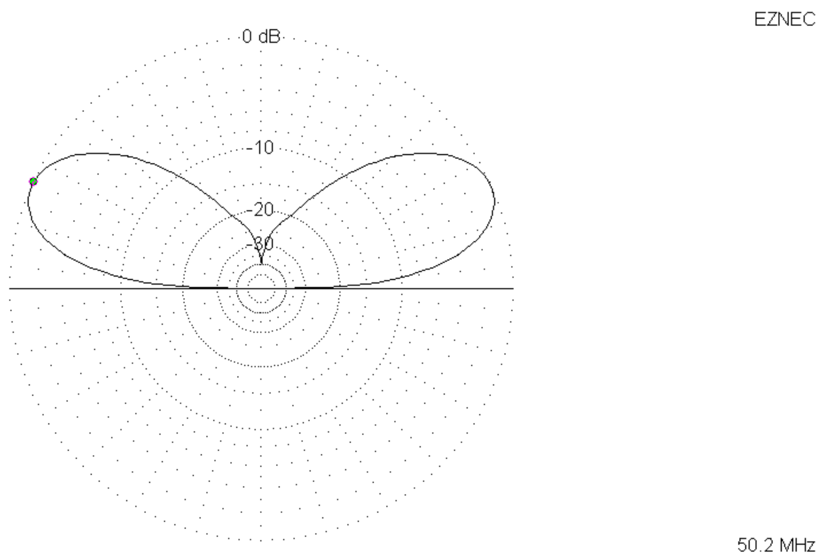


Figure 6 - Modeled gain over high accuracy ground using a height of 0.51 λ. G = 10.15 dBi at a takeoff angle of 24.0° above the horizon.

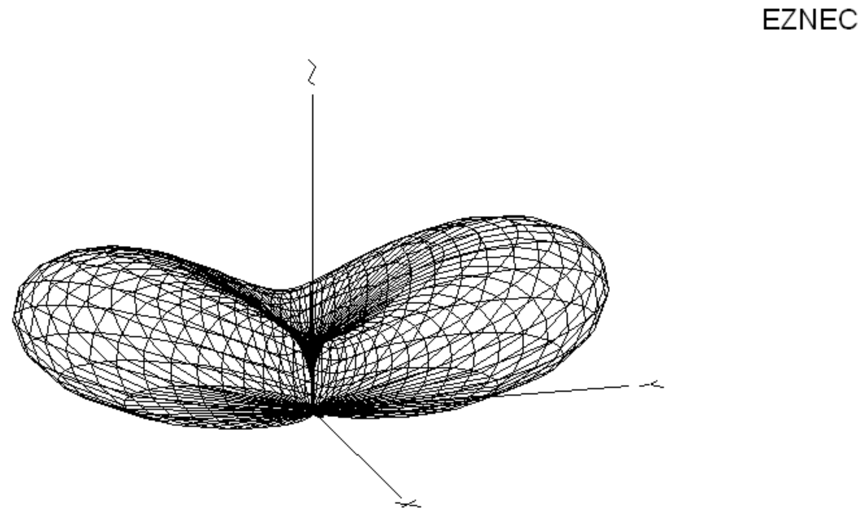


Figure 7 - Modeled 3D gain lobes over high accuracy ground. G = 10.15 dBi. There are no minor lobes.

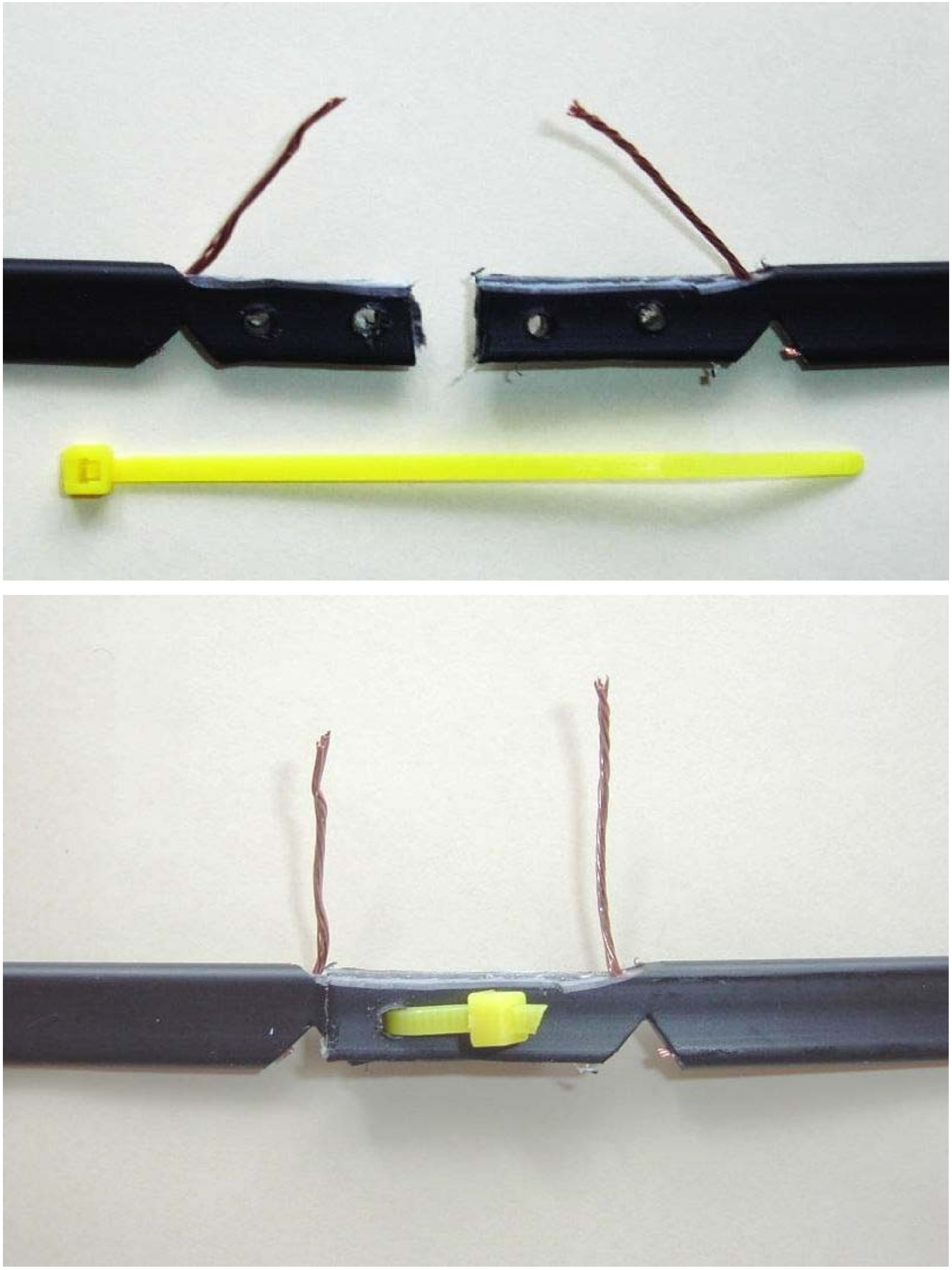


Figure 8a,b – Detail showing how the ends of the twinlead are dressed and connected with a nylon tiewrap.

Figure 8c – Connection of 50 Ω coax to array without a balun.

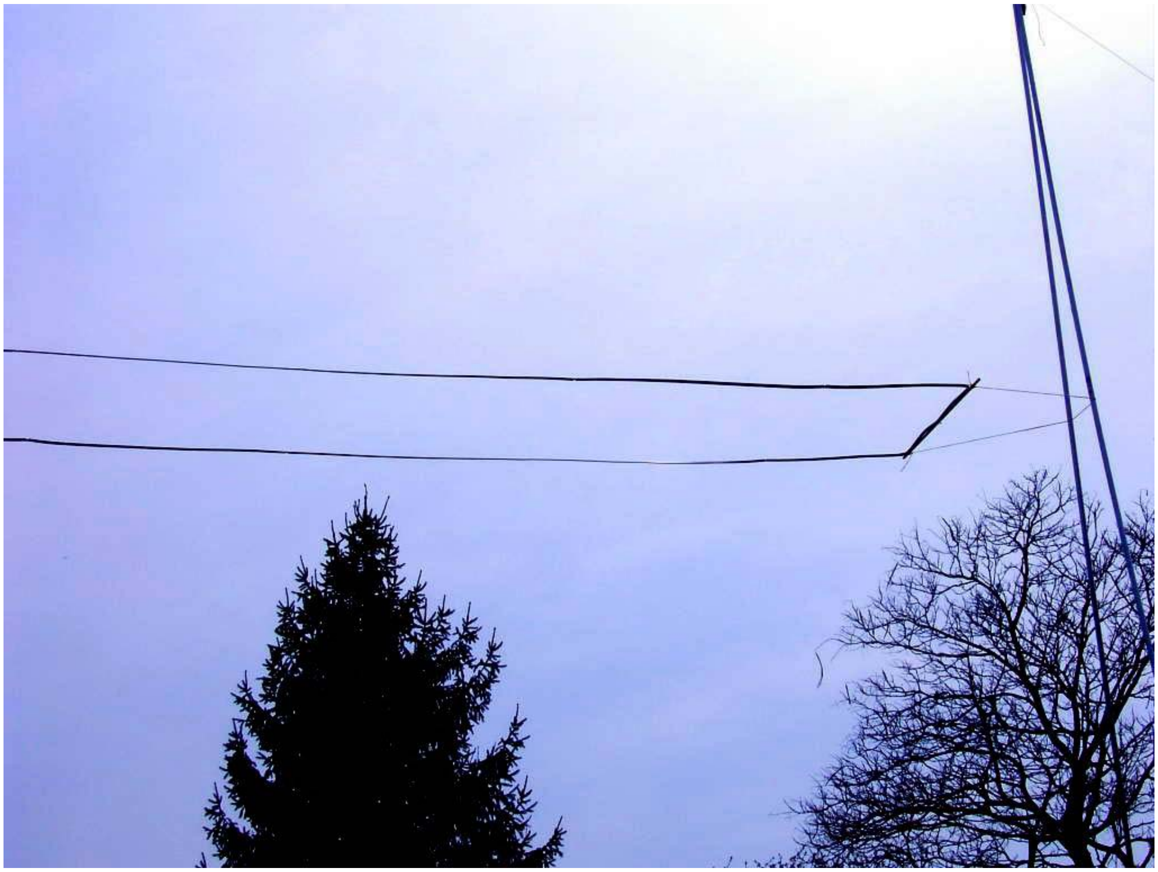


Figure 8d – Far end of array.

Figure 8e – Feed end of array with coax going directly to the operating room. Above the chimney is a 21 MHz uniform current loop also described in this article.

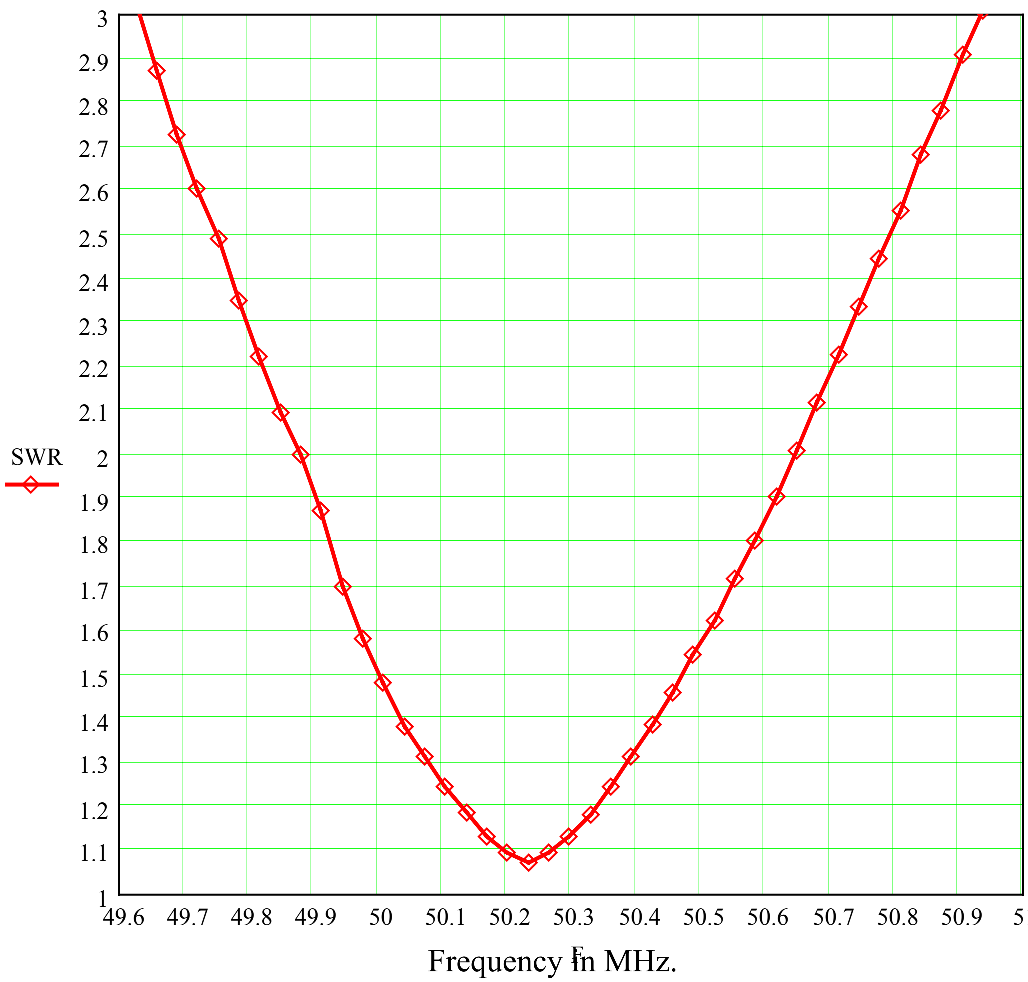


Figure 9 - Experimental SWR curve of W8JK beam antenna. The 2:1 bandwidth is 850 kHz. The curve was measured with an AEA "BRAVO" vector impedance analyzer with a serial port.

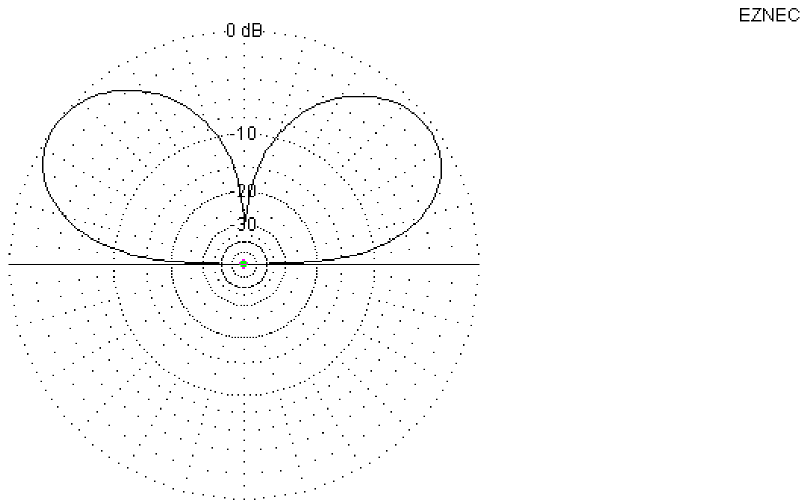


Figure 10 - EZNEC modeled antenna pattern for uniform current loop radiator with a perimeter of 0.80 λ over real earth. The main lobe gain is 4.9 dBi at a takeoff angle of 37.0°.

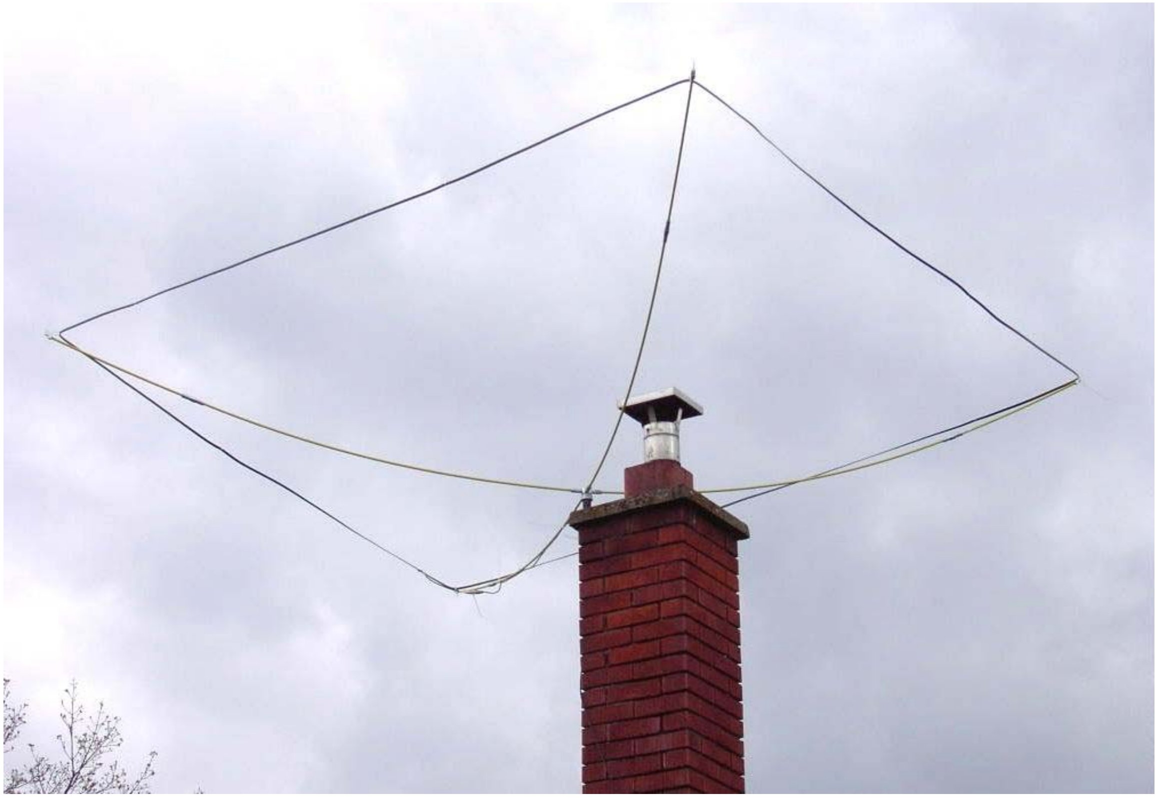
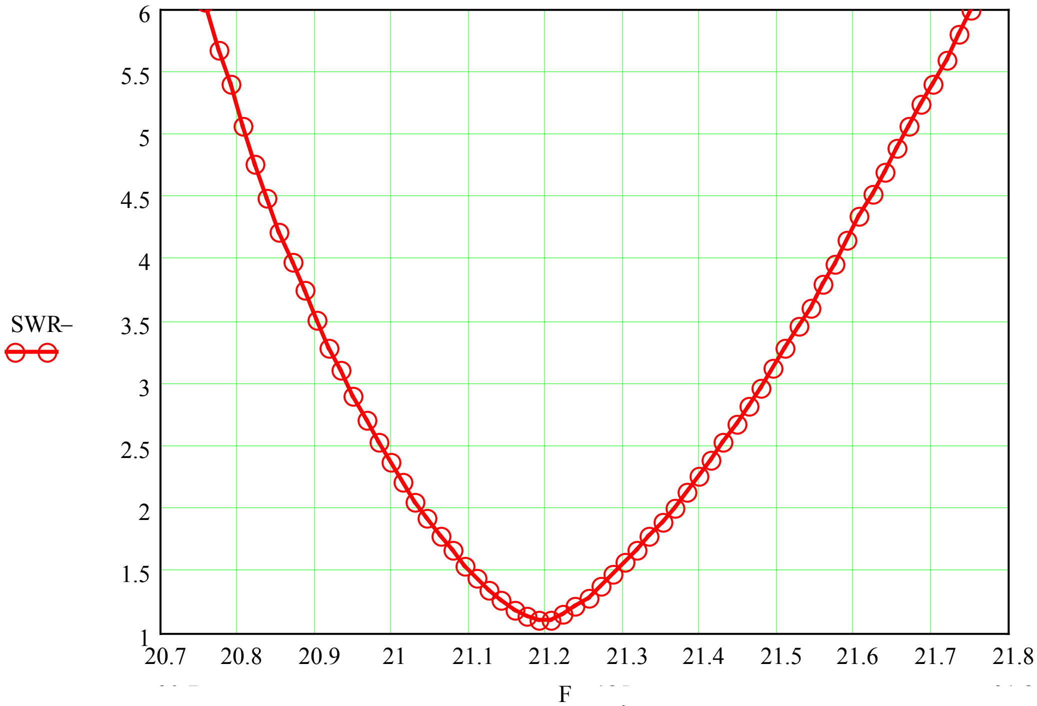


Figure 11 – Photograph of completed 7 section 21.200 MHz uniform current loop.



Frequency in MHz.

Figure 12 – Experimentally measured SWR for 21.200 MHz uniform current loop.