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Confirmation Measurements of Vector Potential Waves

More vector potential communications experiments.

After measurements with multiple antennas and plasma tubes, we confirmed the observations that led Robert Zimmerman and Dr. Natalia Nikolova to announce the detection of vector potential waves.[1] We found another possible explanation for these observations, however, based entirely upon conventional electromagnetic theory and not involving vector potential waves.

We read with considerable interest Robert Zimmerman and Natalia Nikolova's announcements[1, 2, 3] that they had detected and communicated with vector potential (VP) waves, and set out to confirm this discovery. Our approach was twofold. First, we set up an antenna test range for 1296.1 MHz and measured pairs of transmitting and receiving antennas including folded dipoles, a monopole, Zimmerman's waveguide transmit antenna, Zimmerman's plasma tube-in-a-waveguide receiving antenna, a plasma tube in a quart jar, a geometrically similar copper tube in a quart jar and a plasma tube with the cathodes outside the RF path. Second, we modeled these antennas using *EZNEC Pro/2* in ground wave mode to compute the drive impedances and patterns, as an aid to interpreting our measurements. Our experiments began in September 2011 and continued into April 2012. We collected over 500 measurements on the test range.

[1]Notes appear on page 7.

Test Range

Our test range, illustrated in Figure 1, consists of antenna mounts 1.52 m above ground on two telephone poles 15.2 m apart in a goat pasture. The mounts are aligned to bore sight with a tight string. Short lines and wooden clothes pins hold the antennas in position during tests. An isolator at the transmit mount provides low SWR on the transmit feed line. Buried LMR-400 feed lines from the two antenna mounts lead into our shack, where the signals are generated and measurements made.

In the shack, a custom *Java* program digitally generates transmit audio at 1.8 kHz, which is up-converted to 28.1 MHz by a

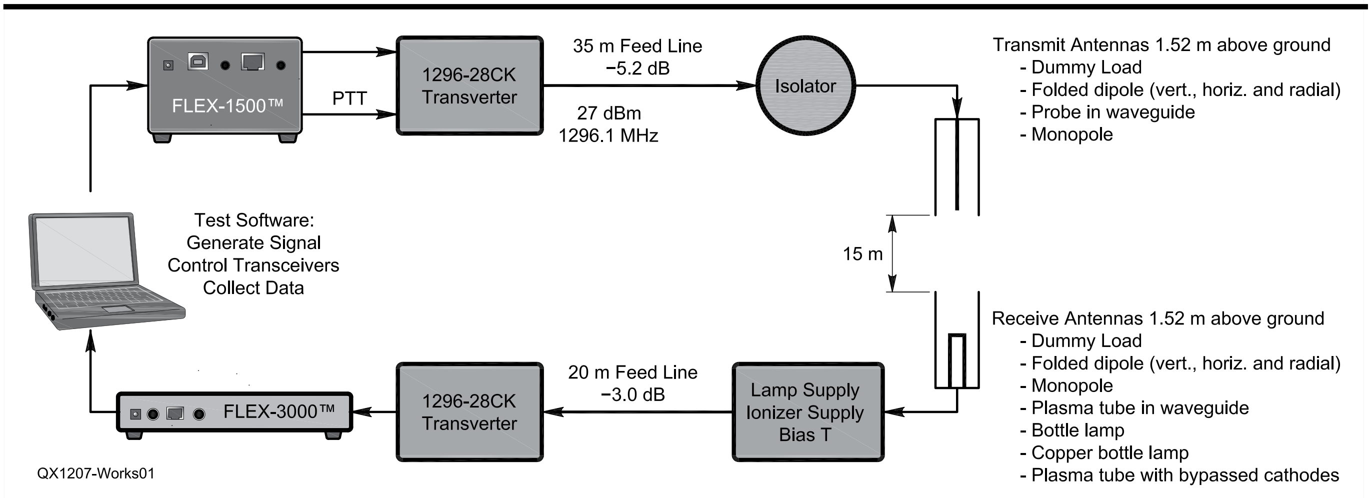


Figure 1 — This diagram illustrates the 1296 MHz antenna test range and equipment set up used for these measurements.

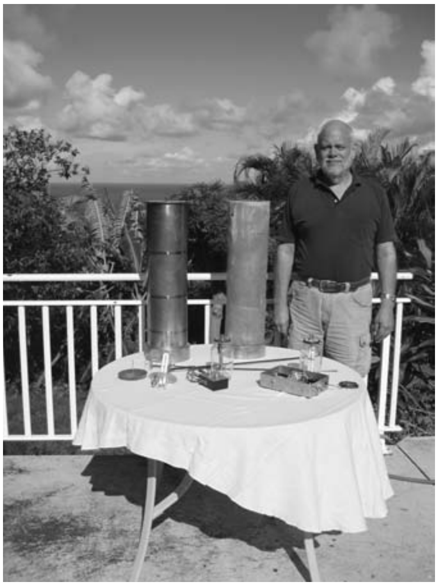


Figure 2 — The author shows the antennas used in these experiments.

Flex-1500 transceiver in USB mode. The transceiver drives a Down East Microwave 1296-28 transverter for further up-conversion to 1296.1 MHz. A second identical transverter feeding a Flex-3000 transceiver, also controlled by the *Java* program, receives the signals. The Flex-3000 receive bandwidth is set to 500 Hz, DSP buffer size to 4096, S-meter averaging to 1.0 s, AGC threshold to 90 and AGC speed to slow. Approximately 21.6 dBm transmit power is available at the transmit antenna. The receive gain is presently uncalibrated, but appears to be constant from day to day.

While George changes antennas on the test range Shelley operates the equipment in the shack. For each test, Shelley informs George of the required transmit and receive antenna types as specified in the test description. George installs the correct antennas and confirms this by cell phone. Shelley starts the test, confirms that the Flex-1500 transmit output is correct, tunes the Flex-3000 to center the received CW signal in the passband, and clicks the "Take Measurement" button on the computer screen. The test software records a file with the date, time, test description, receive frequency and averaged S-meter reading for each measurement. Each measurement set includes receiver noise, cable crosstalk and two folded dipole-to-folded dipole measurements to validate that all is working correctly. Setting up, collecting a full set of measurements, and taking down the equipment in the pasture requires about one hour for each run. Tropical showers and inquisitive goats make it inadvisable to leave equipment set up between runs.

Antennas

Figure 2 shows the assortment of antennas and the plasma tube power supply that we use in our experiments. We fabricated transmit and receive waveguide antennas based on Zimmerman's designs, with 178 mm diameter waveguides 690 mm long. The transmit waveguide is made of sheet brass rather than a stovepipe, and the receive waveguide is made of copper screen wrapped with fiberglass-epoxy. We added waveguide chokes to both antennas to reduce electromagnetic radiation. Folded dipoles are from a design in *The ARRL UHF/Microwave Experimenter's Manual*.[4] The monopole is a quarter wave probe mounted on an N connector centered on a quarter wave radius brass plate.

We used widely available Sylvania Dulux S compact fluorescent lamps, part number CF9DS/78, which look identical to the lamp in Zimmerman's photos. These are "low mercury" lamps, which is the only type now sold in the US. Zimmerman's lamp was apparently not a "low mercury" lamp. We removed the plasma tubes from their bases, which contain lamp starters. The two leads from one end of the plasma tube are soldered directly to the center pin of an N connector, and the two leads from the other end are soldered to a ground lug. Figure 3 shows a fluorescent lamp as received, a lamp with its base removed, and a plasma tube installed on a brass plate ready for mounting on the receive waveguide. A thin piece of Kapton tubing supports the plasma tube.

In addition to the plasma tube in the receive waveguide we installed a second plasma tube in a quart jar with an N connector mounted on the lid, in the same folded monopole configuration used in the waveguide. The tube in a bottle proved to be about 4 dB less sensitive than the plasma tube in the waveguide, but was considerably more convenient to carry around.

We powered our plasma tubes on direct current, like Zimmerman's original design, using a custom-built dc-dc converter and bias-T. The dc-dc converter delivers 260 V dc to an un-ionized lamp, but this drops to about 65 V dc across the lamp after the lamp ionizes. Ionizing these lamps requires about 1600 V dc, which is generated by an accessory cold cathode fluorescent lamp inverter with an added voltage doubler rectifier circuit, also mounted in the lamp supply box. A momentary switch activates the ionizing supply to start the lamp. A bias polarity switch on the supply box allows testing the plasma tube with either positive or negative bias current.

Modeling

We used *EZNEC Pro/2* to model each antenna, with the most complex models, the mesh models for the waveguides, having over 9,000 wires. Computed azimuth patterns for each antenna were constructed in ground wave mode using the actual transmitter power, antenna heights and separations on the test range. Figure 4A shows the mesh model for Zimmerman's transmit antenna, and Figure 4B shows the computed vertical, horizontal and total field patterns including ground wave. No antenna had a total field null deeper than about 20 dB, modeled over real ground, which measurements confirmed.

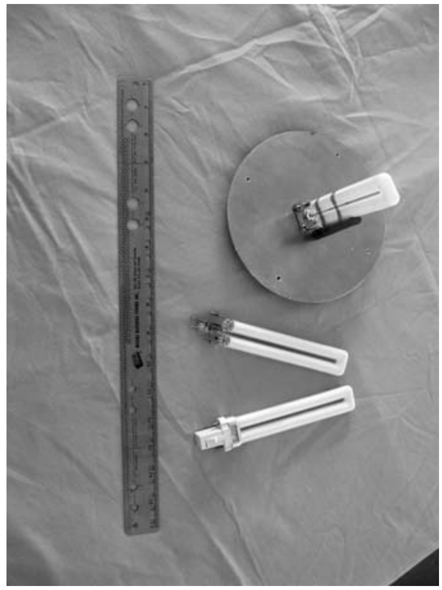


Figure 3 — From the right, here is a lamp, a plasma tube with the base removed and a plasma antenna mounted to a disk to fit in the end of the waveguide.

Evidence for Vector Potential Waves

If there were an antenna that had, over real ground, very deep nulls in its horizontal, vertical and radial fields at the same azimuth angle, then we could declare that any signal we detected with a plasma tube in this near-perfect null was probably due to vector potential waves. We have not discovered such an antenna, either through modeling or measurements, but we found less direct evidence that might suggest vector potential waves.

Nikolova and Zimmerman[3] and later Zimmerman[2] argue that if vector potential waves exist physically and are detectable by a plasma tube, they will modify the momentum of electrons in a plasma that travel at velocities greater than a critical threshold. The phase of the current resulting from the modified momentum depends on the direction of the average current. Reversing

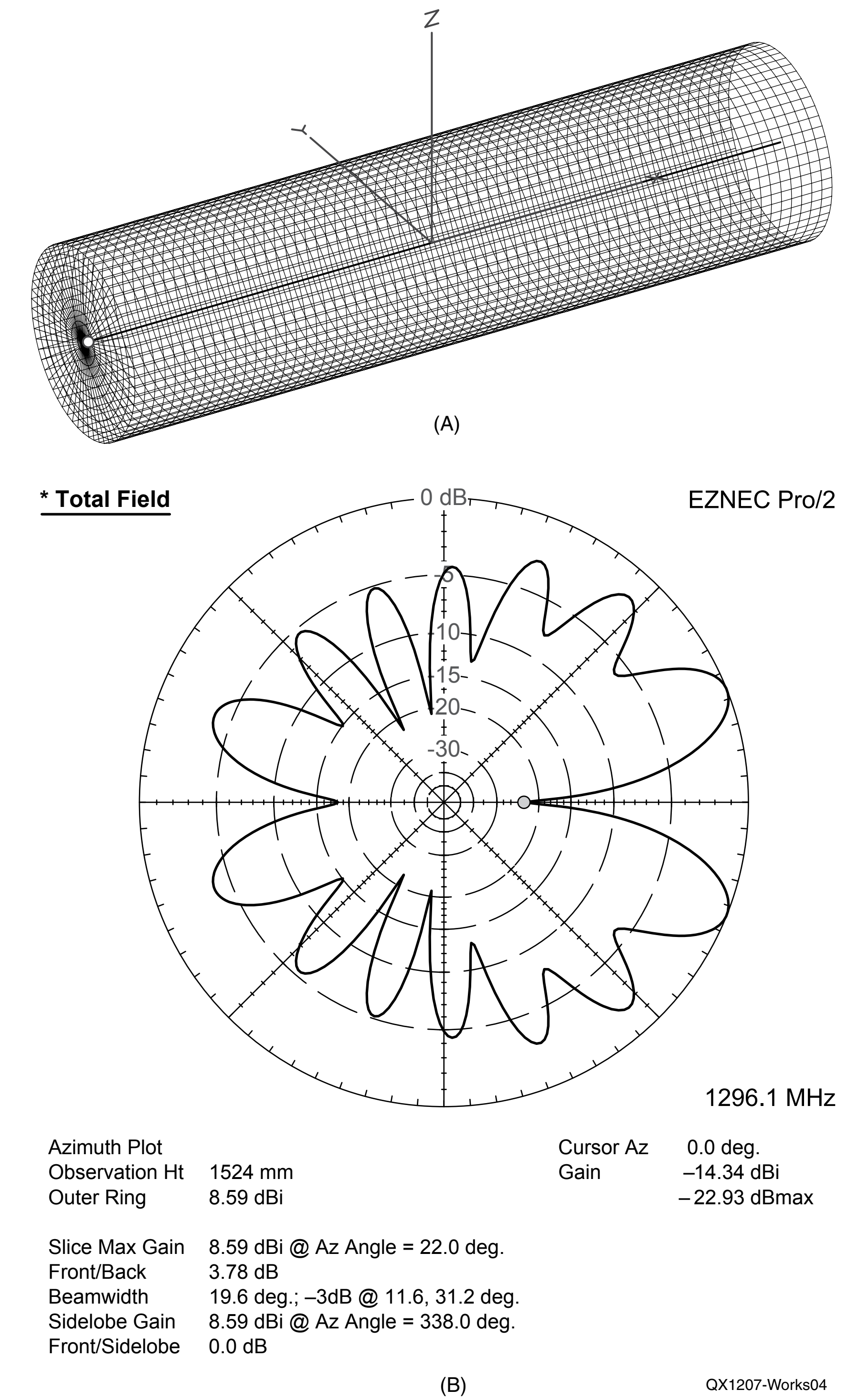


Figure 4 — Part A shows an *EZNEC* mesh model of our (and Zimmerman's) transmit antenna, and Part B is the computed antenna pattern plots.

the bias current reverses the average electron velocity and so reverses the phase of any received vector potential signal. The response of a plasma antenna to electromagnetic waves, however, doesn't depend on the direction of the bias current but only on the plasma's high conductivity. So they expect any signal generated by vector potential effects to add to, or subtract from, the signal due to the electric field.

In particular, they expect to see a greater signal with negative bias than with positive bias if vector potential waves are being detected because the two signals add in phase with negative bias, and out of phase with positive bias. Conversely, if vector potential were not involved, the signal measured with either negative or positive bias should be about equal and it would be equally likely that either one would be the larger. Nikolova and Zimmerman observed these signal differences with bias reversal experimentally using U-shaped plasma tubes similar to ours, with dc bias, and that was key experimental evidence that led them to conclude that they had observed vector potential waves.

We measured signal levels with both negative bias and positive bias on two different U shaped plasma tubes, with five different transmitting antennas, on 89 occasions. In every case the negative bias signal exceeded the positive bias signal as Nikolova and Zimmerman had reported. The probability of that happening due to random chance is less than 2×10^{-27}, which is very unlikely indeed. It seems reasonably certain that something is causing the negative bias signal to be greater but vector potential waves are not the only possible cause. Before we can conclude that we have confirmed the detection of vector potential waves with plasma tubes, we must rule out any other plausible causes for our observations.

Other Possible Causes

Possible sources of asymmetry in our system are the plasma tube structure, the power supply for the plasma tube, the bias T and changes in the plasma shape and fields in the plasma tube associated with the bias polarity. Structural asymmetry in the plasma tube might develop if the tube were operated for an extended period with one dc bias polarity, causing one of the cathodes to be damaged by ion bombardment, or if the mercury relocated to one end of the tube. To explore this possibility we made 10 pairs of measurements on the "bottle lamp" with alternating bias polarity, unsoldered and reversed the plasma tube, and repeated the measurements. The transmitter was a monopole in all cases. For the original configuration, the mean signal difference was 7.2 dB, with a standard deviation of 1.0 dB. For the reversed configuration, the mean signal difference was 6.2 dB, with a standard deviation 0.6 dB. In all 20 cases the negative bias signal was stronger. It appears that any structural asymmetry in this tube is much too small to account for the signal difference.

Asymmetry in our tube power supply might lead to different positive and negative bias currents. Using the bottle lamp load, we measured the bias current 22 times each for positive and for negative bias, alternating the measurements. The mean (of 22) bias cur-

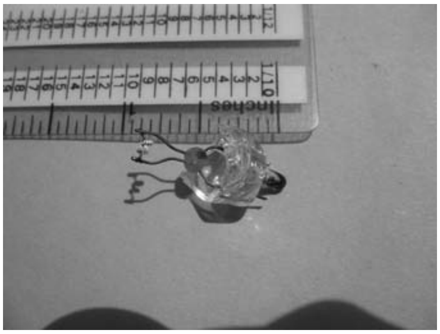


Figure 5 — This photo shows the cathode structure in a CF9DS/78 plasma tube.

rent measurements was 146.4 mA, with a standard deviation of 3.7 mA, and the mean bias current difference (positive – negative) was –2.6 mA with a standard deviation of 3.5 mA. It appears that there is no significant asymmetry in the lamp supply.

Our original bias T design included a pair of 1N4148 diodes shunting the N connector to the transverter as protection against transient voltages from the plasma tube. Large tube noise or coupling capacitor leakage could possibly bias one of the diodes on and attenuate the received signal asymmetrically with bias. We replaced the diodes with a shorted quarter wave stub across the N connector to eliminate this possibility and made 10 pairs of measurements on the "bottle lamp" with alternating bias polarity. The transmitter antenna was a monopole in all cases. The mean signal difference between positive and negative bias readings was 5.3 dB with a standard deviation of 0.8 dB. In all cases the negative bias signal was stronger. Bias T asymmetry does not appear to have caused the bias-dependent signal levels.

Cathode Shift

Ray Cross, WKØO, suggested that an asymmetry may be associated with the cathode location, which shifts from the N connector end to the ground end of the plasma tube depending on bias polarity.[5] He argues that the fields and the shape of the plasma in the tube might be affected by the cathode position, so we investigated the plausibility of this through modeling and direct observation. Modeling can't prove or disprove that these effects actually occur, but it can show whether cathode shift is a plausible explanation for our results that requires experimental investigation.

It seemed possible that at the cathode end, the plasma begins at a "hot spot" on the cathode wire and expands out to nearly the diameter of the tube over a few millimeters. The hot spot would be expected because the higher the temperature of a spot on the cathode wire, the higher the electron emis-

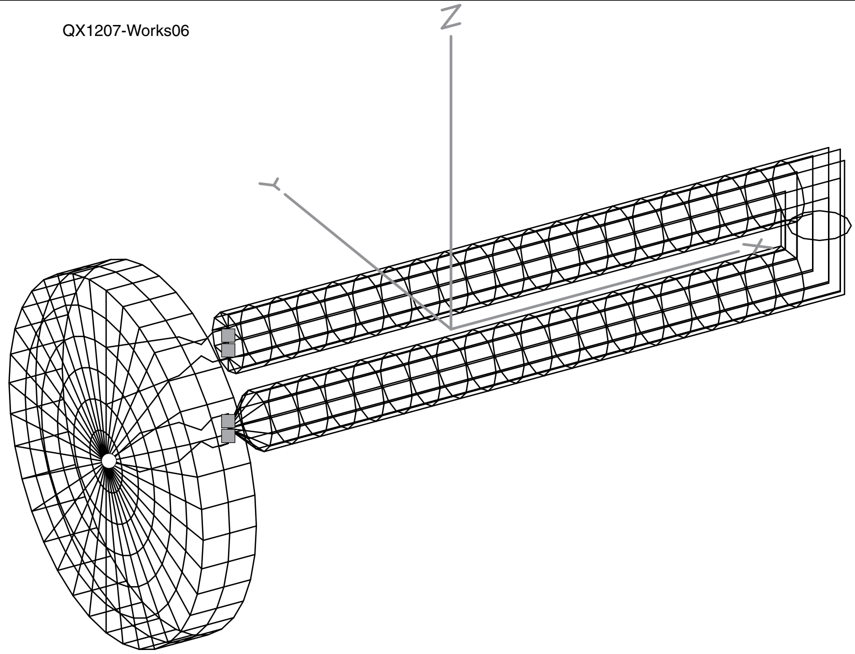


Figure 6 — Here is the bottle lamp *EZNEC Pro* model, with negative bias.

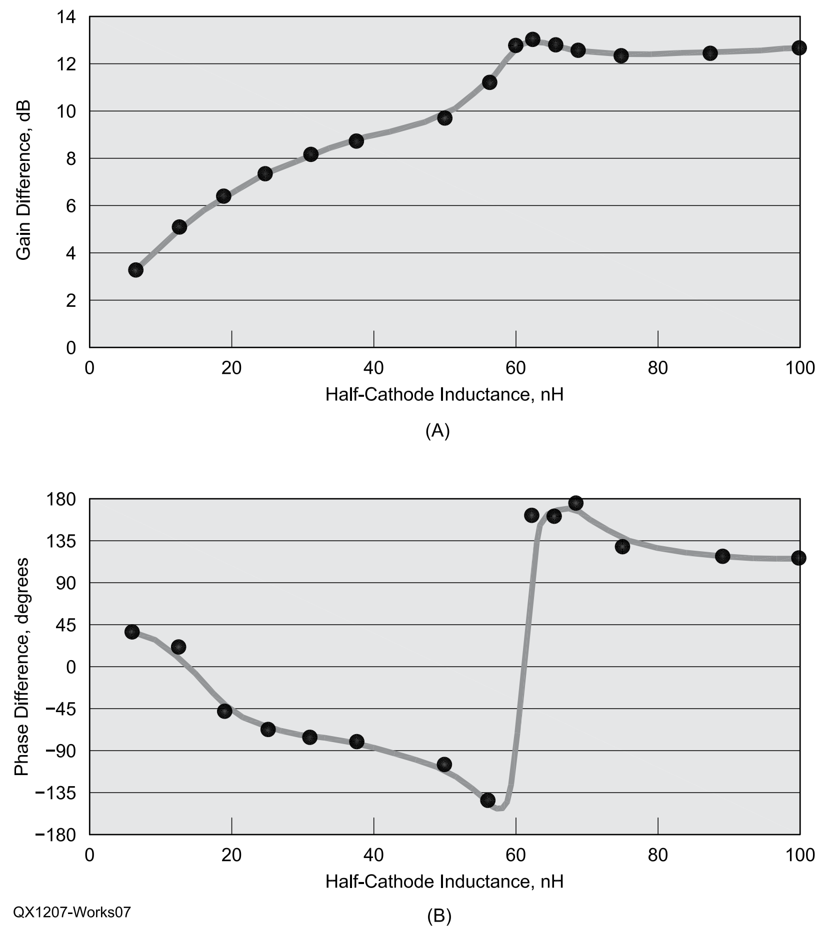


Figure 7 — Part A shows the modeled gain change of the bottle lamp antenna with bias polarity reversal as a function of cathode inductance. Part B shows the modeled phase change of the bottle lamp antenna with bias polarity reversal as a function of cathode inductance.

sion. Higher electron emission means more current, and therefore a higher temperature. But at the anode end electron emission is irrelevant so the plasma might well extend past the electrode wire into the area of the support wires, shorting out the inductance of the electrode wire.

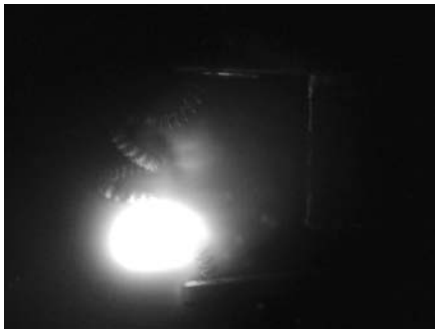
Figure 5 shows a cathode and support wires from one of the CF9DS/78 tubes that we used in our experiments. The cathode is coated with a white electron-emitting material and consists of a coil of very fine wire, coiled into larger coil, and this is coiled into a still larger two-turn coil supported by two horizontal support wires. We measured the inductance of this cathode with an L-C meter at 600 ± 30 nH between the two support wires. If the plasma attached to a hot spot at the center of this wire, it could place the inductance of the two halves of the cathode, paralleled, in series with the plasma tube at the cathode end. This series inductance could be as much as 75 nH.

We modeled the cathode structure and plasma in the bottle lamp, with the plasma beginning at a hot spot in the center of the cathode and ending at the support wires at the anode. Figure 6 shows the mesh model with negative bias. We represented the cathode inductance as a lumped inductance in each half of the cathode, and varied this half inductance while recording the gain and phase of the bottle lamp antenna for each bias polarity. Figure 7A shows the antenna gain difference and Figure 7B shows the received signal phase difference between positive and negative bias as a function of inductance. A cathode half inductance in the range of 15 to 40 nH would be consistent with the 5 to 8 dB gain differences that we measured on the test range. Although we did not measure phase difference, Nikolova and Zimmerman did, and the phase difference that they measured also appears consistent with this model.

There remained the question of whether the cathode hot spot actually occurs in these tubes. We obtained some transparent 9 watt U-shaped tubes without phosphor coating, made for ultraviolet sterilizers, part number PLS9W/TUV, and constructed a second bottle lamp with one of these tubes. Using a digital microscope and optical filter sheets, we were able to photograph the cathode and anode while the tube was ionized.[6] Figure 8A shows the anode and Figure 8B shows the cathode, with different filters required for each image to avoid saturating the digital microscope. The cathode in these sterilizer tubes has a three-turn outer coil instead of the two-turn coil in the tubes that we used in the test range but we would not expect this to affect the presence or absence of a cathode hot spot.

Figure 8A shows that the plasma at the anode end does in fact surround the coiled electrode wire and its supporting wires, and fairly uniformly heats the wire along its length. Figure 8B shows that the plasma attaches to the cathode at a single very bright hot spot. When the tube is first ionized the cathode glows uniformly, and over a period of about one second the glow coalesces into the single hot spot. The exact position of the hot spot varies as the tube is repeatedly turned off and on.

(A)



(B)

Figure 8 — Part A shows an image of the anode and plasma in an ionized 9 W U-shaped tube. Part B is an image of the cathode, showing a hot spot in an ionized 9 W U-shaped tube.

Conclusions

We confirmed Nikolova and Zimmerman's observations that a 9 W U-shaped plasma tube, connected as a folded monopole in front of a ground plane, receives a stronger signal with negative dc bias than with positive bias. This effect seems to be completely explained by conventional electromagnetic theory and the construction of U-shaped fluorescent tubes, however, without any need to assume vector potential waves. This does not prove that vector potential waves do not exist physically. They may exist and be detectable by other means, but their existence cannot be inferred from our experiments.

Our test data, antenna models and design details are available by email request to KJ6VW@ARRL.net.

George Works, KJ6VW, was first licensed in 1961 as WA2PAY. He enjoyed experimentation and constructing his own equipment and served as a volunteer civil defense radio operator. He received a BSEE from MIT in 1966 and held engineering and management positions at several companies before retiring in 2005. George is a private pilot and has captained a sailboat around the Pacific and around the Caribbean where he operated maritime mobile. He now raises goats, cows and chickens on a small farm on the island of St. Eustatius, Dutch Caribbean. He operates a very active Winlink station serving the Caribbean and many maritime mobiles, installs satellite terminals and consults as a volunteer on information technology, solar energy and similar projects on the island.

Shelley Works, KG4SRS, was first licensed in 2002. She received a BS degree in mathematics from Salisbury State in 1976 and worked as a software engineer and engineering manager before retiring in 2005. Shelley is also a private pilot, a sailor and an avid gardener, raising a variety of fruits and vegetables in her extensive garden. She enjoys reading novels in Dutch, which she has learned since retiring. She developed the records and billing software and website for the St. Eustatius Animal Welfare Foundation, and websites for several other island organizations.

Shelley and George discovered St. Eustatius while sailing on their boat in the Caribbean and decided on the spot to buy a house and retire there. St. Eustatius is a tiny Dutch island of 3000 inhabitants with few street numbers and no postal codes. They live on the side of a dormant volcano 700 feet above sea level, overlooking the Caribbean.

Notes

[1]Robert K. Zimmerman, NP4B, "Transmission and Reception of Longitudinally-Polarized Momentum Waves," *QEX,* July/August 2011, Issue 267, pp 31-35.

[2]Robert K. Zimmerman, "Macroscopic Aharonov-Bohm Effect at L-Band Microwave Frequencies," *Modern Physics Letters B,* Vol. 25, No. 9 (2011), pp 649-662.

[3]Natalia K. Nikolova and Robert K. Zimmerman, *Detection of the Time-dependent Electromagnetic Potential at 1.3 GHz,* McMaster University, Research Report CEM-R-46, November 2007.

[4]*The ARRL UHF/Microwave Experimenter's Manual*, The American Radio Relay League Inc, 1990, p 9-7.

[5]Ray L Cross, WKØO, unpublished e-mail correspondence, dated 12 March 2012.

[6]If you plan to observe one of these sterilizer tubes in operation, remember that the very bright UV light can damage your eye as well as saturate an image detector. To be safe, either cover the tube with an opaque shield during operation or wear a pair of UV safety goggles.

QEX