# Broadband Electrically Short Transmitters via Hi-Speed Time-Varying Antenna Properties

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***Abstract*—Antennas that are much shorter than a wavelength typically have very limited bandwidth due to impedance matching issues. We detail a new technique to achieve efficient, broadband operation using impedance matching in the time domain, rather than traditional frequency domain strategies such as a top hat. We present some initial simulations comparing our impedance matching concept to a traditional electric dipole antenna and detail an effort to build such an antenna using two implementation strategies.**

***Keywords*—wideband antennas, electrically short antennas, transmitting antennas, VLF, impedance matching**

## I. INTRODUCTION

Electrically short transmitting antennas have hampered performance, sacrificing either bandwidth or efficiency if not both. This results from a combination of both fundamental physcis and engineering limitations.

If one builds an electrically short dipole with a fixed length and then decreases the frequency, the radiated power will go as $f^4$. But from Maxwell's equations leading to the "Ideal (Hertzian) Dipole", one can see that the scaling should only be $f^2$ (alternatively one can examine the radiation resistance which also goes as $f^2$). The other $f^2$ factor results from impedance matching since the input impedance of a short dipole goes up as $\frac{1}{f^2}$ and is capacitive in nature. As the impedance goes up, the same voltage generates smaller amounts of current, and without current there is no radiation. We cannot change Maxwell's Equations, but if we could get around the high impedance, which is an engineering issue, the fundamental laws of physics ought to allow much better performance for electrically short antennas. In practice, the way around this is impedance matching. Unfortunately, existing impedance matching strategies recover the extra $f^2$ factor but at the expense of bandwidth.

For example, in the VLF band (3-30 kHz), this problem is especially severe. Wavelengths are 10-100 km, far too big for a practically realizable half-wave dipole. A vertically oriented antenna will be too short, and a horizontally oriented antenna will be limited by the image current just below the ground. The engineering solution to this is the top hat, in which a large capacitive structure is placed near the tip, to reduce the capacitive impedance, and then an inductor (positive imaginary impedance) is placed at the base to cancel out the remaining capacitance. This resonant antenna strategy is known to achieve good efficiency for >10 kHz transmitters, but the top hat requires many km$^2$ footprints to achieve at best 1% bandwidth. Furthermore, the solution breaks down below 5-10 kHz, where ohmic losses dominate over the radiation resistance.

On the other hand, if we could build compact and reasonably efficient VLF transmitters (or electrically short transmitters in general), a host of applications would be impacted, including global and undersea communications, global GPS-independent navigation, geophysical prospecting, space physics wave-particle interactions, over-the-horizon radar, and others.

VLF propagation through the Earth-ionosphere is fairly well understood, though complicated being anisotropic and dependent on local geophysical conditions. VLF reception is

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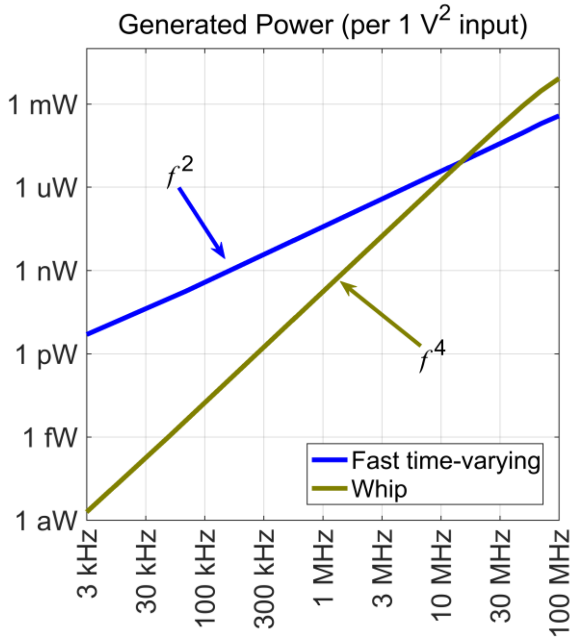
now possible, with highly sensitive receivers in existence far better than 1 fT/rt-Hz sensitivity [1]. But the capability to generate VLF has essentially not changed in many decades.

## II. A NEW APPROACH

We have developed a technique to control the input impedance via rapid variation of the conducting properties of the antenna, faster than the propagation delays of voltages and currents through the system. Under this approach, the antenna never reaches steady state, so that traditional antenna theory, which is usually in the frequency domain, does not describe its properties. Because our impedance matching scheme is done with temporal variations instead of frequency resonance, it is fundamentally broadband in nature.



We have simulated our technique using an FDTD model of an antenna, and evaluated the current moment to determine the radiated power as a function of frequency.

Fig. 1. FDTD simulations of our antenna compared to a standard whip

Figure 1 shows, for a 1-meter antenna, how our calculated power compares to a simulated whip antenna. It should be noted that the whip antenna does not have any impedance matching, so for a given application good efficiency can be achieved, but only in a narrow frequency band.

Our technique is able to achieve that over a huge band. Furthermore, our results agree that we are able to reproduce an $f^2$ dependence of power with frequency, consistent with the creation of an Ideal (Hertzian) Dipole over a huge bandwidth range. This results in several orders of magnitude high efficiency in the VLF frequency band (3-30 kHz).

More broadly than just the electrically-short antenna, we envision a new class of antennas whose properties can be varied on time scales so fast that sinusoidal steady state is never reached.

## III. IMPLEMENTATION

In order to implement this, we need an antenna whose properties can be controlled on very rapid timescales. For instance, for a 1-meter antenna, the propagation delays will be on the order of 10 ns. So we need to vary the properties of the antenna on the timescale of 1 ns (or 1 GHz). On the other hand, we still want the antenna to conduct high power. The requirement for both high speed and high power is not an easy one.

The more straightforward strategy is to use off the shelf electronic parts (transistors, switches, transmission lines) to implement hi-speed antenna manipulation. We are able to find off the shelf semiconductor-based parts that can reach the necessary speeds and conduct hundreds of mA of current. Utilizing our antenna and radiation model, we predict that should allow us to generate roughly 200 μW of power at 300 kHz wih a 3-meter antenna (for which the antenna is 3% of a wavelength). When operated over a ground plane this projects to a magnetic field of roughly 1 fT at `200 km distance, which we are currently pursuing as a demonstration.

A more challenging implementation is to replace the metal/semiconductors with a plasma chamber containing a steady glow discharge. A plasma can conduct a huge amount of current, so if the conductivity can be switched at ns speeds, we could radiate much higher power. We can vary the conductivity of the plasma (or alternatively, the plasma frequency) significantly just by varying the electron density by a couple orders of magnitude. The antenna can also be made to `disappear' from radar detection when the plasma is turned off. However, this requires a carefully engineered system to have both high-speed ionization and quenching, and requires power input to maintain the plasma.

To test out the capabilities of a plasma as a conductor, we have built a plasma test chamber with inputs for gas pressure, ionization and signal injection electrodes, and can vary the type and mixture of gases, voltage on the electrodes, electrode shape and separation, and gas pressure.

We are also modeling the plasma with a particle-in-cell (PIC) code to track the electron energy distribution, so we can theoretically test out different configurations faster than we can experiment in the lab.

## IV. FUTURE PLANS

We are currently pursuing both implementation strategies and will detail them in this presentation. We are also preparing for a demonstration of the electromagnetic principles, using a high-sensitivity VLF receiver known as the `AWESOME’ [1]. We will describe our efforts, both on the theoretical side, and on the experimental side, for both the electronic and plasma configurations.

## REFERENCES

[1] Cohen M. B., U. S. Inan, and E. W. Paschal (2010), Sensitive Broadband ELF/VLF Radio Reception with the AWESOME Instrument, *IEEE Trans. on Geoscience and Remote Sensing*, 48, 1, 3-16, doi:10.1109/TGRS.2009.202833