Discovery and Theory of Small Antenna Near-field Dissipation and Frequency Conversion with Implications for Antenna Efficiency, Beverage Antenna Noise Reduction, Maxwell's Equations and the Chu Criterion

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Abstract— The thermal efficiency measured on surface of small antenna conductors is generally found to be much larger than the radiation efficiency measured outside the near-field region. The difference can reach 10 to 20 dB or more at some frequencies. High thermal efficiency means that the surfaces of the antenna conductors do not get excessively hot even with several hundred watts input. Low radiation efficiency with high thermal efficiency means that RF has 'disappeared' in the near-field region. Measurements made so far have discovered that this missing RF in part is converted into low temperature white noise with a flat spectrum up to about twice the carrier frequency. An additional discovery is that part of the 'lost' energy can become attached to any steady modulation sidebands on the transmitted signal so that in the 'dissipative non-linear near-field region' the carrier is more attenuated than some of the sidebands. The additional sideband energy appears to come from reduction of the white noise.

The theory for this 'near-field dissipation and frequency conversion' effect was developed originally to explain measurements made on the 'Wideband Small Loop-monopole HF Transmitting Antenna' announced at PIERS 2013 in Taipei [1]. It is compatible with and based on the 'Physical Model of Electromagnetism' announced at PIERS 2011 in Morocco, [2] and extended in other subsequent papers [3–10].

The discovery of this small antenna 'non-linear' near-field effect would appear to have widespread implications, for example for antenna efficiency, Beverage antenna noise reduction, Maxwell's Equations and the Chu Small Antenna Q Criterion [12]. This effect naturally links to an Electromagnetic Theory of Everything as initiated in [2] and extended in and from [3–10].

1. INTRODUCTION

A small antenna was required to meet the need for a highly portable wideband transmitting antenna for 'anomalous' wave-tilt measurements in the HF band [13]. The novel 'Wideband Small Loop-monopole HF Transmitting Antenna' [1] was invented and crafted to fulfil this requirement. The original example of this loop-monopole concept is shown in Figure 1 and its simple 'wiring' configuration is shown in Figure 2. The original loop-monopole had two turns of coaxial cable, but an increase to three turns gave a small but useful decrease of lowest frequency of operation [1].

Figure 1: Picture of 90 cm loop-monopole with MiniVNApro (Bluetooth connected) vector network analyser at bottom.

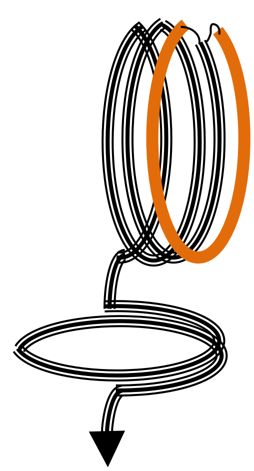

Figure 2: Schematic of loop-monopole seen in Figure 1.

The foldable square loop shown in Figure 3 has three turns of cable. The foldable 'all-coax' loop-monopole of Figure 4 therefore has a total of four turns of cable. All these loop-monopoles exhibit the unprecedented wideband matching performance (2 to 200 MHz) that is characteristic of the loop-monopole antenna.

The total length of the feeder cable was found to be the main parameter determining the lowest frequency of operation of the antenna. The SWR steps down to $\sim 10:1$ when the total coaxial cable length is a quarter wave $\lambda/4$, and steps down to $\sim 6:1$ when the cable length is $\lambda/2$ [1].

2. THE 'MISSING RF' OF AN ANTENNA FOR TRANSMISSION AND RECEPTION?

A very significant discovery for the loop-monopole small antenna at the lower frequencies of operation is the very high measured thermal efficiency $\sim 95\%$ as contrasted with the very poor radiation efficiency $< 1\%$. Thermal efficiency measurements have been with 700 watts input mainly at 3.7 MHz, using non-contact thermometers and a Protek IR thermal camera as noted in [1]. The observed temperature rise of the loop is estimated to correspond with a heat dissipation of ~ 35 watts. The radiation efficiency was estimated by practical measurements of field strength of a transmitted signal of a given power both by 'the two-identical antenna method' and the A/B.

The main question for investigation is what happens to the RF energy that leaves the antenna with 95% efficiency and fails to arrive in the far-field so that the measured radiation efficiency is less than 1%, and the small antenna gain is worse than -20 dB? Is it dissipated as heat or thermal noise energy in the near field space? At what temperature is the heat? What is the heat or thermal energy spectrum for different transmitted frequencies and with different modulation types and spectra? What are the mechanisms of energy conversion? What is the measured formula for (small) antenna efficiency in terms of size and absolute frequency or wavelength? What explanations are there for what is measured? What old or new theory is there for the explanations?

An experiment has been undertaken aimed to detect whether the lost RF energy exerts any measureable reaction force on the loop-monopole antenna structure itself. Figure 4 shows the four turn loop part of the loop-monopole suspended as a pendulum by its own feed cable, with a suspension cable length about 105 cm. The antenna is measured to be directional as a result of the combination of its electric and magnetic radiation modes. With 700 watts of power supplied giving a local magnetic field equivalent to about 4 amps in to 4 turn into a square coil of 70 cm sides, no measureable directional reaction force was detected by the pendulum even when the RF was switched on and off synchronously to excite the pendulum frequency. The limit of delectability was estimated as being < 100 dynes or < 0.1 gram. A null result.

Comparisons of relative antenna gains have also been made of received signal strengths from various distant sources for the loop-monopole compared with full wavelength horizontal loop antennas at 2 m and 15 m heights. The antenna relative gains/efficiencies found by this A/B comparison

Figure 3: 70 cm sided square copper loop foldable loop-monopole with MiniVNApro and battery operated XGA3 DDS signal generator below.

Figure 4: 70 cm square foldable 'all-coax' loop-monopole in plastic conduit, suspended to detect reaction forces. (None seen with 700 w RF input.).

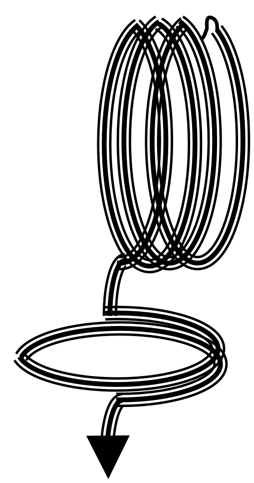

Figure 5: Electrical connection of 'all-coax' loop-monopole. Inner connects to outer of previous turn to make the loop.

reception method are essentially the same as found using the transmission methods. 'Reciprocity' is found to apply.

A further significant discovery is that the received atmospheric noise can be reduced well below thermal noise for the measured antenna impedance provided that low loss coaxial cable is used for the loop monopole construction. Where is the missing RF noise? What is the explanation and theory for this? And how can it be used? What else can it explain?

3. DISCOVERY OF TWO FREQUENCY SPECTRUM CONVERSION PROCESSES IN THE NEAR-FIELD REGION OF (SMALL) ANTENNAS

If the lost RF is not converted into a force or pressure moving the EM ether surrounding the antenna to create a detectable reaction force, then perhaps the lost RF is converted into broadband noise? This is the first assumed conversion process to be investigated. For the assumption that the broadband noise is white and extends only up to twice the carrier frequency f_c, we can calculate the resulting maximum noise level N (in 1 Hz bandwidth at a given frequency f)) relative to the remaining carrier αC) given the proportion α of the carrier power C that has been converted to white noise. This is what can be measured on a spectrum analyser or SDR receiver. Note that it is independent of the pass loss between the two antennas, one of which is the loop monopole. We then have a predicted maximum observable carrier to noise ratio (CNR) of

$$\text{CNR} = N/\alpha C = \alpha/(1-\alpha)2f_c \tag{1}$$

For example at the carrier frequency of 3.5 MHz and assuming 90% of the original carrier power is converted to white noise up to $2 \times 3.5 = 7$ MHz the maximum CNR is $N/\alpha C = 0.9/0.1 \times 7 \times 10^6$ or -59 dBc/Hz. But as yet the measured noise level is usually at least 10 dB lower than this. Not all the lost power has been accounted for.

The second RF energy conversion process that has been discovered is shown in the comparison of Figure 6 with Figure 7. The triple spectrum plots are from WinRadio WR-G31DDC SDR radio receiver. Figure 6 shows the output spectrum of the Elecraft battery operated XGA3 DDS signal generator giving -4 dBm output at 3.52 MHz. The 10 Hz spur sidebands in the top right spectrum are symmetrical about the carrier starting at -63 dBc and falling slowly to about -67 dBc levels.

Figure 7 shows the spectra from the loop monopole antenna when received by a full-sized antenna at a minimum distance of about 15 m, this being the height of this antenna. The received carrier level is -57 dBm and the 10 Hz sidebands as received can be seen to be unsymmetrical and no longer approximate equal in amplitude. The largest sideband at $+10$ Hz is at -48 dBc. This is some 16 dB higher than its original dBc level. The question is what physical process has made this happen? The modulation level of this component has been increased? Why? It is a very significant discovery.

A clue to what is happening can be seen in the top left 17 second spectrum waterfall of Figure 7. Some of the 10 Hz spaced sidebands are fluctuating randomly with periods between 1 and 2 seconds. This means that energy is being transferred to and from each component in by low level coupling

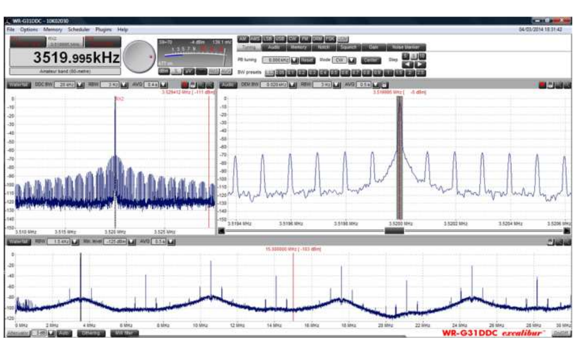

Figure 6: Three direct output spectra of battery operated XGA3 DDS signal generator at 3520 MHz. Clockwise from bottom: 0 to 30 MHz; 60 kHz span; and 120 Hz span showing equal 10 Hz spaced sidebands.

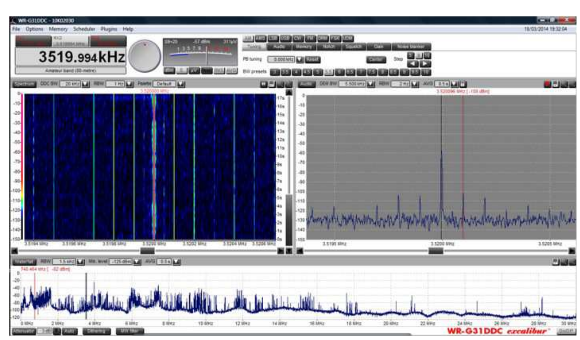

Figure 7: Three spectra of XGA3 at 3520 MHz transmitted from loop-monopole in glass conservatory to outdoor 83 m perimeter loop at 15 m. Clockwise from bottom: 0 to 30 MHz; 120 Hz span upward time 'waterfall'; and 120 Hz span showing time fluctuations of unequal 10 Hz spaced sidebands.

from adjacent noise and spur components. This effect has been found and to some extent explained in LC and crystal oscillator spectra [13, 14].

4. INITIAL THEORY OF SMALL ANTENNA DISSIPATIVE LOSS AND NEAR-FIELD ENERGY FREQUENCY CONVERSION

The near-field loss can be explained by defining radiated power flow as the product of a radially directed (generalised) 'power current density' bi-vector I and a (generalised) 'power potential' vector-scalar Φ in which the power current sits. These I and Φ symbols have previously been defined for use in the 'Generalised Poynting Vector' (GPV) in reference [1].

The power current density and the power potential are assumed to originate at the boundary of the small antenna sphere that contains the small antenna as shown in Figure 8. Local conservation and spherical symmetry requires that I has a $1/r^2$ inverse square law spreading function and Φ has a $1/r$ inverse law spreading function. The total power flux at distance r is $P = I \times \Phi$.

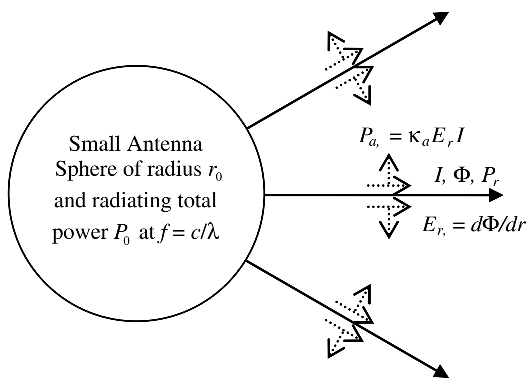

Figure 8: Conversion of lost RF energy to white noise and fluctuating sideband components. Filaments of power beyond the small antenna sphere are progressively attenuated on account of the radial field E_r. The azimuthally radiated power P_a from each radial current filament is opposed by the P_a power from adjacent current filaments. The cancellation of azimuthal power flow appears to cause the attenuation and spectrum conversion of radial power P_r.

But now there is a 'conservation' conflict to be resolved. Classical power conservation states that the total power flux (when in a lossless medium) is constant out to any radial distance. This is the basis of all propagation equations used in sonar, radio, wireless, and optical, communications, radar, and astronomical telescope systems. The classical assumption is that this (inverse square) law extends unchanged down to the sub-wavelength distances of a small antenna. Here we have found by real (not simulated) measurements that this is not so. We need to identify processes that can account for the measured losses of small antennas, and can at least be calibrated to become useful (small) antenna design tools.

Figure 8 shows a process by which the power density from a small antenna is attenuated more than the usual inverse square law spreading function. $E_{r,} = d\Phi/dr$ is the radial field being the gradient of the potential Φ. As in [1] and [2], a radial current I attempts to radiate at right angles proportional to the radial field E_r along each part of the (conical) current filament. κ_a is the coupling constant that determines the radiation proportion per unit (radial) length. The radial potential has the normal inverse distance law so that $\Phi_r = r_0\Phi_{r0}/r$ and $E_r = r_0\Phi_{r0}/r^2$. We then have a (novel) differential equation for the attenuation of the total radiated power P_r with distance, starting at P_0 at r_0, together a solution (of the type originally put forward in [2]):

$$dP_r/P_r = \kappa_a \lambda dr/r^2 \quad \text{having a solution:} \quad P_r = P_0/\left\{1 - \exp(\kappa_a\lambda/r)\right\} \tag{2}$$

With $\kappa_a = \kappa_0 = 1/2\pi$ (the limiting value of EM coupling between two parallel filaments) we find a loss $P_r/P_0 = 1 - 1/e = 0.63$ or 2 dB at the classical small antenna boundary radius of $r = \lambda/2\pi$. But small tuned antennas are found to have radiation loss decreased approximately as the square root of antenna Q. A typical small tuned loop of 1 m diameter will have a $Q \sim 250$, giving a $\sqrt{250} = 15.8$ times reduction in the small antenna radiation efficiency radius. For example a 3.75 MHz tuned loop should have a minimum diameter of 1.6 m to have 63% radiation efficiency.

5. CONCLUSIONS

Measurements confirm that the novel small high power wideband loop-monopole emphatically contradicts the Chu small antenna Q criterion as it was originally stated [11]. Measured antenna Q values are typically two to three orders of magnitude lower than those predicted by the Chu Q criterion. At low frequencies the loop-monopole has low gain but with a noise temperature well below ambient temperature.

However the *radiation* efficiencies of small antennas obtained by field strength measurements do fall with frequency at 6 dB per octave below cut-off frequencies f_e that depend on antenna physical size, type, and operating Q. This is more in agreement with the so-called Chu small antenna 'efficiency' criterion (created by Chu supporters and not by Chu himself) [11]. The efficiency criterion assumes that the lost RF energy is dissipated in any antenna conductor loss resistances. Measurements show that this is not so and that in general small antenna *thermal* efficiencies can be made high ($> 95\%$). Early evidence indicates that the cut-off frequency for *radiation* efficiency f_e is inversely proportional to the square root of frequency in agreement with what has been found in practice for the electromagnetic coupling factor [1–5, 7, 9, 10].

Practical measurements indicated that the 'lost' RF energy is frequency converted partly into low white noise at a density and temperature proportional to the transmitter power and partly attaching to and enhancing some of the longer duration modulation sidebands of the transmitter. On reception this process could account for the reported signal-to-noise ratio improvement of the Beverage antenna, in spite of its low antenna gain.

This discovered 'spectrum conversion process' can be said to be 'non-linear' electromagnetic process. It links into, and can be made an intrinsic part of, an Electromagnetic Theory of Everything as initiated in [2] and extended in [3–10].

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