On the possibility of UWB passive microwave imagery from static discharge effects.

Q-par Angus Ltd

IDEAS ENGINEERED

As published in IEE Electronics Letters

Vol. 40, No. 18, pp1116-1118, September 2004.

Barons Cross Laboratories,
Leominster, Herefordshire, HR6 8RS, UK.
Tel: +44 (0) 1568 612138 Fax: +44 (0) 1568 616373
Web: www.q-par.com E-mail: sales@q-par.com

Technical Report

On the possibility of UWB passive microwave imagery from static discharge effects.

Andrew Mackay

It is well known that spark transmitters can be sources of ultra wide band (UWB) radiation. It is also known that high voltage low energy static discharges are ubiquitous in nature, whenever there is friction between surfaces. We provide a simple electromagnetic model and suggest that it is feasible to construct an ultra wide band correlator capable of imaging a region of space containing such sources. This would permit a new window of observation on several physical processes, with applications ranging from observations of ice flows to covert operations.

Introduction: There are various definitions of what constitutes UWB radiation. For our purposes we will assume, following the OSD/DARPA (1990) definition [1], that a signal is UWB if the 10 dB fractional bandwidth exceeds 0.25. Under this definition, at least some of the early twentieth century spark transmitters were UWB. For example, a relatively recent simulation of a Braun type spark transmitter at 5.0 MHz [2] demonstrates a 10 dB bandwidth of approximately 2.0 MHz (20 dB bandwidth approximately 3.4 MHz) as well as significant power in the neighbourhood of the third harmonic.

In more recent times, microwave emission from spark discharges has been used for detection purposes [3] and there has been renewed interest in their possible use for future UWB communications. It has also been fairly widely observed (though usually unreported) that static discharges give rise to detectable microwave and RF transmission even when there is no readily visible spark. Such static 'micro-discharges' frequently occur in nature, whenever there is friction between surfaces of synthetic or naturally occurring materials. We would expect to observe such effects between ice flows, during seizmic events, in clouds (water and ice particles), etc. though it would seem that in most of these examples evidence is usually anecdotal.

In this letter we present a basic physical model and make the case that the technology exists to image such effects. We propose that micro-discharges can be observed and resolved on the scale of millimetres, offering the ability to observe frictional events which would significantly add to our understanding of the physics of the generating processes. There are also obvious applications in covert observation, where micro-discharges resulting from the friction between fabrics and metal or skin could be directly observed. Within a period of the order of a few seconds, a region of space of the order of 1000 m^3 may contain a large number of such micro-discharge events each with their own characteristic time/frequency signatures. We believe it should be possible to obtain two or three dimensional images of such regions based on the detection and location of such events.

Micro-discharges, a simple physical model: Friction between surfaces can readily generate voltages of hundreds to many thousands of Volts. Discharge, when it occurs, is a non-linear and complex phenomenon resulting in the rapid flow of free electrons within a small volume of space. These regions may exist on the surfaces between insulators or in the gaps between conductors and the physics of the generation and maintenance of such regions is often not well understood.

A simple conductor-conductor model is offered to represent the macroscopic behaviour of frictionally excited micro-discharges, where two conductors separated by an insulator are charged relative to each other. When the two conductors come together, a micro-discharge occurs and radiation results. Micro-discharges can also occur between a conductor and an insulator or between two insulators. Here, the mechanism involves the accumulation and discharge of local charged regions on the insulator surface. Conductor-insulator and insulator-insulator discharges can draw charge across only a small area of insulator surface where under a sufficient potential, under sufficient charge build-up, the matter in the neighbourhood of the surface no longer prevents the local flow of electrons. The duration, τ, of a micro-discharge is expected to be very small, typically less than 10^{-9} seconds (see below) for a conductor-conductor micro-discharge. The duration may be much smaller for conductor-insulator and insulator-insulator discharge events.

Conductor-conductor model: The conductor-conductor model represents a spark gap of the kind used in early telegraphy, except that the conductors form all elements of the system with no external components. The simplest equivalent circuit model is a single LCR tuned circuit, as illustrated in figure

1. There are many old references on the topic (e.g. [4]). Here, the conductors provide the capacitance, inductance and radiation resistance. Initially, before discharge, the two conductors form the two halves of a capacitor with capacitance C. When the discharge occurs, the discharge is represented as a closed switch with initially small resistance (often less than 0.1 ohms) which, after a short time, τ, rapidly increases as the discharge terminates. When closure occurs, current is limited by the resistance R, which includes ohmic losses and radiation resistance, and the inductance L which depends on the shape of the conductors.

Estimates of energy content and frequency: An order-of-magnitude estimate of the form of the radiated wave typical of a conductor-conductor model may be readily determined. For this purpose we assume two cylinders of metal come together as a fat half-wave dipole of total length l. We suppose the diameter and length of each cylinder is D and the separation distance at which discharge occurs is h (see figure 2). It is assumed that h is very small, $h \ll D$.

The DC static capacitance, C_{dc}, is given approximately by,

$$C_{dc} \approx \frac{\epsilon_0 \pi}{h} \left(\frac{D}{2} \right)^2 \tag{1}$$

where ϵ_0 is the permittivity of free space. Let the field strength at which breakdown occurs in air be E_b volts per metre (typically $E_b \approx 3000$ V/mm in dry atmospheric pressure air). If the statically generated voltage between the two cylinders, just before breakdown, is V_b, then $E_b = V_b/h$ and the charge, Q, on the dipole just prior to breakdown, $Q = C_{dc}V_b$.

For a thin half-wave dipole operating at resonance the average radiated power, $\overline{W}$, is given (see e.g. [5]) by,

$$\overline{W} = 73 \frac{(I_0)^2}{2} \quad \text{Watts} \tag{2}$$

where I_0 is the peak current flow at the center of the dipole (in Amperes). We will assume this formula is valid to within an order of magnitude for a fat dipole. If we further assume that the electric discharge occurs at a rate consistent with self-resonance of the dipole at a frequency $f_0 \approx c_0/(2l)$ (where c_0 is the speed of light), then we may estimate $I_0 \approx Q f_0$. Making the approximation $D \approx l/2$, equation (2) then implies,

$$\overline{W} \approx \frac{73}{2} \left(\frac{c_0}{2l} \right)^2 \left[\epsilon_0 \pi (l/4)^2 E_b \right]^2 \approx 2 \times 10^{-6} (E_b l)^2 \tag{3}$$

in SI units. If we assume $E_b = 3 \times 10^6$ V/m and $l = 10^{-2}$ m, $\overline{W} \approx 2000$ Watts. This estimate is independent of the charge voltage V_b.

The total available energy $\mathcal{E} = QV_b/2$. We may thus estimate the time of discharge, $\tau \approx \mathcal{E}/\overline{W}$. Using the above estimates for $\overline{W}$ and Q,

$$\tau \approx \frac{64V_b}{73\pi c_0^2 \epsilon_0 E_b} \approx 3 \times 10^{-7} \frac{V_b}{E_b} \quad \text{seconds} \tag{4}$$

Assuming a 1000 Volt static discharge (not unreasonable), the previously assumed figure for E_b implies $\tau \approx 1 \times 10^{-10}$ seconds. This should be compared with $1/f_0 \approx 7 \times 10^{-11}$ seconds. I.e. there is time for a little over one oscillation at the resonant frequency before dissipation, which is consistent (to our level of approximation) with our earlier assumptions.

Detection methods: Signals of this sort require UWB receivers and conventional inverse synthetic aperture radar methods are not appropriate for imaging. If we assume that the discharge sources generate a radiated field with a frequency spectrum (time waveform) whose functional form is only weakly dependent on the transmit angle, then each discharge source may be assigned a distinctive radiation characteristic which may be located using correlation methods.

For example, suppose we consider the use of two UWB receiver arrays for imaging a two dimensional field, as illustrated in figure 3. To aid processing, we suppose the UWB signals from each element of an array are first amplified and then used to amplitude modulate an optical carrier. Both amplifiers and optical modulators are now or will shortly become available with 40 Gb/s performance[1].

Considering just one array, the angle of arrival may be determined by summing delayed copies of the signal from each element of the array. Signals will only add coherently when the signal from each subelement originate from the same source in the direction, θ, defined by the implemented delays and the separation between array elements. The first antenna array senses in direction θ_1, the second array in direction θ_2. Note that there is no means to determine the range to the source using a single antenna but with two antenna arrays, triangulation can be performed. Each antenna determines the angle of arrival of multiple signals for different values of θ. The outputs, one from each angle channel of each antenna, may then be tested for mutual correlation. This can be achieved by mixing the optical signals from the angle

[1] See, for example, Picosecond Pulse Labs (www.picosecond.com).

bins of each antenna array. In general each angle channel from one antenna must be cross correlated with each angle channel of the other. The resulting correlation values form a time-fluctuating image in the 2D angle space of θ_1 and θ_2. Unfortunately, there is an unknown relative delay τ_i associated with each image point so correlations must be calculated, for each value of θ_1 and θ_2, over a valid range of τ_i such as to maximise the correlation with respect to τ_i. The valid τ_i range is set by the intersection envelope of the gain patterns of the two antenna arrays.

Conclusions: A simple model is provided for the RF emission of static discharges, consistent with known observations. We suggest that static discharge effects may be used to provide images of a number of physical processes and that the technology exists to build such a system. An example of such a system is proposed.

References

[1] T.W.BARRETT *'History of Ultra Wideband Communications and Radar: Part 2, UWB Radars and sensors'*, Microwave Journal, pp 22-46, Feb. 2001.

[2] J.S.BELROSE *'The Sounds of a spark transmitter: Telegraphy and telephony'* Radio Sciences Communications Research Centre, December 1994, pp1-8 (available on web address www.physics.otago.ac.nz /ursi/belrose/spark.htlm).

[3] H.R.HOLLIDAY *Private communication concerning 'Detection of RF emissions from 150 KV switchgear for break timing' (Q-par Angus internal report. 1995-1997).*

[4] *'Admiralty Handbook of Wireless Telegraphy, Vol 2.', H.M. Stationary Office, 1938.*

[5] I.S.GRANT, W.R.PHILLIPS *'Electromagnetism'*, Wiley and Sons 1975.

Author's affiliation:

Andrew Mackay, Q-par Angus Ltd., Barons Cross Laboratories, Leominster, Herefordshire HR6 8RS, UK. E-mail: andrew.mackay@q-par.com

Figure Captions

Fig. 1 Simple equivalent circuit of discharge

Fig. 2 Dipole dimensions at the point of discharge

Fig. 3 A possible antenna array configuration

Figure 1

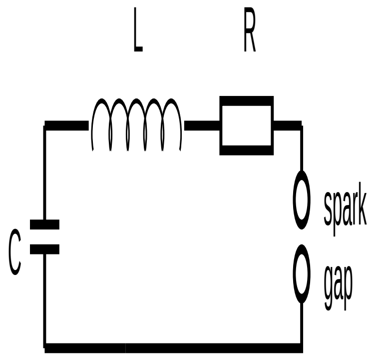


Figure 2

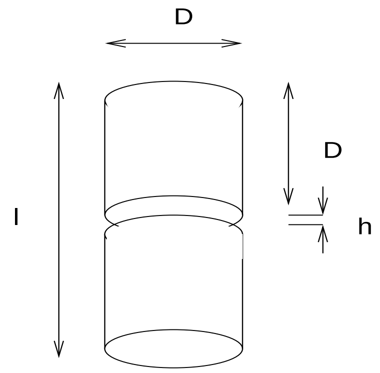
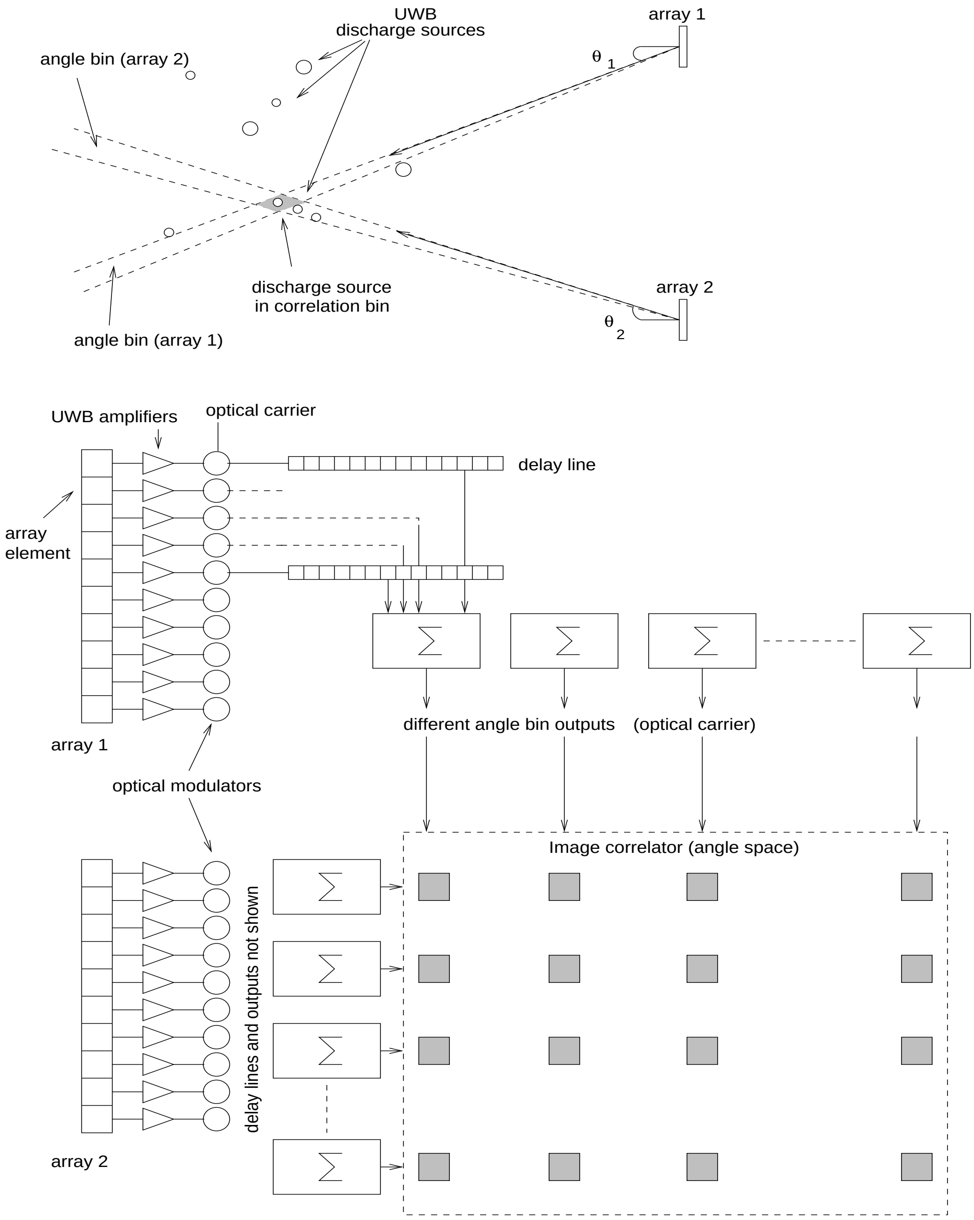


Figure 3



UWB
discharge sources
array 1
angle bin (array 2)
θ 1
discharge source
in correlation bin
array 2
θ 2
angle bin (array 1)
UWB amplifiers
optical carrier
delay line
array
element
different angle bin outputs
(optical carrier)
array 1
optical modulators
Image correlator (angle space)
delay lines and outputs not shown
array 2