The Generation of VLF Emissions by Meteors

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1 Introduction

This article reviews the interesting, but not widely known, possibility that an ionised meteor trail can generate Very Low Frequency (VLF) emissions in the range 1 to 10kHz. The work of several academic authors is referenced to describe the phenomenon and explore the physical mechanism that may be involved.

One of the earliest investigators was Keay[1] who produced a paper entitled *Progress in Explaining the Mysterious Sounds Produced by Very Large Meteor Fireballs* in 1993. His investigation was initiated by trying to understand reports that strange sounds had been heard simultaneously with the sighting of brilliant meteor fireballs, many tens of kilometres distant. The term "electrophonic sounds" was widely used to describe them and to distinguish them from the normal sonic effects heard after the fireball has passed by.

Keay presented the history of this perhaps neglected branch of meteor science in some detail, drawing attention to the theoretical difficulties which stood in the way of a scientifically plausible understanding until the early 1990s.

In this article we discuss the possibility of amateur radio astronomers being able to detect meteor radar echoes and simultaneous Very Low Frequency (VLF) signals in an attempt to establish a causal connection.

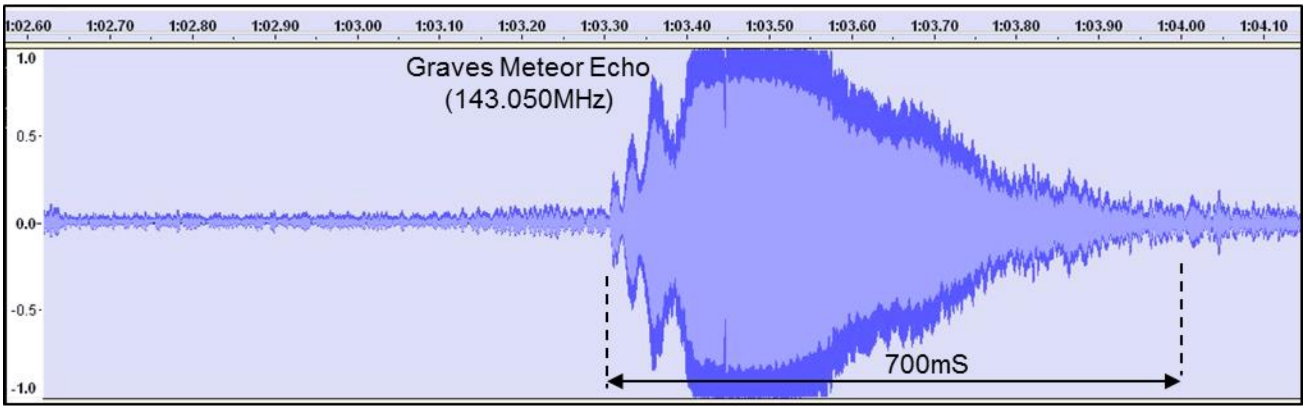

Figure 1.1 A Meteor Echo from the French Graves Radar on 143.050 MHz

2 Description of the Phenomenon

Keay relates that the entry into the atmosphere of a large meteor fireball is one of the most awesome natural phenomena that a human being can witness, without being greatly endangered. The largest and most spectacular meteor fireballs are very rare events, and few people ever see one during their lifetime. For about ten percent (Lamar and Romig, 1964)[2] of those who do witness a very luminous meteor fireball, the mental impression is heightened by strange swishing, hissing and popping noises coincident with its passage across the sky. Such sounds are quite anomalous in that they imply acoustic propagation at the speed of light. This anomaly was first recognized more than two centuries ago.

The first lucid account of electrophonic sounds related to the flight of a large, bright meteor fireball or “bolide” originated from China in 817 AD. At the same time as it was seen, the bolide made "a noise like a flock of cranes in flight" (Astapovich, 1951[3] ; LaPaz, 1958[4]). There is no doubt about the electrophonic effects of a large bolide seen over England on the 19th of March, 1719. Edmund Halley (1719) reported some eye-witnesses "hearing it hiss as it went along, as if it had been very near at hand," but he dismissed such claims as "the effect of pure fantasy." This rejection is related to Halley's realization, by careful triangulation from many observations, that "they abundantly evince the height thereof to have exceeded 60 English miles", which is far too distant for sound waves to arrive instantly. Halley was one of the first to show that meteors occur at a great height compared to most other atmospheric phenomena and that their velocity was "incredible", being "above 300 such miles in a minute." Even when electric fields and radio waves became well understood, the solution to the problem of instantaneous sounds from bolides remained elusive.

Hawkins (1958a, b)[5], conducted a search for radio emissions from meteors at several frequencies, namely 475, 218 and 30 MHz and also at 1 Hz using a magnetometer. The meteors Hawkins observed had visual magnitudes between -1 and +5. He concluded, "Thus it is probably true to state that meteors do not emit radio noise within the frequency range 1 Hz - 500 MHz above the limits of sensitivity of these measurements. Meteors therefore show a surprisingly low efficiency in converting kinetic to radio energy."

The most notable work was undertaken by Professor I. S. Astapovich, who compiled an extensive catalogue of electrophonic bolides and drew several important conclusions from his detailed investigations (Astapovich, 1958)[6]: Only bolides brighter than -9 absolute visual magnitude produce sustained electrophonic sounds; the majority of reports noted that the bolide trajectories had very small inclinations to the horizontal, and, since all of the bolides were observed at mid-latitudes, their low inclinations meant that they were moving at a large angle to the earth's magnetic field lines.

This observation that the Earth’s magnetic field might be involved, proved to be significant in the eventual explanation of the VLF generation mechanism.

It was well known from the literature on the subject that Soviet scientists were actively investigating naturally occurring electrophonic phenomena. In the US a contract was awarded to the Rand Corporation, which assigned Mary Romig and Donald Lamar to the work. Their study was “motivated by the possibility that a better understanding of these phenomena will lead to new techniques for determining the size, nature and path of any large body entering the earth's atmosphere" (Romig and Lamar, 1963). The motivation for this contract may well have been to gain a better understanding of the possibilities for detecting intercontinental missile re-entry bodies returning to Earth.

There are obviously two physical mechanisms involved in the production of electrophonic sounds from meteors: the first is the generation of the VLF electromagnetic wave and the second is concerned with how such a signal can be transduced into a sound wave.

It is not the intention of this article to explore the transduction mechanism, but rather to understand how the initial VLF signal is generated and what experiments may be performed to measure the relationship between the appearance of the meteor and any linked VLF emission.

Figure 2.1 Example of a Meteor Fireball or Bolide

3 The Electromagnetic Energy Generation Process

Keay suggests that a large bolide sheds its kinetic energy at rates upwards of tens of gigawatts. Its luminous efficiency, a function of velocity and composition, is of the order of a few percent. Ionization is of the same order, while the remaining energy is mainly liberated as heat. The extremely high energy density residing in the plasma trail should excite all EM oscillatory modes possible, including those at frequencies in the audio range (ELF/VLF radiation). The problem is to discover a realistic generation mechanism. One possibility appeared to be through excitation of a hybrid-mode magnetohydrodynamic wave within the plasma of the bolide trail.

A possible mechanism, involving the expulsion of the geomagnetic field from the ionized region surrounding the bolide, also bears examination.

The ratio of thermal to magnetic energy per unit volume in the plasma sheath of the bolide is given by

$$\frac{3\mu_o \rho_p RT}{B^2 M} \approx 1.3 \times 10^8$$

where the molecular weight M is taken as the standard value of 29 and the strength of the geomagnetic field B is taken as 0.3 gamma (3 X 10^{-6} G). This indicates that the energy density in the sheath is 8 orders of magnitude greater than the geomagnetic field energy density and therefore the geomagnetic field is easily pushed aside by the bolide. The power radiated is related to the cross-sectional area of the plasma and the bolide velocity.
But this yields less than 100 watts for a bolide of magnitude -16, a consequence of the trail expansion expending most of its energy doing work against the ambient air pressure rather than against the geomagnetic field. This suggests that there must be other factors in play for significant VLF generation.

Keay introduces the notion of turbulence in the meteor plasma tail. Turbulent motions in the wake have characteristic frequencies upwards of around 500 Hz, as energy is transferred to smaller eddies. The turbulence excites vibrations of the geomagnetic field giving rise to the emission of electromagnetic radiation in the ELF/VLF region of the spectrum. A major release of stored magnetic energy occurs when the conductivity falls, due to recombination or electron attachment as the plasma cools and the magnetic Reynolds number falls to less than unity. The twisted and tangled "magnetic spaghetti" then relaxes, releasing its strain energy as vibrations of the geomagnetic field within the earth-ionosphere cavity. These field vibrations have wavelengths of the order of 100 km, corresponding to an electromagnetic wave frequency of 3 kHz.

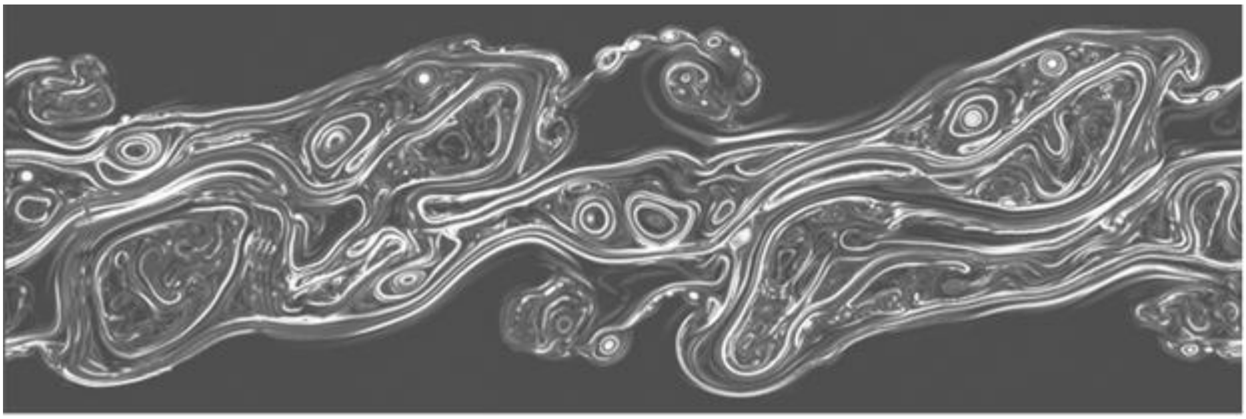

Figure 3.1 A visualisation of Turbulence in Meteor Magnetoplasma Tail

The above mechanism for the generation of electromagnetic radiation from large bolides is in accord with the observational finding that only very large bolides give rise to reports of electrophonic sounds. Astopovich (1958)[6] claimed that only those bolides having an absolute visual magnitude brighter than -9 produce sustained electrophonic sounds. This empirical criterion has been upheld by model calculations based on the need for the bolide to penetrate the atmosphere deeply enough to produce a turbulent wake in order for geomagnetic field trapping and scrambling to occur.

Soon after the development of the above bolide radiation mechanism by Keay in1980, it was confirmed by Bronshten (1983a and b)[8], who showed that a typical electrophonic bolide of magnitude -13 could generate well over a megawatt of radio power in the ELF/VLF region of the spectrum.

4 Measurement of VLF Emissions from Meteors

Price and Blum[9] made measurements during the Leonid meteor storm on 18 November 1999

Electromagnetic measurements were continuously recorded to try and detect the radio waves produced by meteors. Since the best viewing location for the 1999 meteor shower was the Middle East, they were ideally located for this task. A permanent field site for observing ELF/VLF signals was located at the Desert Research Institute of Ben-Gurion University, at Sde Boker in the Negev Desert (30 N, 34 E).

The antenna was designed to pick up very weak signals in the extremely low frequency (ELF: 100 Hz < f < 3000 Hz) and the very low frequency (VLF: 3 kHz < f < 50 kHz) range for use in lightning research.

However, these frequencies are exactly those expected by Keay to be produced by meteors and the setup was ideal for studying the meteor signals. The ELF/VLF antenna was 10 metres high, with two orthogonal triangular loops, each with a baseline of 18 metres and a height of 9 metres, giving an area of approximately 81 m^2 for each loop. One loop was aligned in the magnetic north-south direction, with the other along the magnetic east-west bearing. The sensitivity of the system in the broadband range (0.1–50 kHz) was 6 μV/meter. The dynamic range of the antenna/preamp set was approximately 100 dB, allowing them to detect lightning discharges from great distances. The data were collected on digital audio tapes (DAT) with GPS timing, to correlate with the optical measurements.

The antenna was sensitive to both lightning discharges and possible meteor pulses, therefore a way was needed to differentiate between lightning and meteor signals. Spectral analysis was brought to bear.

In Figure 4.1 we see an example of a lightning pulse over the frequency range 0.1 to 50 kHz.

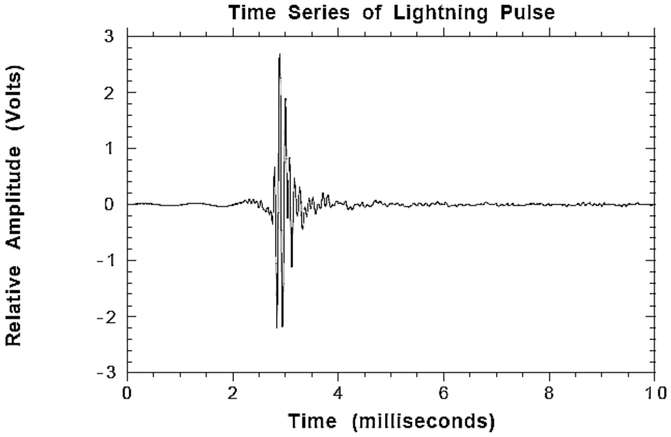

Figure 4.1 A Typical Lightning pulse

Figure 4.2 shows what is claimed to be a VLF pulse form a Leonid meteor on the night of 18th November 1999.

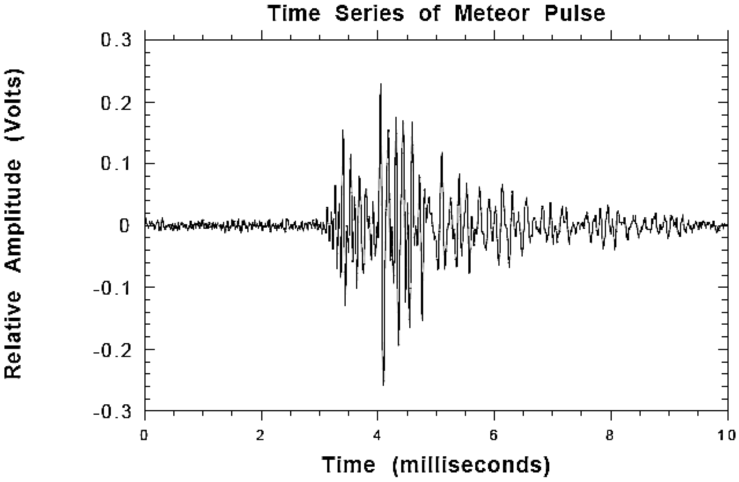

Figure 4.2 A VLF Pulse from a Leonid Meteor

There is naturally a corresponding difference in the signal spectra as shown in Figures 4.3 and 4.4

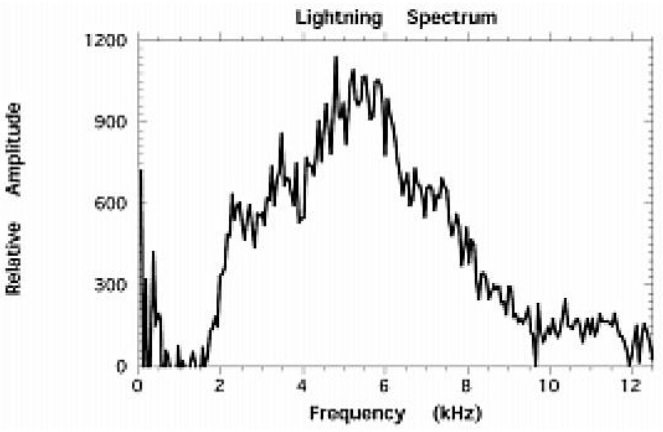

Figure 4.3 Spectrum of typical Lightning Pulses

The meteor VLF spectral energy appears to be concentrated at significantly lower frequencies (around 1 kHz) whereas lightning pulses have their spectral peak at 5 kHz.

Price and Blum do not make it clear how representative these pulses and spectra are and to what degree they can be used to differentiate phenomena.

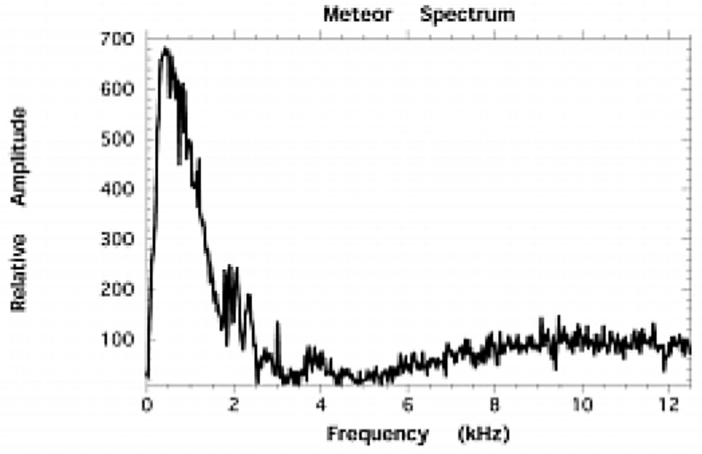

Figure 4.4 Spectrum of Claimed Meteor VLF Pulses

Price and Blum do however produce convincing evidence to show that they can correlate the selected meteor VLF pulses with visually observed meteor counts for the Leonid shower of 1999. This can be seen in Figure 4.5.

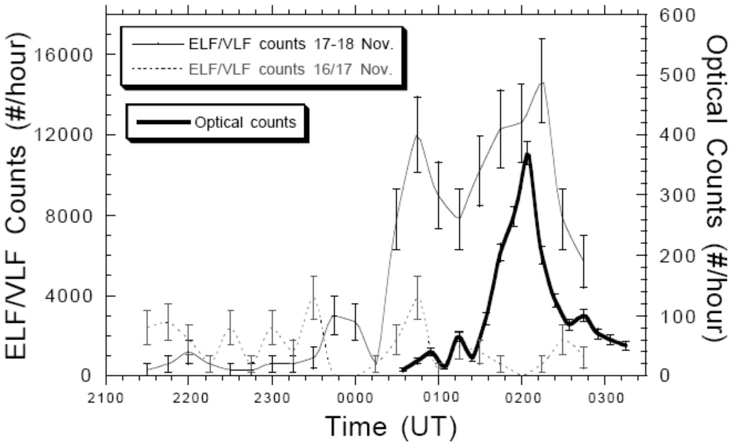

Figure 4.5 Hourly counts of optically observed meteors during the night of 17 -18 Nov 1999

The ELF/VLF method of counting the meteor flux produced a figure of 15,000 per hour as compared to 350 per hour using optical methods.

The only theoretical explanation of how these radio waves are produced has been presented by Keay. However these measurements challenge his theory in respect of observed VLF generation from sub-visible and small meteors rather than only from bright fireballs (bolides).

Further work on this question has been carried out by Beech, Brown and Jones[10] but with a limited data set.

A significant study of VLF emissions from meteors has been conducted by Guha, Barin Kumar De and Rakesh Roy[11], where the field experiments were performed during 12–17th December, 2007 and published in April 2009. They report results of day-time detection of GEMINID 2007 meteor shower from dynamic VLF radiation spectra in Tripura (23.50 N, 91.25 E), India.

The VLF emissions lie in the range from 8 kHz to 13 kHz which is 10 to 15 times higher than previous reports. The mean duration of each VLF emission calculated from dynamic spectra is found to be 6 s and the mean bandwidth is 3.6 kHz. These results are significantly different from previously reported measurements - and leave open a question concerning the actual characteristics of meteor VLF emissions. This makes it difficult to set up an observing campaign as the frequency bands, spectra and pulse timing of emissions are not well defined. Measurements have been made by the author in frequency bands around 10 kHz, 5 kHz and 1 kHz. However only the 10 kHz measurements have currently been analysed and are reported in this article.

In the work conducted by Guha et al the experimental setup consists of an inverted vertical L type omni-directional antenna, a preamplifier with surge protection and SpectrumLab V2.7b14 software VLF receiver.

The effective height of the antenna is 7.85 m and the terminal capacitance is 35.42 pF. The voltage induced at the antenna is amplified ten times and passed through a VLF band pass filter having a bandwidth of 30 kHz at the preamplifier. Guha reports that the peak activity of Geminid 2007 meteor shower was predicted to occur on 14th December, 2007 16:45 UT i.e. 22:15 Indian Standard Time (IST). Accordingly, they collected VLF spectrum data from 11th December to 17th December, 2007. Observers all over the world collected visual data and during predicted peak activity, an hourly rate of more than 120 was reported by International Meteor Organization.

A sample of Guha's "fair weather" (no nearby thunderstorms and no meteors) dynamic VLF spectrum is shown in Figure 4.6.

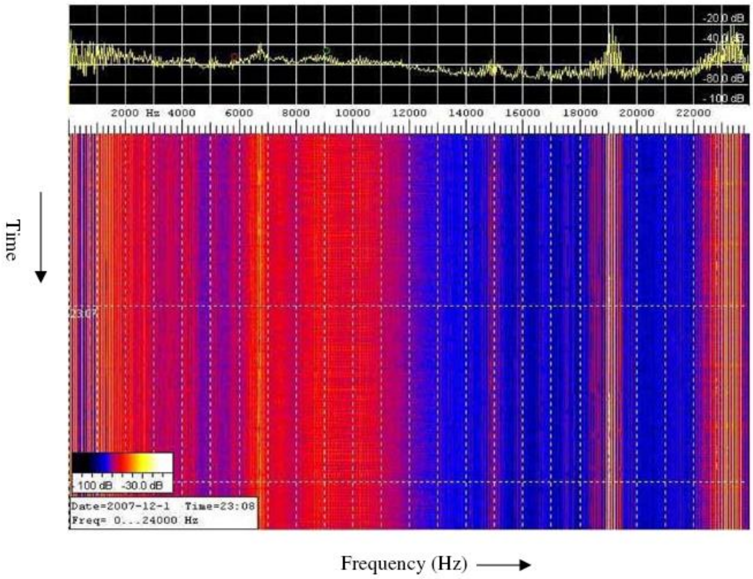

Figure 4.6 Fair weather VLF emission Waterfall Plot

(Guha et al)

The corresponding waterfall plot during the Geminids on the 15th December 2007 is shown in Figure 4.7.

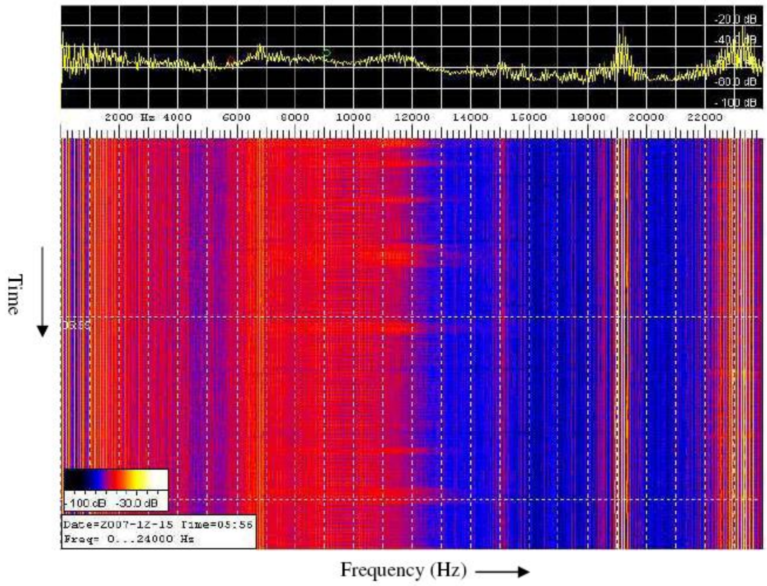

Figure 4.7 VLF waterfall plot during Gemininds 15/12/2007

(Guha et al)

Guha reports that for the total observational period, VLF emissions lay in the range between 8 kHz and 13 kHz. The initial bandwidth was found to be around 5.5 kHz, followed by two peaks having bandwidth of 4.25 kHz and 3.25 kHz. It seems then, that the meteor VLF emission spectra can change with time during a shower. A histogram of the VLF bandwidth on 15/12/2007 is shown in Figure 4.8.

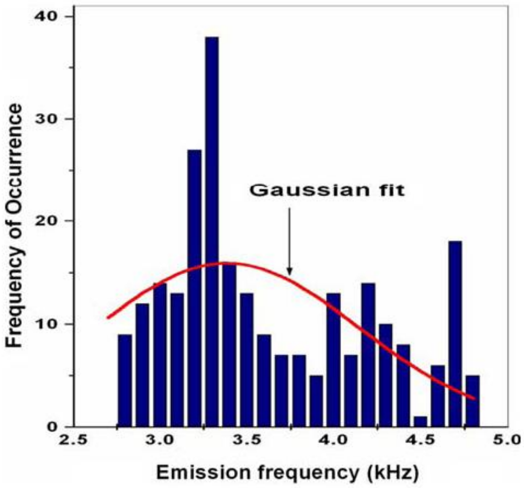

Figure 4.8 Histogram of meteor VLF Emission Bandwidth on 15/12/2007 (Guha et al)

Guha concludes that these observations show a difference in VLF emission frequency from Geminids compared with other reports involving VLF emission from Leonids. He observed VLF emission in a band between 8 kHz and 13 kHz while previous reports from Leonids were mostly in ELF/VLF bands not exceeding 3 kHz (Garaj et al)[12] and Price and Blum 2000).

It may be recalled that the Geminid meteor shower arises from an object named 3200 Phaethon, which is thought to be an extinct comet. On the other hand, the Leonid meteor shower results from an active comet named 55P/Tempel-Tuttle. The production of VLF waves at different frequencies originating from different meteor showers can be explained, according to Guha et al, by the production of Kelvin-Helmholtz (K-H) instabilities[11]. The speed and density of particles for Geminids are expected to be different from that of Leonids which might have resulted in the emission of VLF waves in a different frequency band.

Two kinds of VLF emission were documented by Guha et al. during the Geminid meteor shower. One is sustained VLF emissions for few seconds and the other is short duration ‘‘bursters’’ lasting for a fraction of second. The sustained VLF emissions are believed to be generated via an interaction between the turbulent plasma column trailing behind an ablating meteoroid and the Earth’s magnetic field. On the other hand, the short duration ‘‘burster’’ emissions are believed by Guha to be generated as a consequence of shock waves propagating along the fireball’s plasma column. He says it should also be noted that all the reports that fall into the ‘‘burster’’ category are only 10% of the total observed VLF emission events during a meteor shower.

Finally, Guha et al. comment that none of the theories satisfactorily explains all the phenomena - such as the explanation of production of VLF waves from extremely faint meteors.

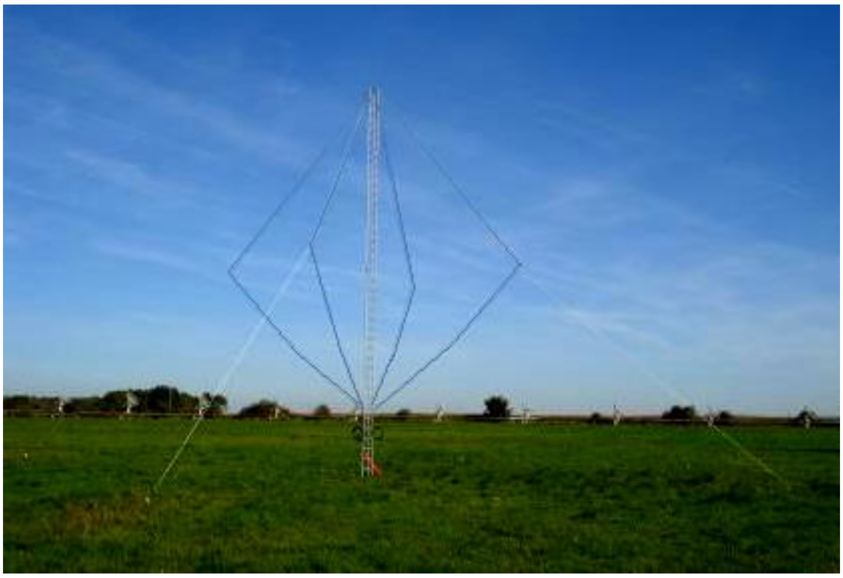

Figure 4.9 A Typical VLF Antenna System used in the foregoing studies

5 Amateur Receiving Station to detect VLF Emissions from Meteors

Following an enquiry from a fellow amateur astronomer (Phil Busby) as to whether meteors could be detected by monitoring VLF transmitters during the night, the author conducted an on-line literature survey. This resulted in the review given earlier in this article.

The somewhat unexpected evidence that meteors can generate electromagnetic emissions in the VLF frequency range prompted the establishment of a measurement system to try to detect these emissions whilst using the Graves transmitter in France to detect the presence of a meteor.

In this section we describe the efforts made to set up a working system and some of the issues that had to be considered.

The VLF system used an upgraded VLF monitoring instrument that had been developed for detecting sudden ionospheric disturbances (SIDs)[13]. This was married with an existing SDR meteor radar receiver on 143.050 MHz using a

FunCube Dongle[14]. Although a very speculative venture, it was hoped that detection of near coincidence between a radar return and a VLF emission would establish that meteors can generate VLF pulses that are capable of being detected by amateurs.

The VLF receiver is described in the following:

The block diagram of the receiver is shown in Figure 5.1

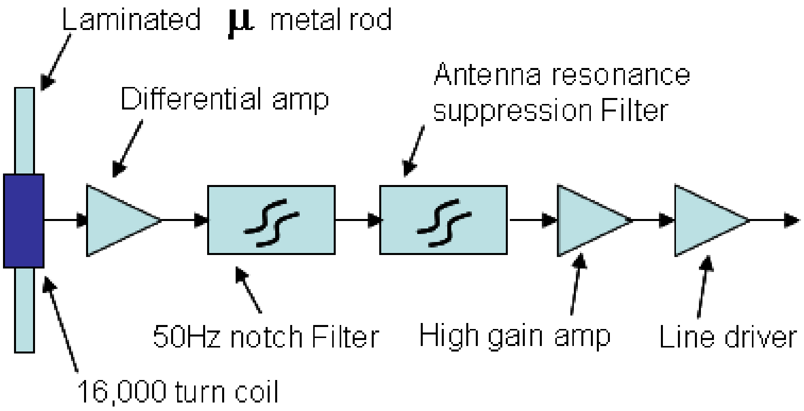

Figure 5.1 Compact wideband VLF Receiver

The frequency response of the VLF receiver is 20 Hz to 24 kHz. The device is pictured in Figure 5.2.

The VLF receiver was situated 30 m from the nearest building and orientated to minimise 50 Hz mains pick-up. However this proved to be insufficient to allow interference-free reception around 1 kHz (one of the 3 bands to be monitored) due to multiple mains harmonics.

The VLF signal was fed to one channel of a PC sound card that was used by the Spectrum Lab analysis software[15].

The meteor detector employed the French Graves Radar transmitter[16] shown in Figure 5.3.

Figure 5.3   Graves Transmitter on 143.050 MHz (CW)

The line of sight from the author's observatory to the transmitter is shown in Figure 5.4.

Figure 5.4 Line of sight to the Transmitter

One of the problems in using a radar method to establish the presence of a meteor is that unlike a visual observation, the meteor cannot be located exactly without multiple receiving stations. A further complication is that the transmitter beam repetitively sweeps the sky – adding to the difficulty in knowing where the meteor is located. This means that any time difference of arrival of the radar echo and the VLF emission signal due to possible frequency dispersion in the ionosphere cannot be allowed for. Nevertheless, it was thought to be interesting to see if any near simultaneous radar and VLF signals could be observed.

The meteor radar and VLF receivers were connected as shown in the system block diagram in Figure 5.5. Two PCs are used here as the VLF signal enters the PC2 soundcard channel 1 and Spectrum Lab can't accept both the sound card and the USB input from the FunCube dongle at the same time.

The waterfall plots for both the VLF and meteor detection signals are plotted together on a single screen to show any evidence of temporal coincidence. The Watch List output shows signal levels from both the VLF and meteor channels together with ‘trigger’ plots for both when they exceed set detection level thresholds. These trigger plots are used to count the meteor detections and the VLF pulses.

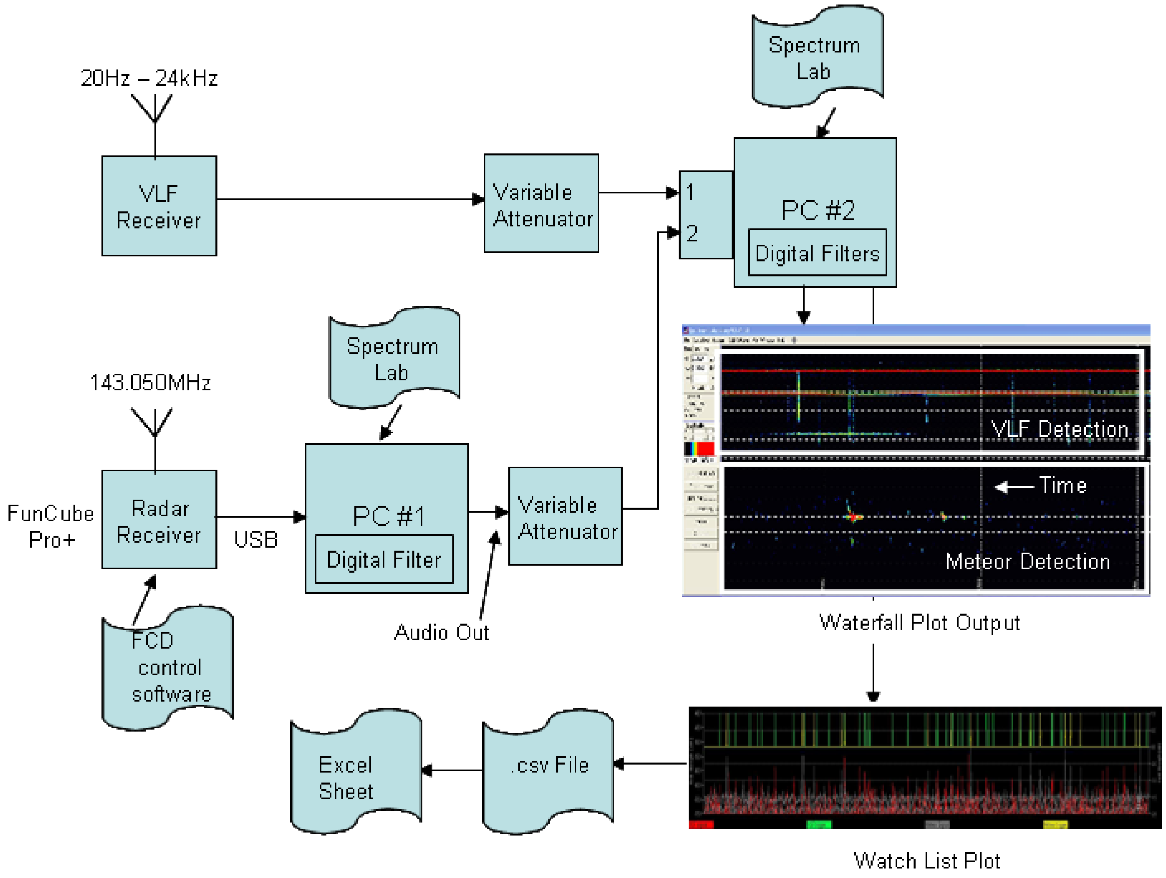

Figure 5.5 The System Block Diagram

Figure 5.6 shows the screens connected to the two PCs. PC1 processes the signal from the FunCube Pro + SDR meteor echo receiver. Spectrum Lab on PC1 is set to filter the audio output within a 500Hz bandwidth around 1.4 kHz to produce a good signal to noise ratio for the meteor echoes. This audio output from PC1 is fed into PC2 channel 2 of the sound-card, whilst channel 1 accepts the raw VLF signal.

Figure 5.6 View of Receiving System

Figures 5.7 and 5.8 show the main display screens in more detail.

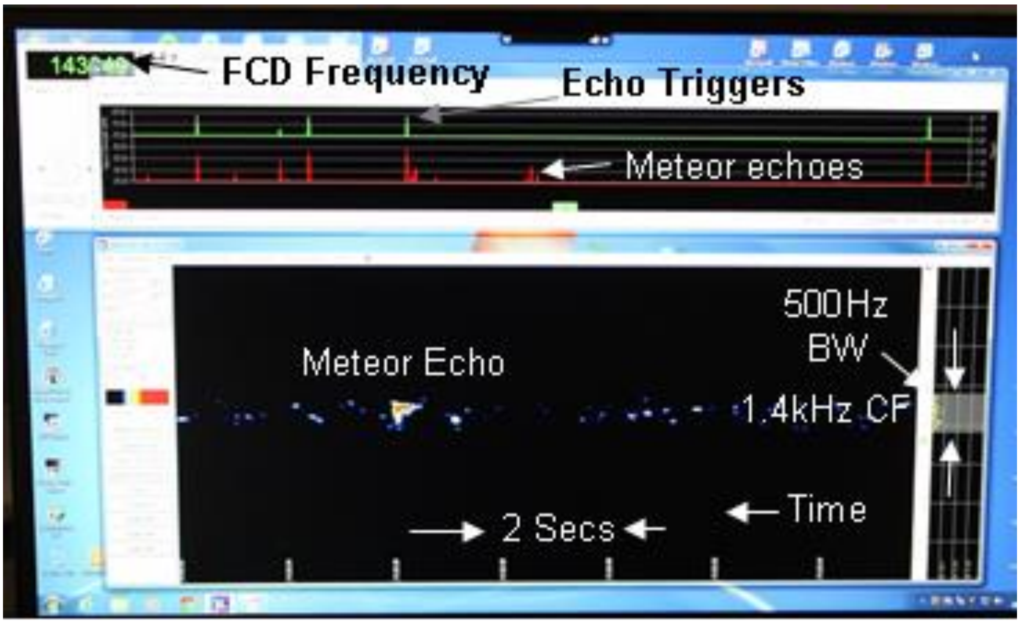

Figure 5.7 Meteor Echo Screen

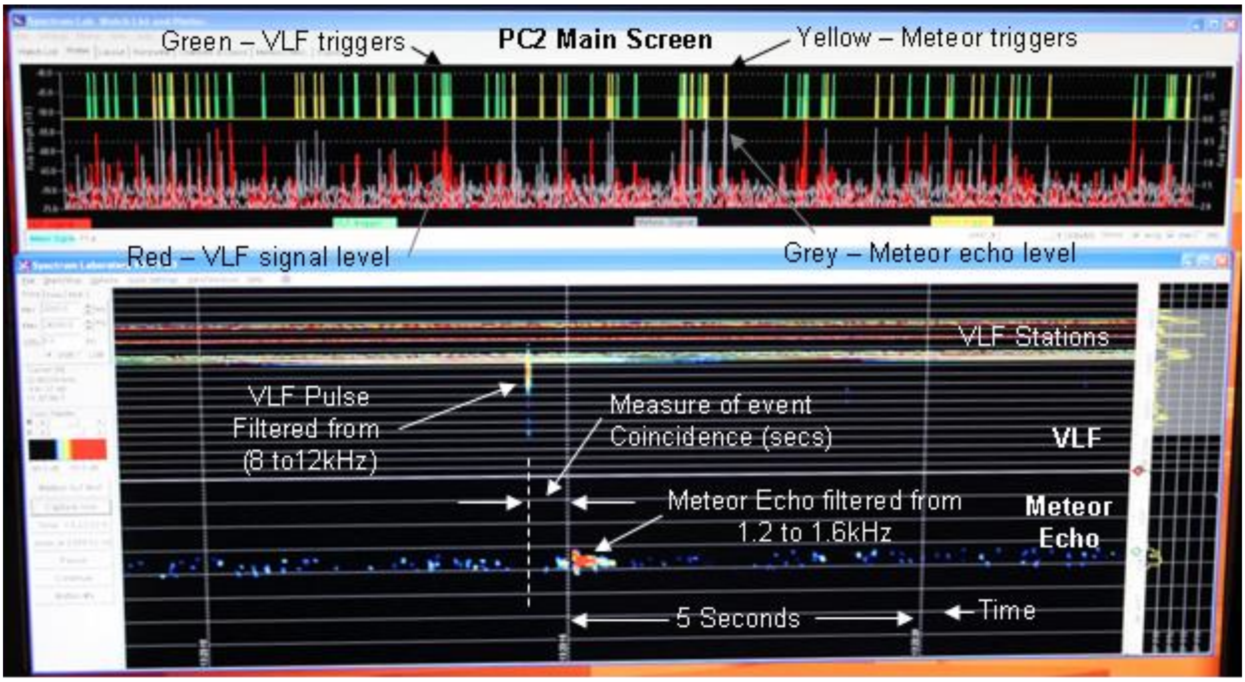

Figure 5.8 VLF pulses and Meteor Echoes on same Screen

The degree to which meteor echoes and VLF pulses are coincident can be observed from this screen. The time differences can be measured and transferred to Microsoft Excel, for example, for statistical analysis to establish the likelihood that a VLF pulse is associated with a meteor echo.

This can be time consuming as there are many more VLF pulses – mostly ‘spherics’ from man-made and natural lightning discharges – than are likely to be generated by meteors, especially when the measurements are made outside of meteor shower dates.

What is reported here from measurements made during a non-shower period is the process of establishing a working stable receiving and detection system which will be put to the test during the next meteor shower. This will be the Perseids on 12/8/15.

It is hoped to be able to report a set of coincident or near coincident VLF pulses and meteor echoes that displays an increase in number as the shower progresses and thus establish that some VLF pulses are connected with meteors.

Note
During this setting to work process the FunCube meteor receiver was replaced by a conventional communications receiver (Icom IC-R7000) which enabled the use of only one PC and removed a source of meteor signal delay due to the calculations performed by Spectrum lab running on PC#1.

Either approach provides good data: some experimenters may not have an expensive communications receiver but should still be able to engage in this type of work by obtaining a FunCube Pro+ dongle at a modest cost.

Figure 5.9   FunCube Dongle Pro+   and   ICOM IC-R7000 Receiver

6 Examples of Initial Measurements

It should be noted that the measurements described here are preliminary and are intended to ensure that the detection system is capable of satisfactory working. One of the aims of this article is to bring to the attention of amateur radio astronomers this little-known and little-understood phenomenon of VLF pulse generation by meteors. It is hoped that other people will wish to set up similar detection systems and generate a useful body of data in 2015 and beyond that can be shared and discussed.

A typical plot of a nearly coincident meteor echo and a VLF pulse is shown in Figure 6.1. It is not assumed that the VLF pulse is generated by the meteor. The plot merely shows that such coincidences – if they were to occur – could be seen.

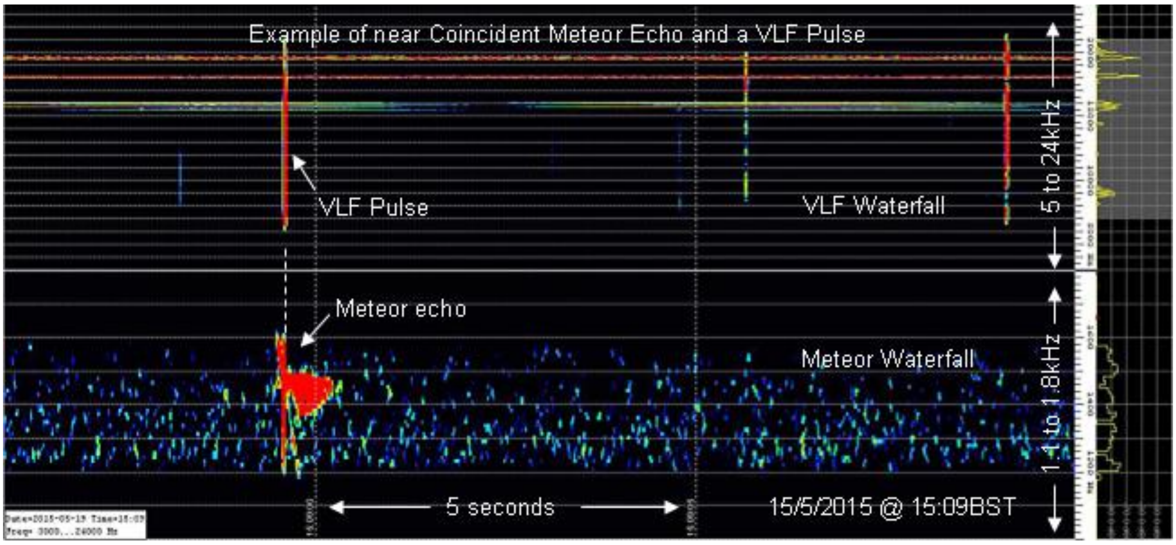

Figure 6.1 Nearly coincident Meteor echo and VLF Pulse

The Watch List meteor triggers are used to automatically record plots such as that in Figure 6.1 where meteors are evident, by writing a jpeg file to the PC2 hard drive. These can then be examined to select those where meteors and VLF pulses are nearly coincident. Even during a non-meteor shower period, hundreds of meteor echoes are seen over a couple of hours.

It is obviously important to establish any signal delays that occur in the meteor echo and VLF channels so that that any difference in arrival time on the display can be calibrated out. This can be accomplished by injecting VHF and VLF signals into the two receivers simultaneously – or by using suitable broadband EM pulses in the environment. An example of a ‘common’ pulse measurement, probably generated by domestic mains switching, is shown in Figure 6.2.

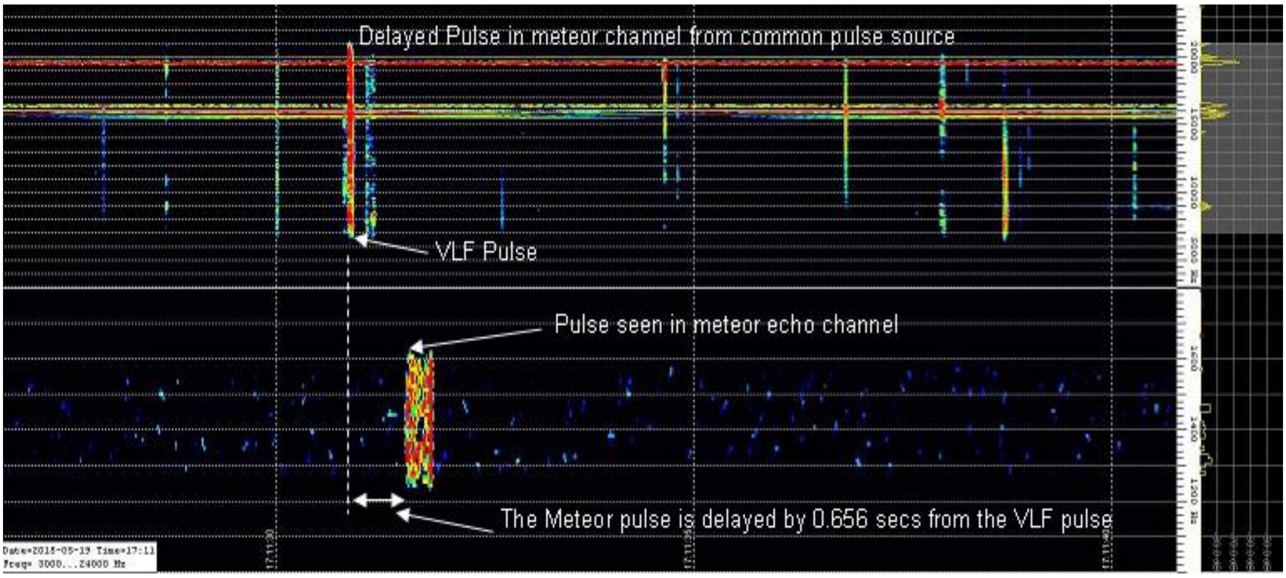

Figure 6.2 Calibrating the Meteor Channel Delay

Fourteen separate pulses were recorded and the delay time measured and plotted to show that the delay time was constant - this is shown in Figure 6.3.

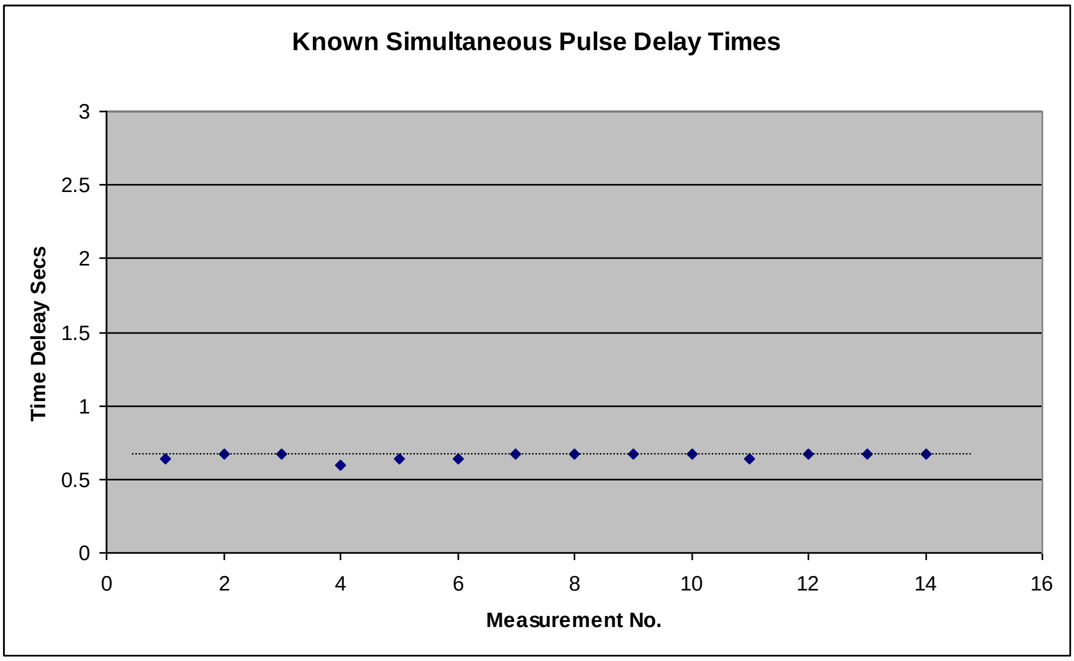

Figure 6.3 Delay Times of 14 Calibration Pulses

Using this calibrated delay it was then possible to measure the actual delays between meteor and VLF pulse arrivals. This was done for 40 measurements where meteor and VLF pulses were almost simultaneous, with the intention of determining whether delay times clustered around being simultaneous or were randomly distributed. It was thought that this might indicate if there was a substantial connection between meteor arrivals and VLF pulses. The scatter of measured delay times is shown in Figure 6.4.

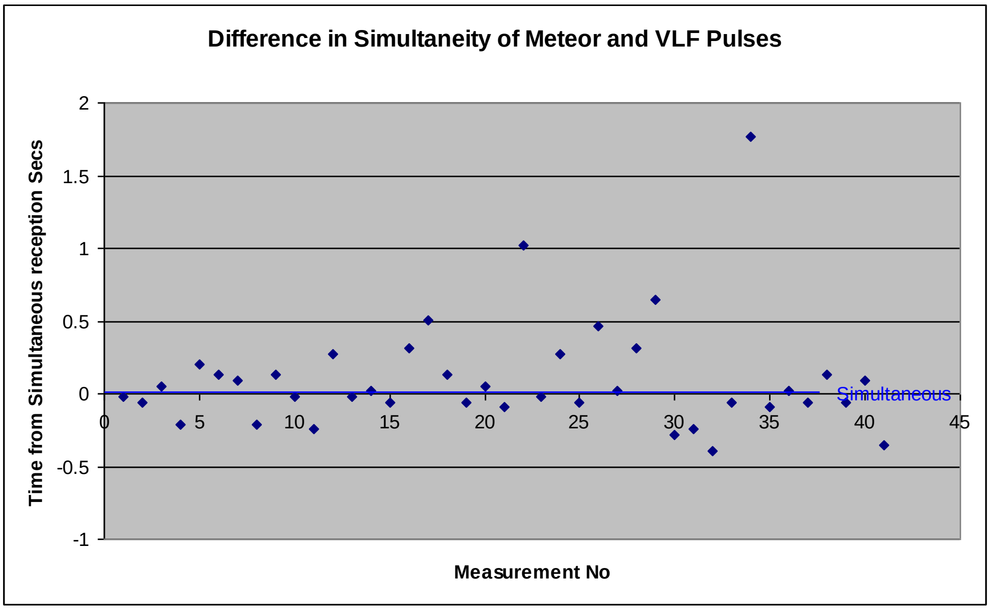

Figure 6.4 Plot of delays between Meteor and VLF arrivals

If we plot the frequency of delays within different delay bins we can obtain the graph in Figure 6.5. This shows that there is a clustering of arrivals that are nearly simultaneous ie within +- 15% of the simultaneous delay time of 0.656s.

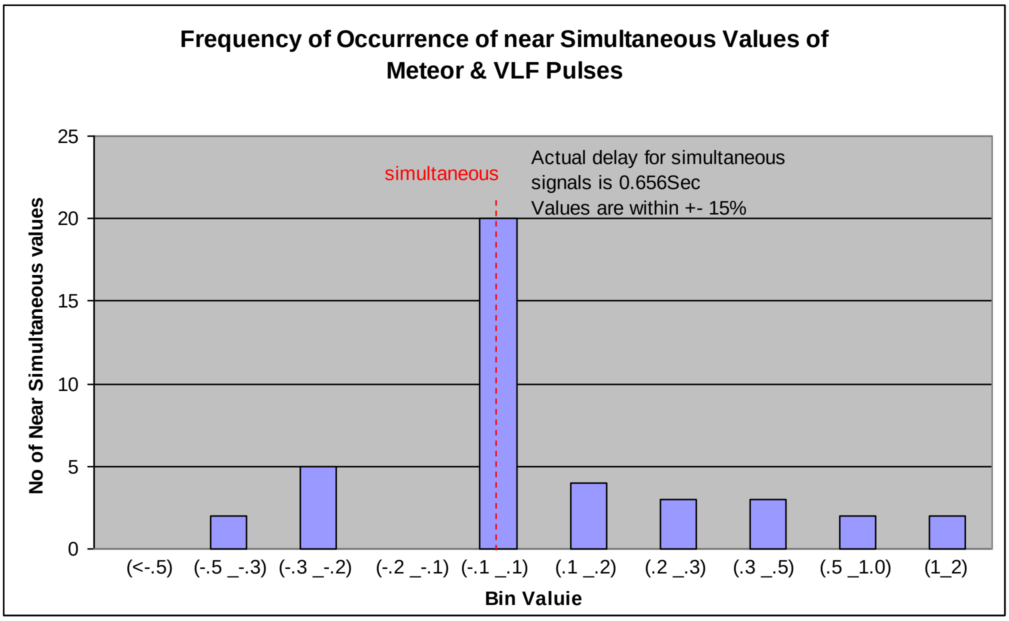

Figure 6.5 Plot suggesting that Meteor Echoes and VLF pulse arrival times may be connected

Even at this early stage of the initial investigation there was considerable doubt about the meaningfulness of this data. It was suspected that the ‘apparent statistical correlation’ of arrival times was probably due to biased selection of near simultaneous events and would disappear if data for all meteor echoes was used, irrespective of whether there was a nearby VLF pulse.

Probably there are only two unambiguous ways of discovering if a VLF pulse is connected with a meteor echo. The pulses have to be nearly simultaneous, but also we have to show that the VLF pulse spectrum is not that of a lightning pulse and is instead concentrated around 1 to 3kHz. The second method is to show that the number of near simultaneous VLF pulses increases with the onset of a meteor shower. As mentioned previously, this is planned for the Perseids in August 2015.

To examine the doubts about the validity of an over simplified statistical analysis of the apparent coincidence of arrivals of VLF pulses and meteor echoes, a further set of measurements was made on the evening of 20/5/2015. The FunCube dongle was used again to receive the meteor echoes and as some elements of the meteor data processing in Spectrum lab on PC1 had been changed, a recalibration of ‘coincidence delay’ was carried out. (The delay produced by the calculations in Spectrum Lab depend on parameter settings – particularly the digital filter settings).

The calibration plot is shown in Figure 6.6.

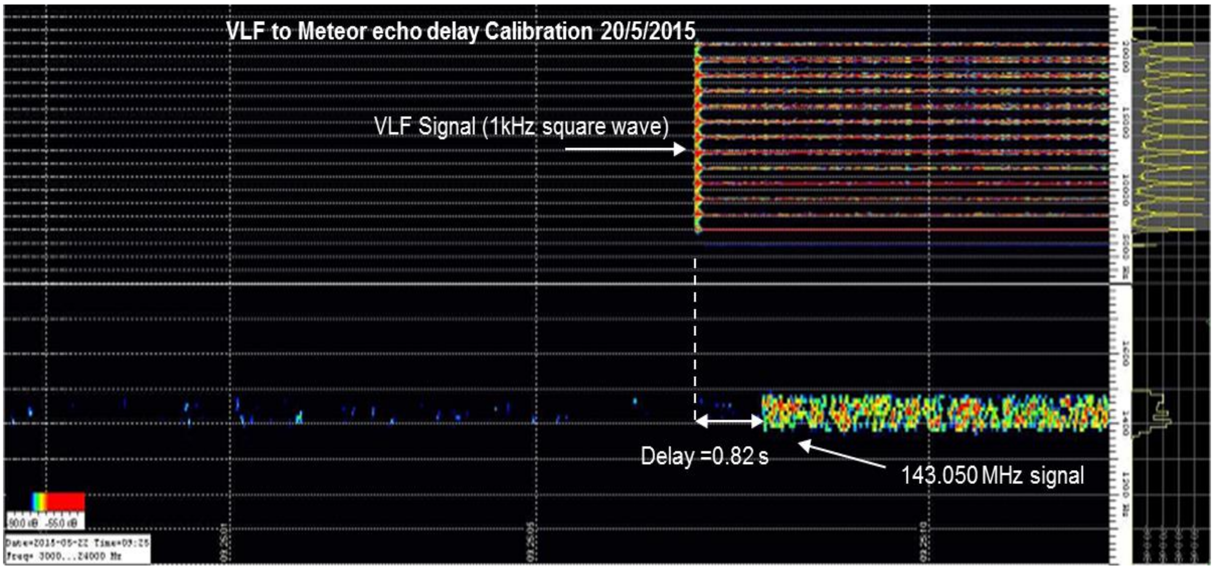

Figure 6.6   Calibration of Signal Delay 20/5/2015

This delay time was used in the subsequent set of measurements.

7 Further Experiments on Coincidence Detection

Data was collected from 13:00BST to 16:00BST on 20/5/2015 and 300 meteor echo / VLF plots were automatically recorded. An example is shown in Figure 7.1.

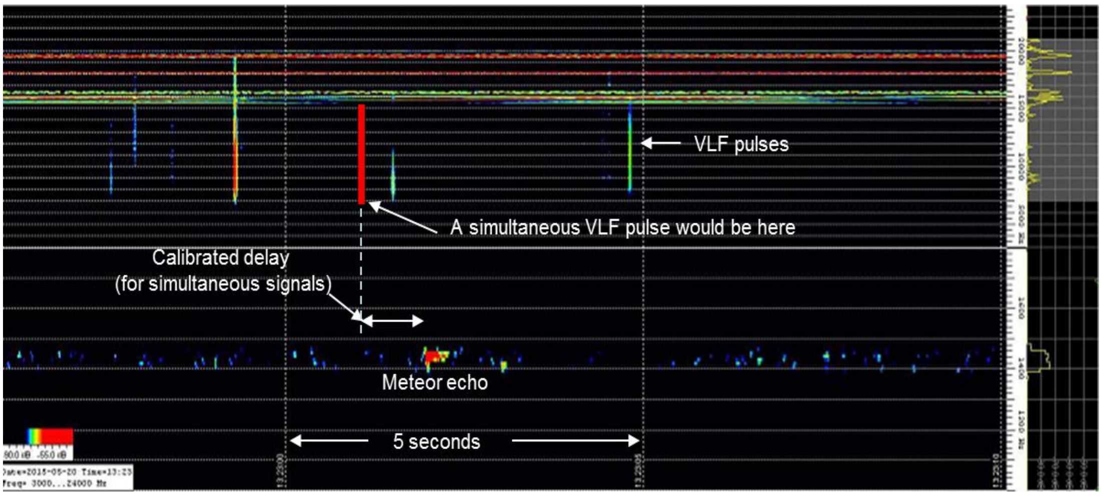

Figure 7.1 Plot showing where a VLF pulse that would be simultaneous with the meteor echo would be located

There is no nearly simultaneous VLF pulse in this example record. There are 3 pulses present on the same plot however, but they are not connected with the meteor.

The plot in Figure 7.2 shows an ‘apparent coincidence’ between the meteor echo and a VLF pulse as they are ‘lined up’.

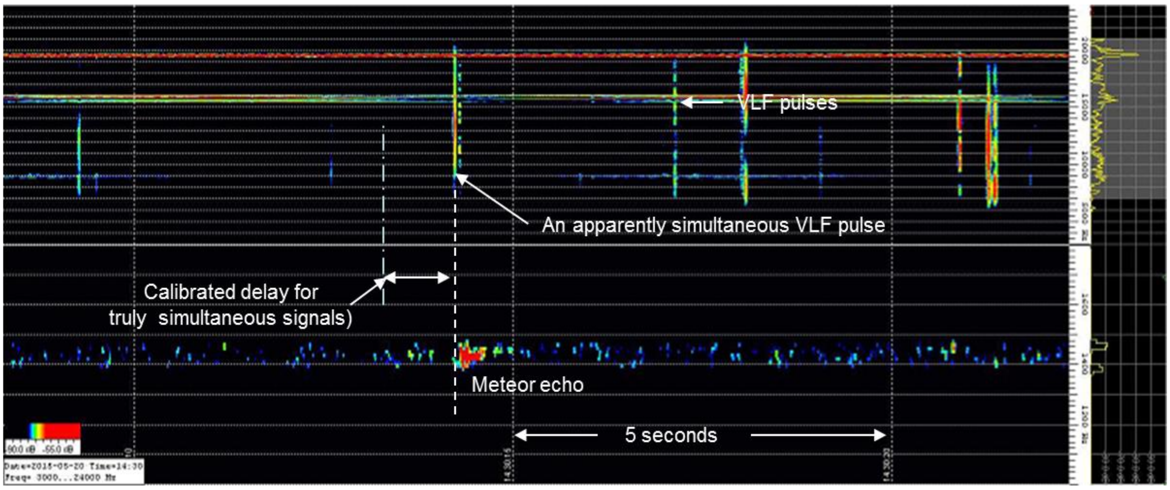

Figure 7.2 A VLF pulse that is ‘apparently’ simultaneous with the meteor echo

We are now in a position to propose a simple test of the meaningfulness of the plot in Figure 6.5, which shows a peak suggesting that VLF pulses are coincident with – and may be associated with – meteor echoes.

We can perform a simple frequency of occurrence analysis for two groups of plots. Namely the ‘actually’ coincident pulses exemplified in Figure 7.1 that may have a causal connection, and the ‘apparently’ coincident pulses of Figure 7.2 for which there is NO reason for a causal connection. If the frequency of occurrence plots for the two groups show similar shapes, then it is very likely that clustering of VLF pulses around a meteor is simply a result of selecting VLF pulses that are close to the meteor echo. If this is the case then we cannot attach real significance to the result in Figure 6.5. This would confirm that we need not only ‘actual’ coincident pulses, but also pulse spectra information AND numbers of actual coincidences as a function of time through a meteor shower to show that there is a causal relationship between meteors and VLF pulses.

The result for ‘actual’ coincidence’ is shown in Figure 7.3 and that for ‘apparent’ coincidence in Figure 7.4.

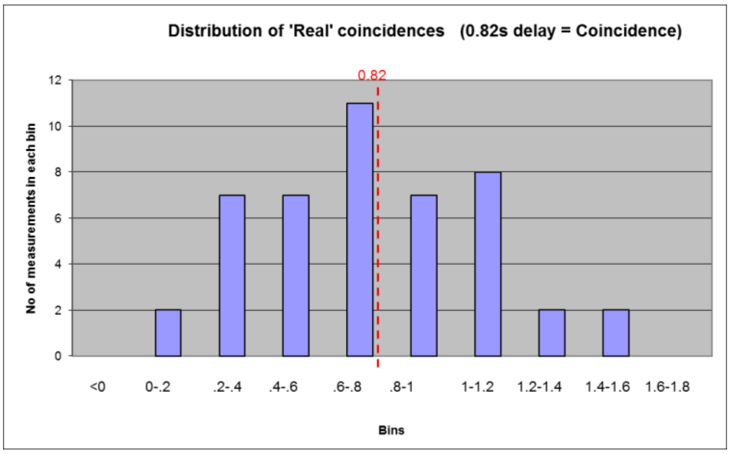

Figure 7.3 Frequency of Occurrence Plot for ‘Real’ Coincidence (where the meteor echo is around 0.82 s after the VLF Pulse

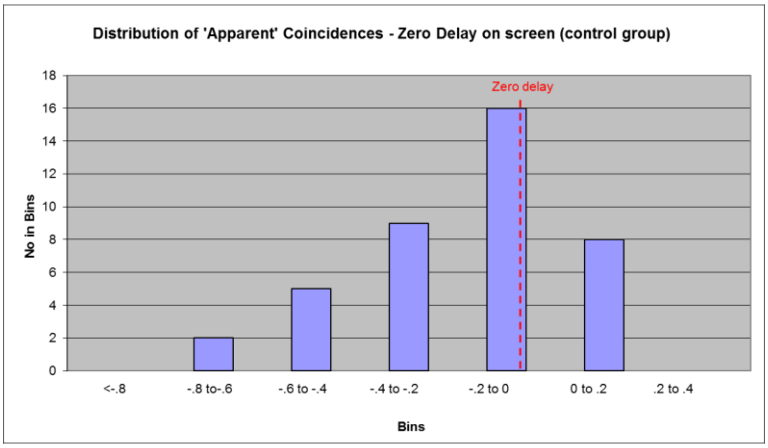

Figure 7.4 Frequency of Occurrence for ‘Apparent’ coincidence (Zero delay on Waterfall Plot)

This suggests that we *cannot* infer a firm connection between echoes and pulses as both distributions show similar peaks.

8 Simultaneous Display of Meteor echo & VLF pulses

In preparation for the measurement to be made during the 2015 Perseids in August, it was decided to use a communications receiver to detect the meteor echoes as this eliminated the processing delay in PC1 (Figure 5.5). The ‘real’ meteor echo and coincident VLF pulse are then displayed together in the waterfall plot and the waveforms of both signals can also be plotted on an ‘oscilloscope’ type display. This will help understand the fine detail of any echo and pulse coincidence.

The first step is to conduct a calibration to demonstrate that both signals do arrive simultaneously. This was done using a single two pole relay to switch a 1kHz square wave into the VLF channel and an RF signal generator on 143.050MHz into the communications receiver. See Figure 8.1.

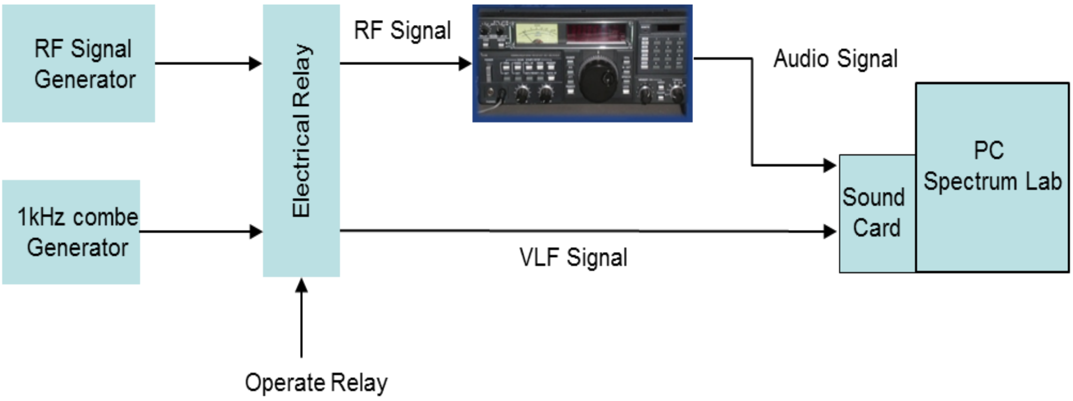

Figure 8.1 Calibration of Communications Receiver based Meteor Echo Channel

The plot showing simultaneous signal reception is shown in Figure 8.2.

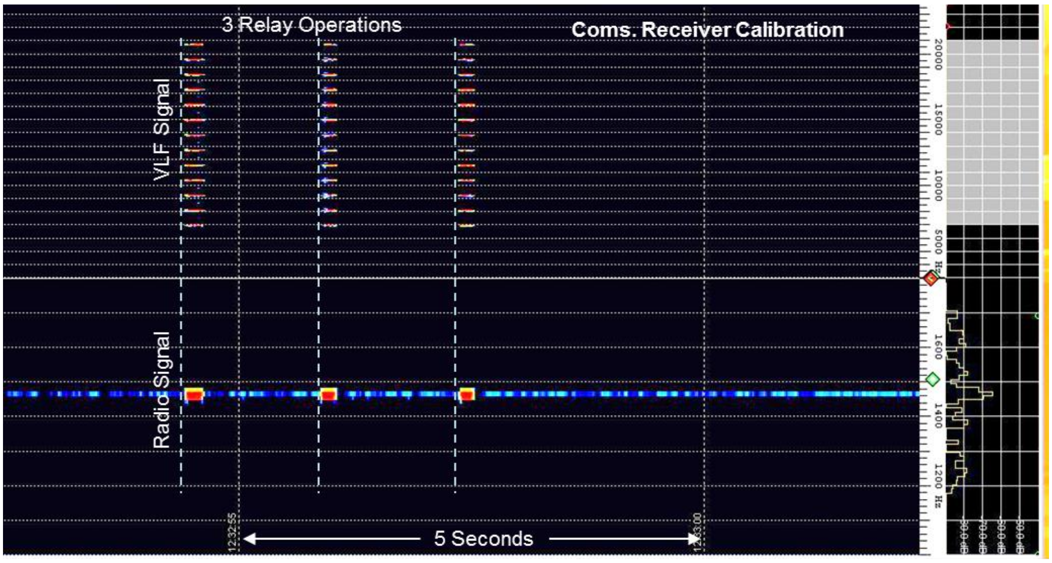

Figure 8.2 Simultaneous reception of VLF and RF signal (via Communications Receiver)

The waveforms of simultaneous signals can now be examined in detail on the digital oscilloscope available within Spectrum Lab, as shown in Figure 8.3.

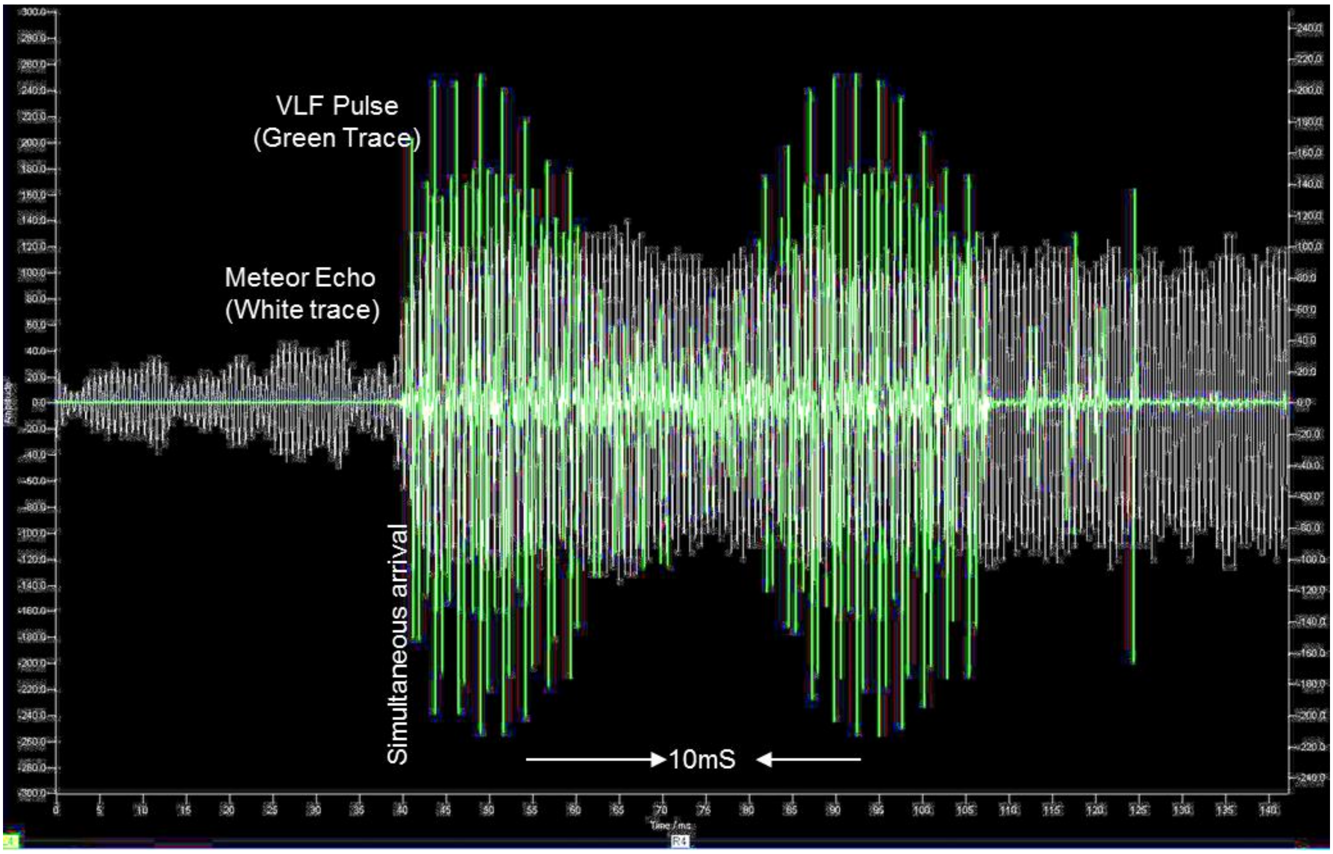

Figure 8.3 Simultaneous Echo and VLF signals (Calibration)

Live measurements of meteor echoes and VLF pulses were made using the communications radio on the 22nd of May 2015. An example of a genuine coincident pulse is shown in Figure 8.4.

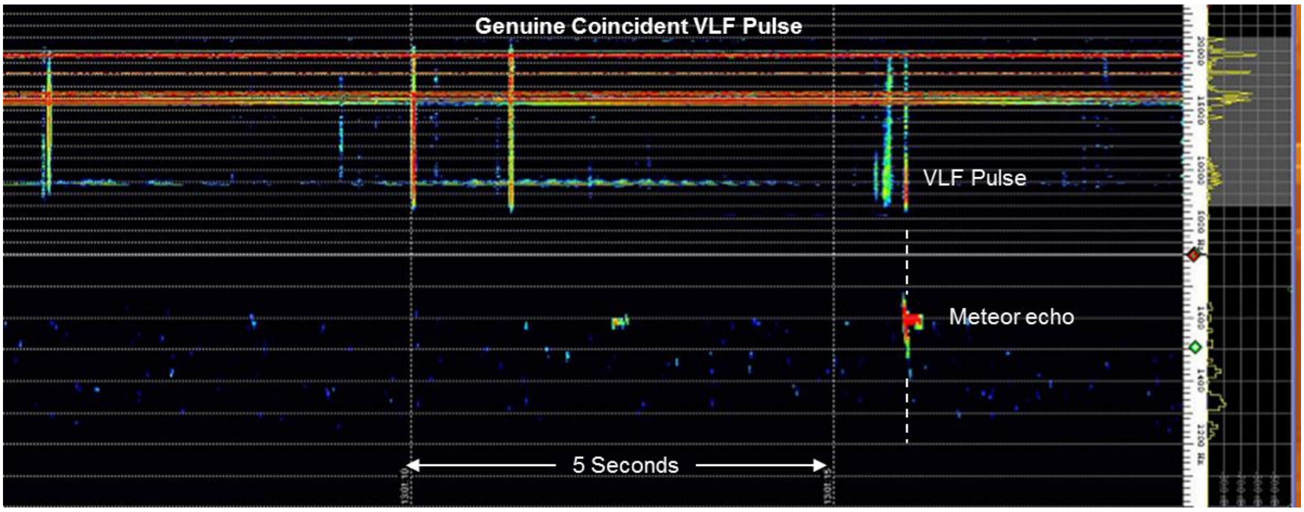

Figure 8.4 Genuinely Coincident Meteor echo & VLF Pulse

The two signals in Figure 8.4 are shown plotted together on the Spectrum Lab digital oscilloscope screen as seen in Figure 8.5.

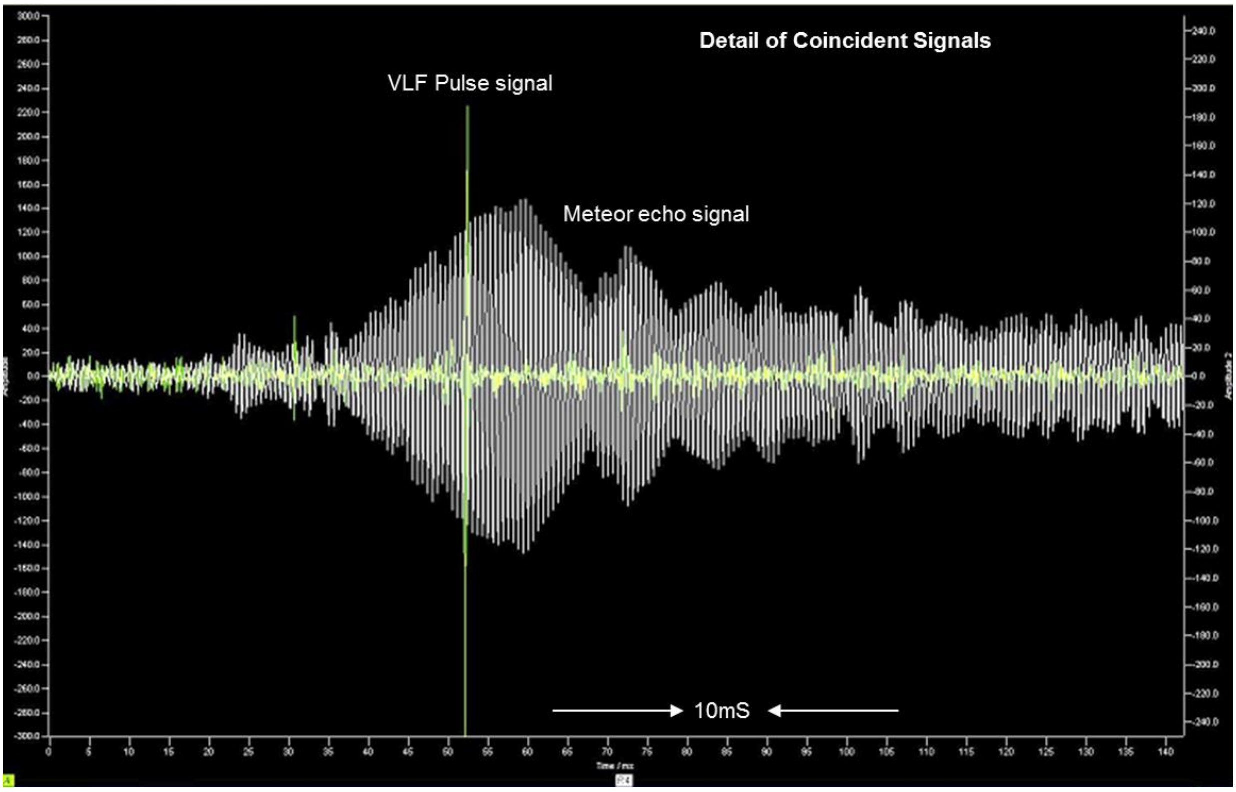

Figure 8.5 Detail of Meteor Echo and VLF Pulse waveforms at 13:02 BST 22/5/15

This is considered to be the final step in preparing the measurement system for monitoring the Perseid meteor shower in August 2015. With this equipment it may be possible to collect unambiguous examples of VLF Pulsed emissions from meteor trails.

If this article has encouraged others to attempt similar measurements during the Perseids in August it would be good to pool data and discuss results.

Some amateur measurements have already been made in 2009 by Jean-L. RAULT [17] F6AGR IMO (International Meteor Organization) Radio Commission. The work was a collaboration between Rault in France and Romero in Italy.

A tentative VLF/VHF observations campaign was performed with the help of Renato Romero. The live VLF data being received in Cumiana, Italy by Romero were retrieved from the Internet and compared to the VHF meteor pings detected near Paris, France. Rault comments that: “time synchronisation issues occurred, because the sample frequency used by Renato was never exactly the same as the one produced by my own computer, so the VLF/VHF correlations task wasn't possible.”

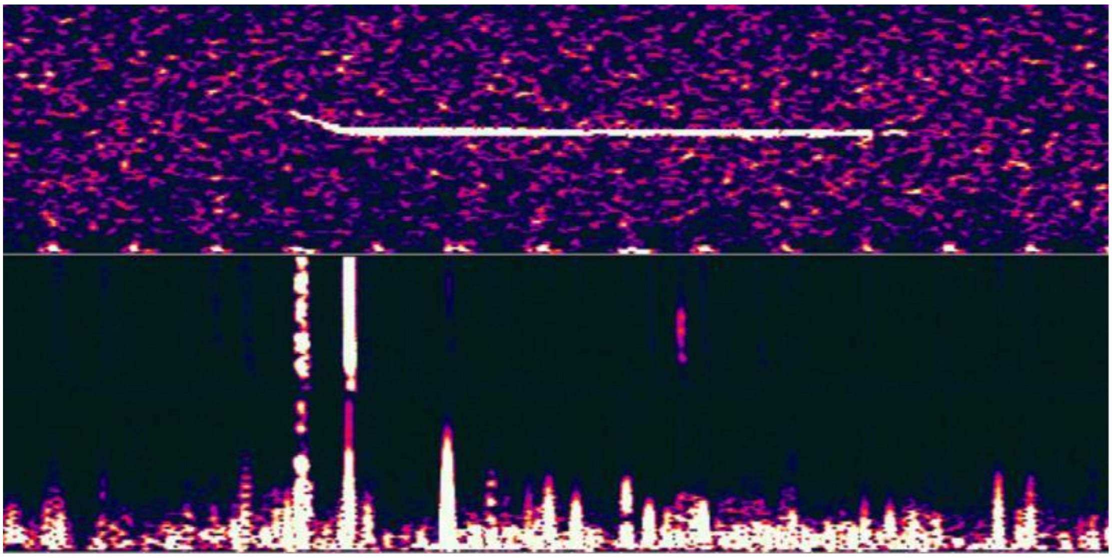

Figure 8.6 Suggested Near Coincident VLF pulses with Meteor Echoes (J L Rault)

Rault also comments that: “Looking for correlations between meteors and ELF/VLF events is a very demanding and a very time consuming task. The detection of the interesting events can't be automated, because the ELF/VLF events signatures are not known in advance”.

He goes on to suggest: “The theories stating that some meteors can radiate low frequency electromagnetic energy seem to be supported by the present practical study which is based on hundreds of actual discrete observations of meteors and ELF/VLF events. However, more data are still needed to confirm such a conclusion.”

9 Conclusions

- A somewhat under-explored aspect of meteor physics has been presented which combines the two different Radio Frequency disciplines of passive Very Low Frequency (VLF) detection and a Radar-like technique for detecting meteors.

- A brief history of academic study of the production of VLF pulses by meteors is given and a broad view of the theory of the physical generation mechanism is presented.

- A relatively small data set exists dealing with this topic and a few examples of VLF emissions from meteors are given. In particular the claim that meteor VLF pulse spectra differ from lightning pulses is considered.

- It would appear that the full theoretical description of the generation mechanism is still to be developed by academics.

- An example is given of the correlation between meteor generated VLF pulses and the development of a meteor shower, proving that a significant number of meteor VLF pulses are produced during such events.

- The configuration of an amateur receiving system is explained and its characteristics explored.

- Initial measurements made with this equipment are described and a simple statistical type analysis of the coincidence of meteor radar echoes and VLF pulses is carried out.

- The results show that a causal relationship between meteors and VLF pulses cannot be established by coincidence detection alone. Other measurements of pulse spectra and correlation of VLF pulse detection rate within meteor showers are required.

- An amateur measurement campaign in 2009 is reviewed and the conclusion that it was not possible to unambiguously link VLF pulses with meteor radar echoes is stated.

- Having built a suitable detection system the author is intending to undertake measurements during the Perseid meteor shower in August 2015 in the hope of gathering sufficient data to demonstrate a link between meteors and VLF pulses which they are said to generate.

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