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Recognising and classifying echoes from the GB3MBA Meteor beacon.

The GB3MBA meteor beacon is located at the Sherwood observatory and illuminates a region of the ionosphere above the UK. At an altitude of 80-100km the region illuminated has a diameter of more than 400km.The beacon transmits on a frequency of 50.408MHz, a wavelength of 6m, and beams vertically up with Right Hand Circular Polarisation.

Fig 1

A network of receivers (see Fig 1) detect echoes from ionisation created as meteors burn up due to friction with the atmosphere. Echoes from other events such as Sporadic E and Aurora are also detected from time to time along with aircraft echoes and interference from various sources including lightning and man made interference.

A region will become reflective to radio at a given wavelength when the free electron density reaches a sufficient level.

It would be useful to automate recognition of events of interest so that they can be captured discarding the unwanted echoes and interference. The data would then be classified and saved for later analysis.

Meteor Echoes

It is convenient to display radio echoes from meteors using a “Waterfall Display”

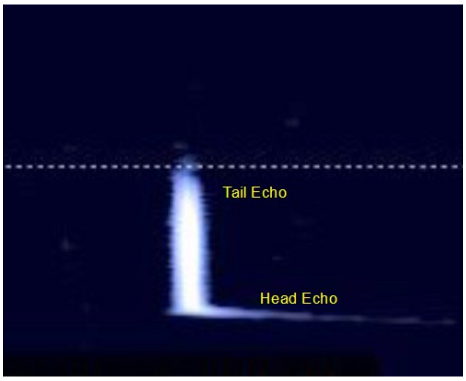

Fig 2

Echo strength is represented by brightness, the horizontal scale is frequency, used to indicate Doppler shift and the vertical scale is time, flowing down the screen hence the name “waterfall”. See Fig 2.

Meteor echoes can have two distinct parts Head and Tail echoes. “Head echoes” are very short lived and exhibit rapidly changing Doppler shift as the reflection path length changes and the meteor decelerates due to friction. Head echoes appear as near horizontal lines on the waterfall display. “Tail echoes” can last much longer, have smaller Doppler shift and can be spectrally spread sometimes creating complex patterns we call exotic echoes.

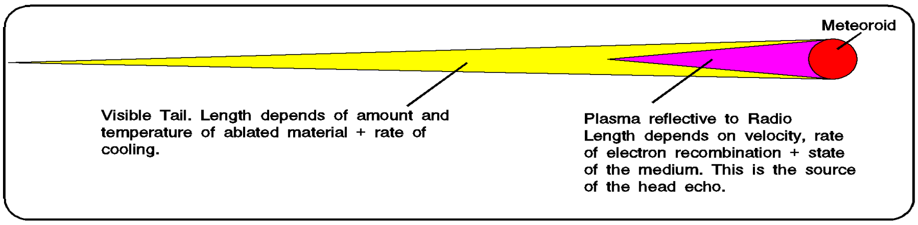

Fig 3

Head Echoes are from the relatively short trail of ionisation following the meteor creating a a rod like structure. Free electrons re-combine rapidly so this structure is relatively short and of variable length typically up to perhaps a few wavelengths long at 6m.

This structure behaves like a conducting rod or wire flying across the sky. See Fig 3. Whilst the illuminating radiation is circularly polarised, this structure collects and re-radiates energy with linear polarisation determined by the meteors' trajectory. Like a rod or wire of this lengths it re-radiates with lobes and nulls created by interference patterns according to it's length. There will always be a deep null along the axis of the trajectory. So head echoes can be highly directional and can go unseen by some receivers depending on the reflection geometry.

Tail Echoes sometimes form when material ablated from the meteor in conjunction with pre-existing ionisation in the region through which the meteor has passed causes the electron density to rise to that required to reflect radio of a given wavelength. Tail echoes can last much longer than the “head Echo”. Figs 4 and 5 illustrate tail echoes.

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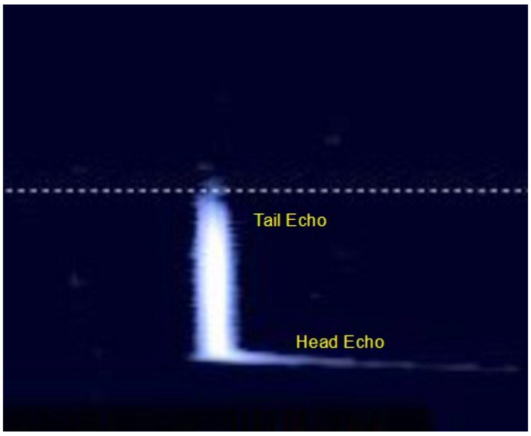

Fig 4 A classic echo on a waterfall display

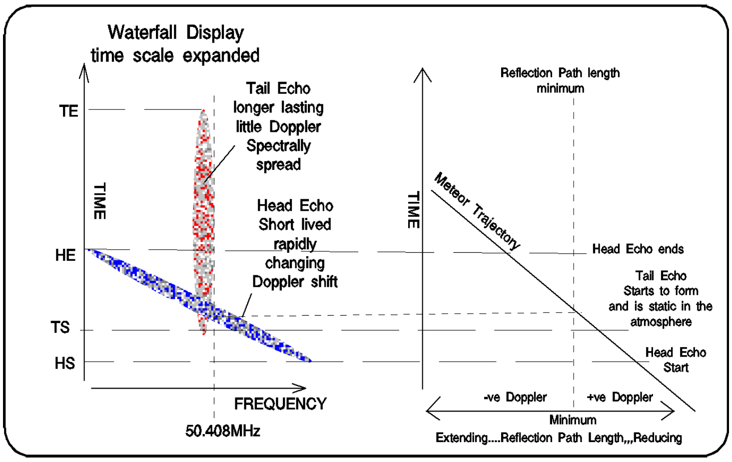

Fig 5 A classic meteor echo explained

Tail Tail echoes echoes can last from a few seconds to minutes and are static in the atmosphere so any Doppler shift is due to wind. Echoes similar to tail echoes can occur due to other phenomena in the ionosphere such as Sporadic E. The presence of a “Head Echo”, seen by any of the receivers confirms that the event <u>was</u> triggered by a meteor.

Recognising Meteors and other events of interest.

It is necessary to recognise unwanted echoes \ and interference. . Unwanted signals include Aircraft echoes and the direct signal from the beacon by tropospheric propagation . Interference can come from various sources both natural and man made.

Aircraft echoes

Receivers within about 400km of the transmitter will see aircraft echoes. These are characterised by curving near vertical lines on the waterfall display. (changing Doppler shift due to the motion of the aircraft) .They have little spectral spreading. See Fig 6.

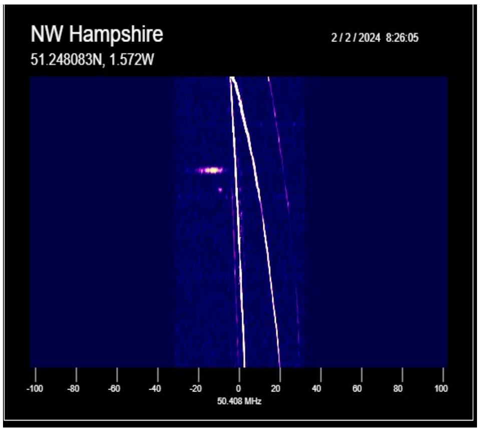

Fig 6

Spurious interference

Spurious emissions from poorly suppressed electronic equipment may produce similar narrow traces.

See the faint trace in Fig 7. Any line sloping from lower left to upper right must be interference from a drifting spurious signal. It starts with high negative Doppler shift and ends with a high positive Doppler shift. This cannot be explained by the motion of an object / reflecting source.

Direct signal

This will be exactly on the transmit frequency of 50.408000MHz producing a vertical line on the waterfall display. It's strength will depend on the distance from the transmitter to the receiver and on prevailing propagation conditions. Fig 6 shows a direct signal along with an aircraft echo and a small meteor echo.

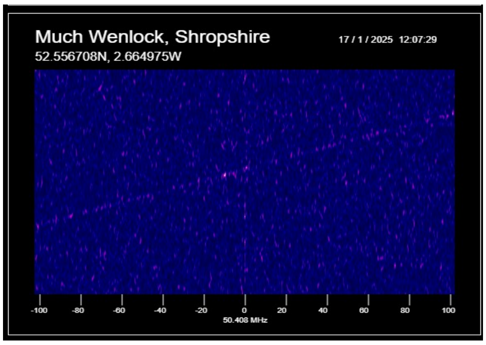

Fig 7

Wide band Interference

This can include burst interference such as lightning strikes, electric fences, thermostats etc. or continuous interference from badly suppressed LED lighting, Solar Panel optimisers etc. The noise floor will be raised locally if such interference is present.

Fig 8 shows an example of wide bandwidth noise bursts. This turned out to be from a fault in the electricity supply network but lightning can produce a similar result.

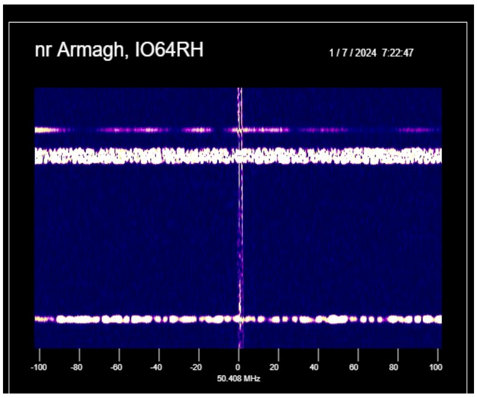

Fig 8

Wide band continuous noise

Sometimes we may see the noise floor raised for a period of time. Fig 9 shows such a situation. If seen on just one receiver this is likely to be caused by local interference. If seen by multiple receivers at different locations it could be caused by Aurora.

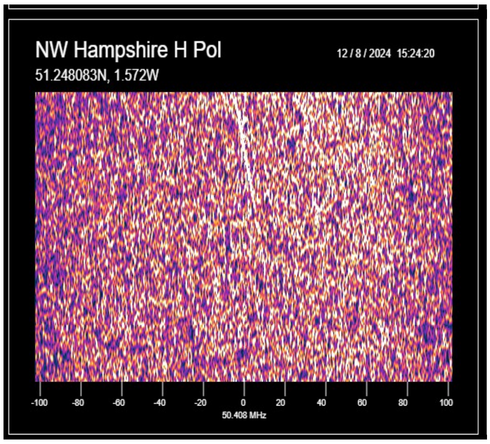

Fig 9 Wide band continuous

Beacon Identification

The transmit beacon is required to identify every few minutes. It does this by sending its call sign GB3MBA in morse code using A1A (ON / OFF) keying. This produces some key clicks which in the presence of a strong signal such as from an aircraft echo produce a pattern as shown in Fig 10.

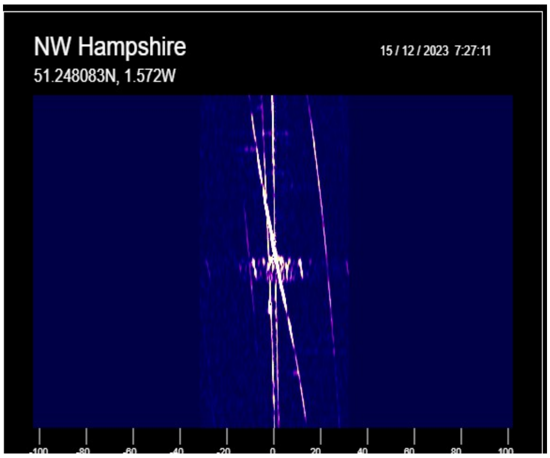

Fig 10

Network effects

We sometimes see some as yet unexplained effects probably associated with network interruptions. They may be more common on the receivers using StarLink . See Fig 11.

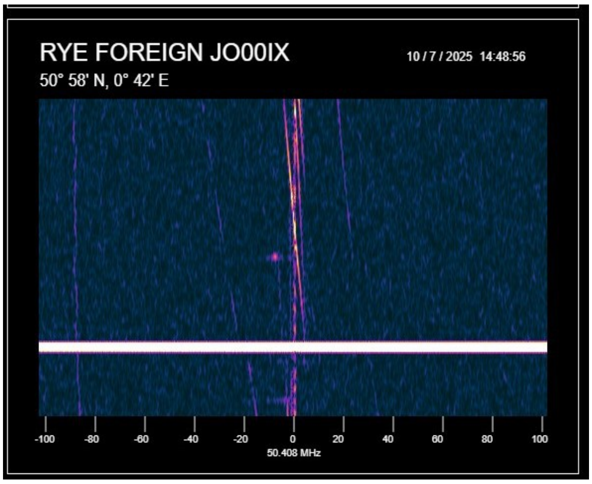

Fig 11

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Raw Data

To design software to recognise and analyse echoes it is necessary to work with the receivers raw data which is available at the system server..

We have stored example raw data from all the main receivers in the network for research and development purposes. These can be found at:- https://ukmeteorbeacon.org/LivestreamRecordingsList The spectrum centred on 50.408MHz is sampled at 7.812 k SPS (samples per second) and is in the form of two 16 bit values, one for each I and Q data point. This is similar to .wav format. For every 4096 bytes of data we add a 32 byte header, so in total the data stream from each receiver occupies a band width of approximately 31.5KBytes/second. This bandwidth includes the precision timing marks that are injected into the front end of the receivers so that data can be correlated in time, correcting for the various sources of latency through the receiver and internet to the project server.

UTC time and other information is pulse width encoded into the 60 one second timing marks every minute. The leading edge, the bottom of the marks when viewed on a waterfall display, is synchronised to UTC See Fig 12. This is described in document MBA_RxTimingUnit.pdf at https://ukmeteorbeacon.org/Documents2List .

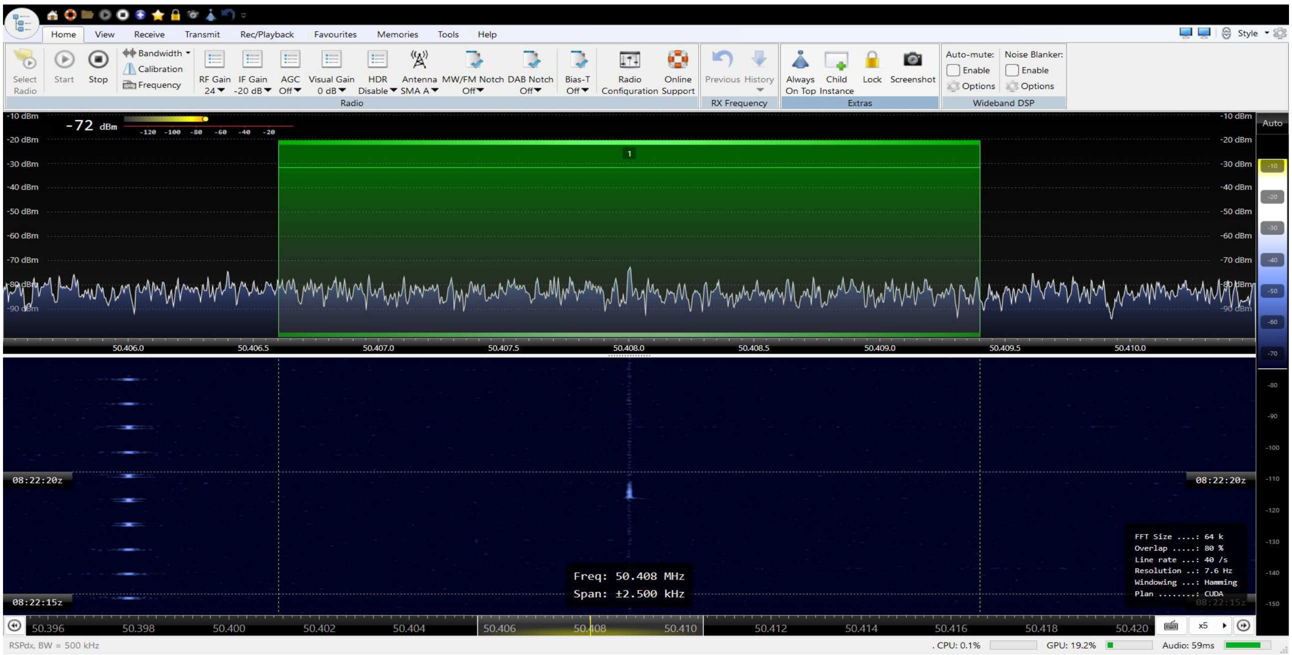

Fig 12 An example showing 5KHz of the raw data with timing marks

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Analysis of echo data

Some thoughts on the things to consider.

Presence or absence of head echo

ditto – Tail echo (s)

Peak brightness of head echo

Extent of observed Doppler shift of head echoes. Ie start freq and stop frequency

Start time and end time of head echo, for potential triangulation, and duration of head echo (likely to be mS to a maximum of about 500mS)

Doppler shift at peak brightness .

ditto tail echo (s)

Number of tails

Doppler shift of tail echoes, max and min.

Duration of tail echoes ..(likely to be zero to minutes)

Head Echo

Was a distinct head echo seen – for each receiver in the network ? As head echoes can be highly directional not all receivers will see a head echo especially for small meteors.
If so what was it's start time and frequency, end time and frequency, Duration ? at each receiver.
What was the maximum brightness level? Average brightness Level ?
Note Start and end times are set by a preset brightness level. Set for each receiver. We may need to do some work on calibration to make maximum use of this data.

Tail Echo

For each receiver. Was a Tail echo seen ?
Single or multiple tails ? Max and Min Doppler shift / spectral spread?
Duration.
Max Brightness, average brightness, total energy ?
Was the associated Head Echo seen ? Y/N.

Exotic Echoes

From time to time we see “exotic echoes” with multiple tails. See Fig 13. These may be associated with break up of the meteoroid and / or its passage through regions of wind shear. Such regions may have an increased level of ionisation prior to the passage of the meteoroid.
Sometimes these exotic echoes can be complex. See Fig 13
Exotic echoes appear to be related to pre-existing ionisation perhaps due to wind shear, solar and other radiation. ?

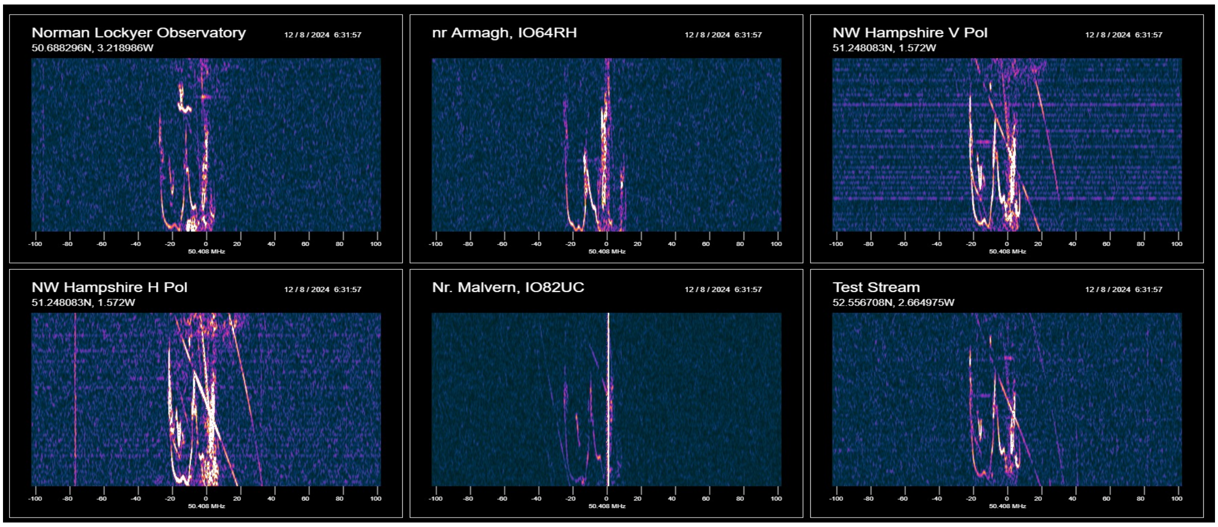

Fig 13 An exotic echo seen by all receivers in the network.

Signal level

This is represented by brightness on the waterfall display. The live display at https://ukmeteorbeacon.org/beaconclient/ has a limited dynamic range from Dark to fully saturated of around 10dBs. This produces a workable display. But the raw data from each of the receivers has a far greater dynamic range which may be needed for the larger events. Most of the meteor echoes we see are from meteors around the size of grains of sand and so produce echoes of relatively low strength. These occur at a rate of around two per minute. But we are particularly interested in the much less common larger meteorites which may produce much stronger echoes.

At some point we will have to decide on a signal level that triggers the recognition process. This should be a preset variable. Also while every effort has been made to ensure the receivers are equally matched and located in radio quiet locations the software should have a facility to set the noise floor for each receiver independently.

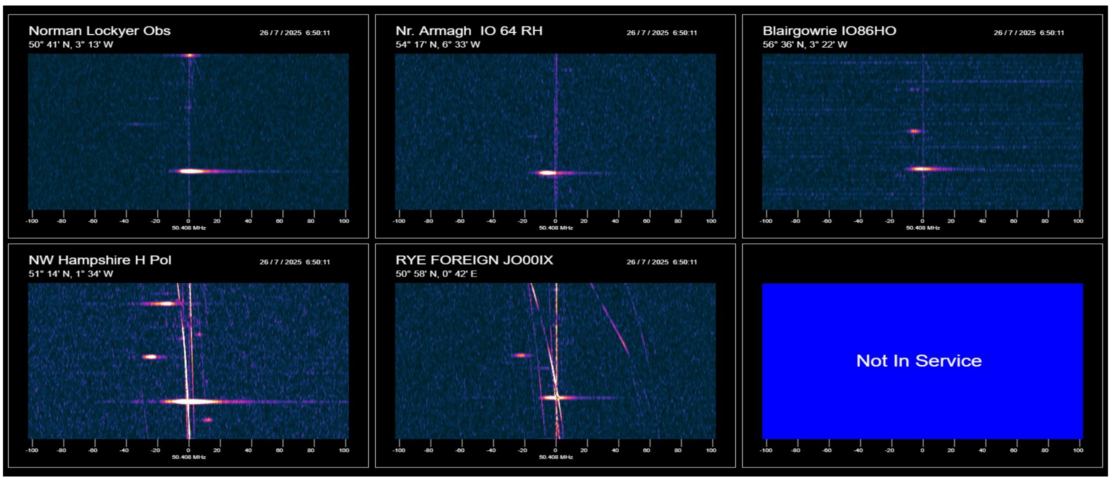

Fig 14

Fig 14 shows a head echo seen by all 5 operational receivers in the network. Although this is probably from a a small meteor it shows the potential for triangulation.