Lightning scatter: a faint and rare mode of propagation

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Reflections on layers of the ionosphere, reflections on ionised meteorite trails, echoes on airplanes, EME, reflections on auroral ionised clouds … Various modes of radio propagation have been explored and used for a long time by radio amateurs.

Could lightning also be capable of scattering radio waves?

This article deals successively with a theoretical and a practical approach to lightning scatter.

1.0 Theoretical point of view

1.1 Is a flash of lightning able to reflect radio waves?

Any ionised medium is liable to reflect a radio wave. A thunderbolt is a violent electric discharge that heats and ionises the ambient air. Temperatures can reach 20 or 30,000°K and the electron density can raise up to 10^{17} to 10^{18} electrons per cm^3 [2]. Knowing that the electron density necessary to get full radio waves reflection is as follows [4]:

$$N_e = \frac{\pi \cdot m \cdot f_N^2}{e^2} \qquad (1)$$

m and *e* being respectively the mass and the electric charge of an electron and f_N being the frequency of the reflected wave, one can see that a flash of lightning is theoretically able to reflect the entire radio spectrum.

Replacing *m* and *e* by their numerical values and using electrons per cm^3 for N_e, the highest reflected frequency is:

$$f_N = \sqrt{\frac{N_e}{1{,}24 \cdot 10^4}} \qquad (2)$$

with f_N given in MHz and N_e in electrons per cm^3.

So one can see that 3×10^9 electrons per cm^3 is a density that is high enough to allow a reflection of VHF or UHF radio waves.

A lightning flash ionised channel can be several kilometres long [6], with a diameter being a few centimetres in size. 80 % of the flashes are of cloud-cloud type (CC, see fig 1), 20% being of the cloud-ground type (CG, see fig 2).

The extremely high temperature gradient affecting the air layer close to electric discharge could possibly participate in

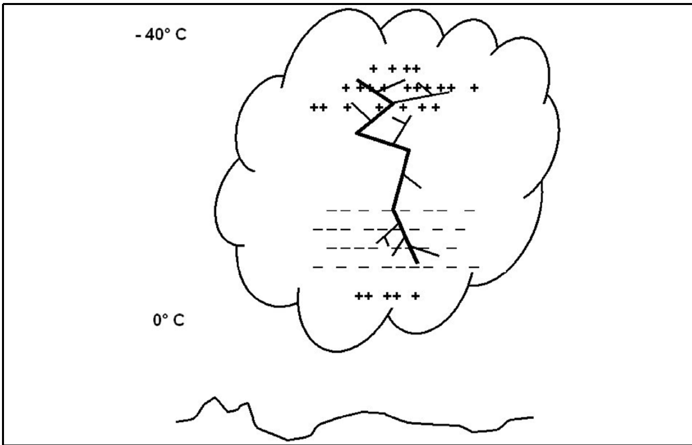

Fig 1: Cloud to Cloud (CC) flash.

the radio waves reflection.

1.2 What could be the effective duration of reflection from a flash of lightning?

A CC or a CG lightning flash is composed of several phases.

At the beginning, low intensity precursors (where electrical current reaches a few hundreds amperes) appear in a highly charged part of a cloud. When a conductive channel is connected between two parts of a cloud with opposite polarities, or between a cloud and the ground, a return stroke appears which carries a huge quantity of electricity (several ten thousands amperes).

A complete lightning flash includes several return strokes and can last several hundreds of milliseconds [2], [3].

1.3 What is the probability of occurrence of lightning flashes?

Most of the 3000 thunderstorms that appear each day around the world occur in the equatorial area.

In Europe, the occurrence is around some tens of electrical activity days per year [1]. See Fig 3 for a map of France showing an example of the yearly statistics. Knowing that a single thunderstorm

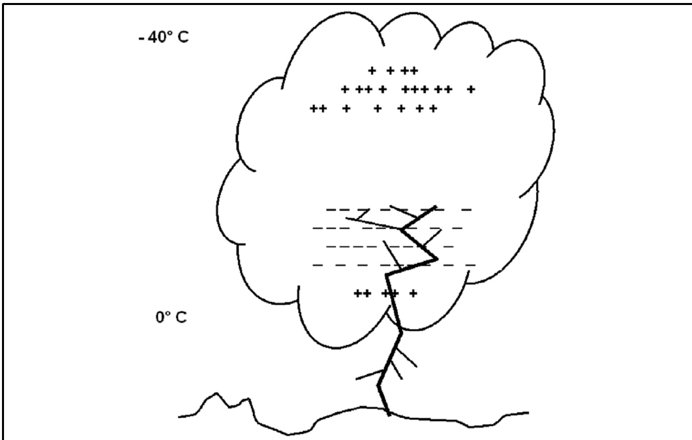

Fig 2: Cloud to ground (CG) thunderbolt.

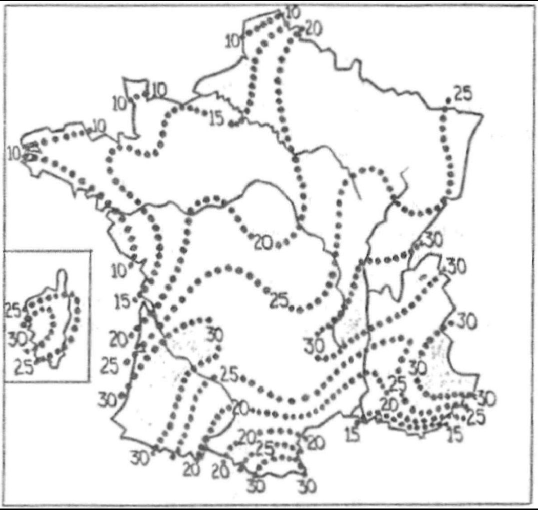

Fig 3: Annual statistics about thunderstorms in France.

generates hundreds or thousands of lightning flashes, one can see that the probability to get some echoes is not negligible.

1.4 What is the maximum distance one can expect for lightning echoes ?

The maximum echo range for a transmitter and a receiver located both at ground level (if we consider they have the same altitude) depends on the mirror altitude.

The range is as follows:

$$D_{\max} = 2 \cdot R \cdot \arccos \frac{R}{R+h}$$

R being the Earth radius and h the height of the reflecting part of the lightning flash.

For example, a height of 5000m gives a range of 500km, assuming that the mirror is located half way of the transmitter and receiver, and a little bit more if the atmosphere refraction is taken into account.

2.0

Practical experiment

A reliable test procedure has to be established, to be sure to catch, record and analyse any lightning scatter.

Just listening to distant beacons during a stormy day is too subjective and not convincing enough to prove that lightning scatter really exists.

The following key points were taken into account when establishing the test programme:

- choice of a radio beacon transmitting a stable and well known signal
- absence of interference around the beacon frequency
- distance between beacon and receiver large enough to avoid any reception when there is no ordinary tropospheric propagation
- probability of frequent thunderstorms on the beacon/receiver path

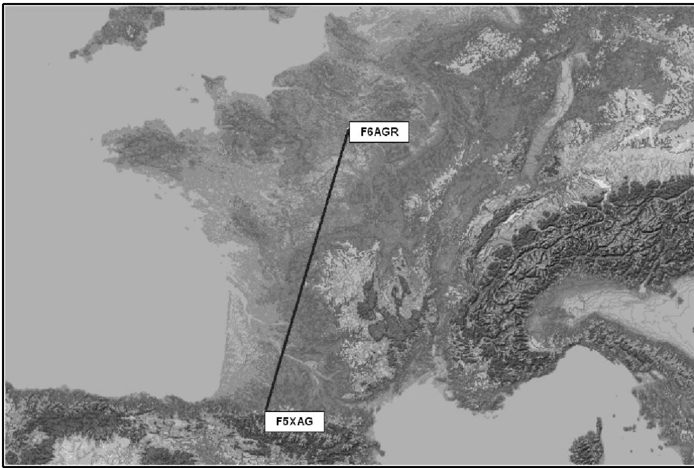

Fig 4: F5XAG to F6AGR path.

- automatic record of receiver audio output to allow further batch analysis
- simultaneous automatic record of radio noise generated by the lightning flashes in order to allow further correlations analysis
- monitoring of thunderstorm predictions and real time activity thanks to weather agencies Internet providers

With all these prerequisites in mind, a campaign of systematic audio records was performed during summer 2004. The radio amateur beacon, F5XAG, was chosen because it fulfils most of the required criteria.

At each end of the 648km path under investigation (see fig 4), the equipment was as follows:

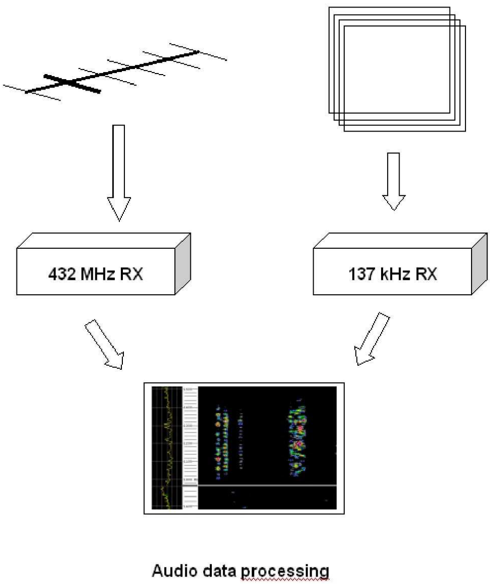

Fig 5:Schematic diagram of experimental equipment.

Fig 6:144MHz and 432MHz aerials.

Beacon:

Name:	F5XAG
Location:	IN93WC
Altitude:	550m
Frequency:	432.413MHz
ERP:	40W
Beam:	NNE

UHF receiver (432MHz):

Name:	F6AGR
Location:	JN18DQ
Ant. altitude	66m
Antenna	2 x 10 element yagi RHCP/LHCP
Receiver	ICOM IC-821H + masthead preamplifier

LF receiver (137kHz):

Name:	F6AGR
Location:	JN18DQ
Ant. altitude	56m
Antenna	23 turns 1.2m^2 square loop
Receiver	ICOM IC-738

Antennas configurations are shown in

Fig 7: 137kHz receiving loop antenna.

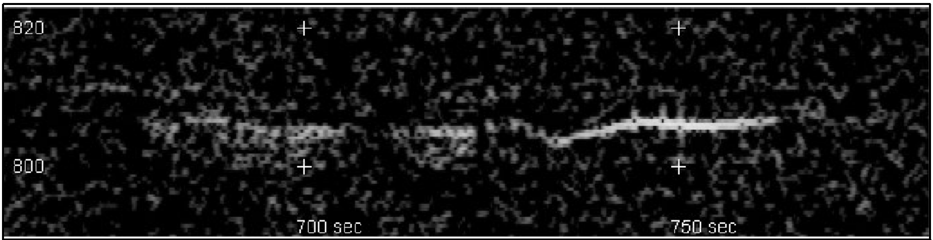

Fig 8: F5XAG long burst of signal.

figs 6 and 7.

The 137kHz amateur band was chosen as the lightning flash monitoring frequency because it gives a good compromise on the detection range of European thunderstorms. Watching flashes on VLF would have given too many pulses generated by very distant thunderstorms. On the other hand, the energy radiated by a thunderbolt in the VHF/UHF band is quite small, and so the range on these bands is limited.

2.1 Receiver/recorder configuration

The audio outputs of the 432MHz and 137kHz receivers are connected to a PC fitted with a stereo sound card (see fig 5). The computer is also used to analyse the records and to track any interesting echoes.

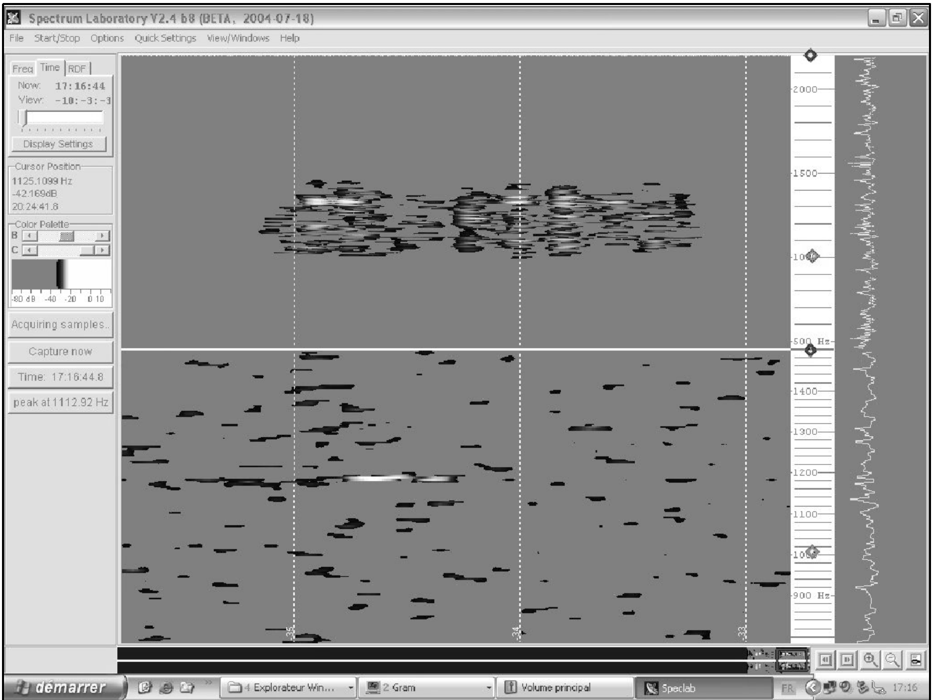

Fig 9: F5XAG lightning scatter.

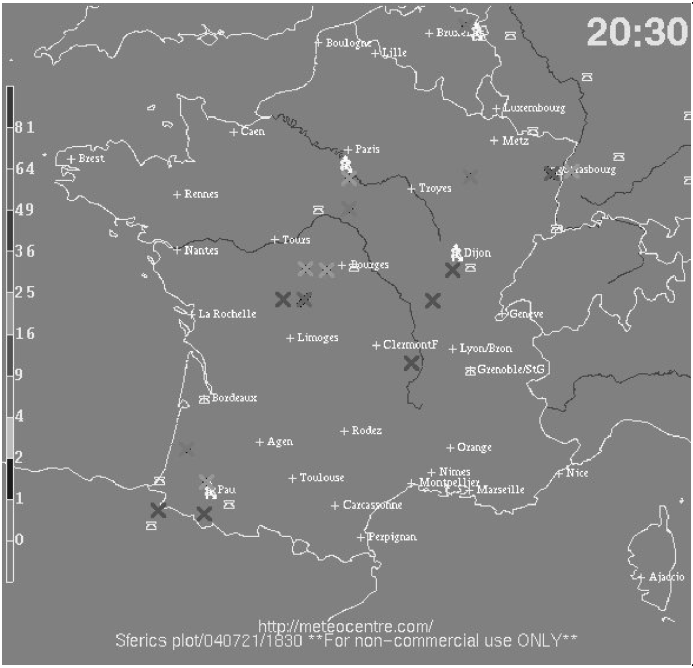

Fig 10: Real time observation of lightning strikes (21 July 2004). ed - looks better in colour, see VHF Communications web site.

The UHF receiver is equipped with an OCXO, which is mandatory to tune the VFO to the correct frequency without receiving any permanent signal (provided that the beacon transmits on the correct frequency).

Both audio channels are recorded in parallel, with 16bit resolution. The sample frequency being adjusted to get the best compromise between the audio pass band and the volume of stored data. For example, one hour of stereo recording with an audio pass band of 4kHz and a 16bit resolution is more than 115Mb.

Recordings are performed in real time on the hard drive of the computer and then stored on 4.7Gb data DVDs. Data compression such as those performed by MP3 algorithms are not usable, because they distort the signal too much, so only WAV recordings offer the necessary record fidelity.

To identify any faint and short echoes, a solution is to use a spectral analysis tool. Although an FFT algorithm is not the best tool to track short pulses, FFT software is very easy to find and to download from Internet.

A graphical display showing frequency on the Y axis, time on the X axis and some colours to give an amplitude indication is very easy and pleasant to examine visually. A quick look is much more effective for identifying a short and faint echo than spending a very long time to listen to white noise.

Two complementary software tools were used for the experiment:

- CoolEdit 2000 from Syntrillium
- Spectrum Lab, developed by Wolfgang Büscher DL4YHF

CoolEdit 2000 is very valuable for juggling with long audio records, offering useful functions such as Rewind, Forward, simple FFT controls, time and

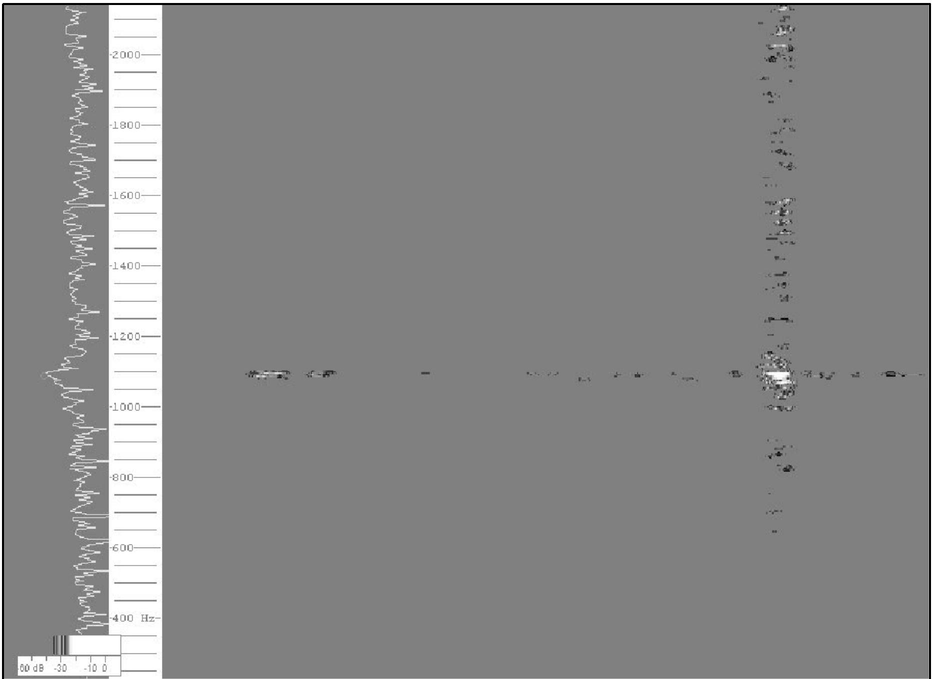

Fig 11: F5XAR lightning scatter.

frequency zooms, all of which are very simple to use.

Spectrum Lab is a powerful spectral analysis tools kit allowing many parameters adjustments. However it requires some knowledge of signal and data processing to be fruitfully controlled.

3.0

Results of the experiment

Several 24 hours-a-day audio records have been performed during calm and thundery days of summer 2004.

The first result is that on this N/S path, bursts of signal coming from the F5XAG beacon were clearly received night and day. Each burst was some tens of seconds long, separated by minutes or tens of minutes of silence. An example of such a burst is shown in fig 8. Some bursts show a typical Doppler effect indicating that the signal is may be reflected from high altitude airplanes, but some others present some frequency splitting and drifts which are not easily explainable.

Several occurrences of lightning scatter on 432MHz were clearly identified in the summer 2004 records. Fig 9 shows an example of such an echo received on July the 21st around 20:30 local time.

The lower trace (432 MHz channel) shows a beacon echo around 1200Hz that goes on for about 500 milliseconds. The signal to noise ratio is about 10dB. No noise at all generated by the lightning

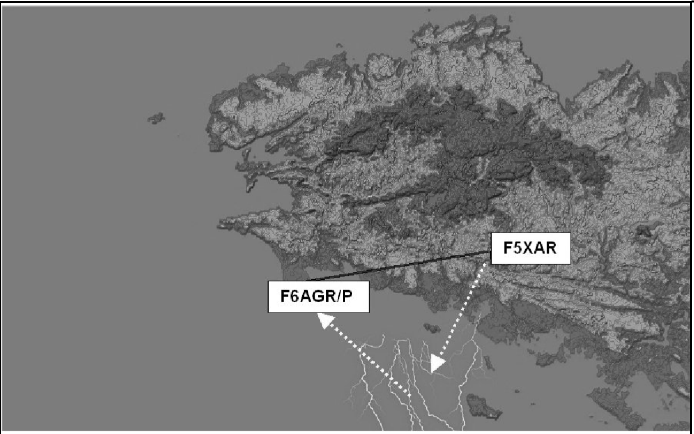

Fig 12: F5XAR to F6AGR/P path.

flash itself was detected. The upper trace shows the corresponding 137kHz activity, which consists in broadband spikes generated by each electrical discharge. Fig 10 shows the real time status of thunderbolt ground hits at 20:30.

During summer 2004, a sea thunderstorm in Brittany allowed another lightning scatter hunt on 144 MHz. The ground path was 82 km long (see fig 12). The conditions were as follows:

Fig 11 shows an example of the echoes which were clearly identified. The horizontal line indicates that the beacon was received most of the time and the vertical line shows the wide band noise received from the flash itself. On the example, the echo was composed of two successive bursts, with a total duration of less than 300mS. The ratio echo/permanent carrier was better than 20dB.

Further to the encouraging results obtained on 144 and 432MHz, old records performed previously in 2002 on 21MHz for a meteor scatter study were re-analysed carefully in order to track any possible lightning scatter on that band. The station used as transmitter was a powerful short waves French broadcast station (Radio-France International) that is very useful to track meteor scatter activity. The 21MHz path was 250km long.

The results were amazing and lightning echoes were identified at a rate of about 6 per minute (see fig 13). The refracted carrier was received permanently and the echo level was 6 to 10dB over the permanent carrier. The length of each echo was a few hundreds milliseconds.

4.0

Conclusion

This lightning scatter experiment shows that radio scattering from thunderbolts really exist.

But many questions remain unanswered… What is the best location and orientation of a lightning flash referred to a transmitting and a receiving station? Are some frequencies better than others? What could be the maximum length of an echo?

Elves and sprites, triggered by powerful positive lightning flashes have been discovered recently, thanks to sensitive video cameras. Could these large lumi-

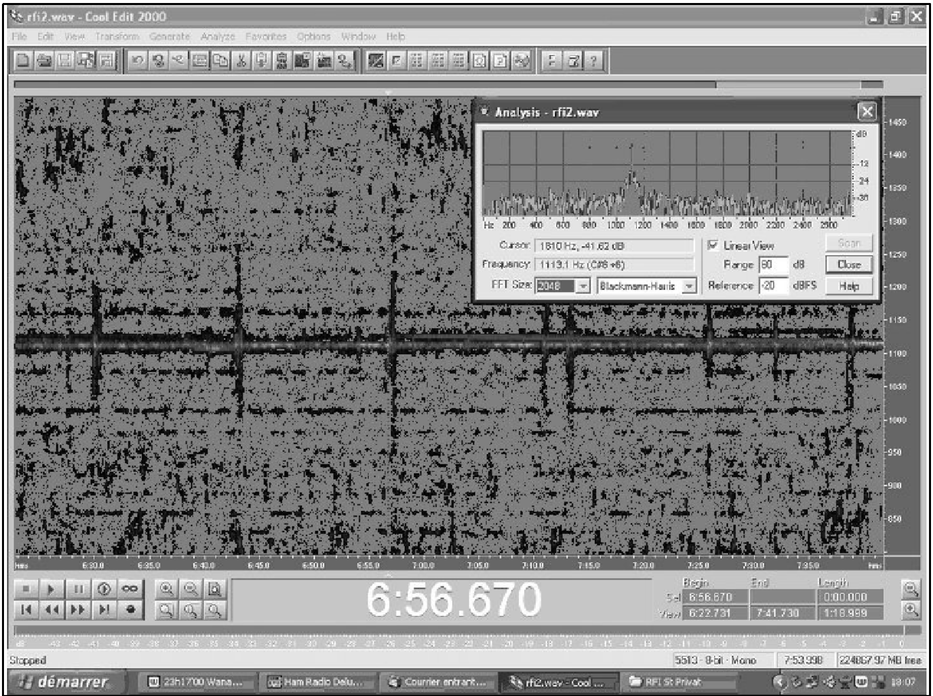

Fig 13: Radio France lightning scatter.

nous discharges happening in the lower part of the ionosphere also contribute to the scattering of radio waves?

That's another interesting story!

5.0

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Ed - Colour pictures from this article can be found on the VHF Communications web site - www.vhfcomm.co.uk