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Long-Delayed Radio Echoes, Observations and Interpretations

The final propagation speed of electromagnetic waves generates a time delay between the transmission and the reception of a radio or light signal. In terrestrial radio traffic, this time delay can be ignored for most practical applications. Only with particularly long propagation paths does the effect become perceptible. In the short-wave range, radio waves can go all the way round the world, under special conditions, which leads to a time delay of about 138 ms. (round-the-worldechoes). Even more impressive are the echoes reflected from the Moon, where the propagation path corresponds to twice the distance between the Earth and the Moon (time delay of about 2.5 s.). The phenomenon described below can be explained by neither of these processes. LDE's (long delayed echoes) can involve a time difference measured in tens of seconds between transmission and reception.

1. First Observations

The first systematic observations were reported by Hals, Stoermer and van der Pol (1).A previous accidental observation had been logged by Hals, who had received long delayed echoes from transmitter PCJJ in Hilversum in the vicinity of Oslo in 1927 (time delay app. 3 seconds). However, experiments carried out over many months on 9.5 MHz were initially fruitless. In October, 1928, long delayed echoes could finally be demonstrated to exist without any doubt, with delay times of between 3 and 30 seconds. Further observations were also reported in subsequent months by other experimenters. (8) contains a comprehensive historical retrospective, in which a further LDE observation from Hals is mentioned, with time delays of 260 s. and 195 s. However, after 1935 interest in this unusual phenomenon appeared to diminish.

2. Scientific Observations

In the years 1947 - 1949, renewed experiments took place involving observations of long delayed echoes. The research was carried out in Cambridge by Budden and Yates (2). They transmitted at 13.4 MHz with a power of 30kW and at 20.6 MHz with a power of 1kW. The aerial used was a half-wave dipole, the structural height of which was intended to make vertical radiation possible.

Unhindered by the ionosphere, the radio waves were to travel on into space, for there were ''well-founded indications'' that ''ionised clouds'' were being emitted from the Sun towards the Earth, which were taken into consideration by the authors as possible reflectors for radio waves (note: in 1951, Biermann drew the conclusion from observations of a comet's tail that a particle stream must exist, moving away from the Sun, which we now refer to as the solar wind.) Budden and Yates published their experimental results in 1952.

Altogether, about 27,000 test signals were transmitted. Round the world echoes were certainly frequently detected, but no long delayed echoes. (Note: the round the world echoes indicate that the aerial radiation system selected could not suppress the ionospheric wave propagation, as had been intended.) The authors conjectured that the transmitter frequencies selected, high in comparison with previous experiments, were as inappropriate as was the vertical radiation. They further conjectured that there was an ''earthbound'' origin for the long delayed echoes, for the rapid solar particles should have triggered a Doppler effect, which had, however, never been reported by previous experimenters, and had been, to some extent, explicitly denied (see, for example, (1)).

Laboratory experiments on echo effects in plasmas aroused interest in long delayed echoes at Stanford University. The mechanisms discovered in the laboratory also appeared to be conceivable under the conditions of ionospheric plasma, but this conjecture had to be verified by more precise research. Nevertheless, experiments were carried out using a 20kW

Year	Call Sign	Band	Delay Time	Mode	Echo Signal
1932	W6ADP	28 MHz	18 s	CW	Own
1950/51	W5LUU	7 MHz	5 s	CW	Own
1965	K6EV	14 MHz	3 - 4 s	SSB	Own
1967	W5VY	28 MHz	3 s	SSB	Own
1968	W5LFM	10 MHz	0.5 s	Time Marking	Station RID
1968	W6KPC	28 MHz	1 s	SSB	Other
1969	W6OL	14 MHz	6 - 10 s	SSB	Other
1969	K6CAZ	2 MHz	2 s	SSB	Other/Own

Table: LDE reports, as per (3)

transmitter (5 to 25 MHz) and a log-periodic aerial, although the equipment was modified several times during the experiments, between 1967 and 1970 (4).

The first long delayed echoes were registered in October, 1968, but had to be rejected as internal interference signals. A pulse diagram was finally to improve the unambiguous identification of the actual signal transmitted. The authors mention the difficulty of automatic plotting and the particular capability of human hearing to recognise signals of this kind among background interference. In January and February, 1970, three long delayed echoes were received at 11.02 MHz and 10.62 MHz, with time delays of 15 s. and about 20 s.. By December, 1971, the number had risen to 31, according to (12).

An automatic observation apparatus was described by Duffet-Smith of Cambridge in 1975 (6). Experiments using a 250W transmitter produced no results. The automatic recording system proved not very effective, due to short-wave interference. The author explains that all earlier research had confirmed human hearing as the most sensitive detector. On the basis of the negative results of his research, evaluations of the phenomenon of long delayed radio echoes tended to be cautious.

A critical evaluation of previous research was published by scientists at Stanford University in 1985 (12). Some experiments were undertaken, using a vertically radiating frame aerial, on the WWV time signal transmitter (5.865 MHz).However, the seven echoes registered (time delay between 1.5 s. and 18.3 s.) could not finally be regarded as authentic. The earlier measurements from Stanford University (see above) were also put in doubt and were linked with technical side effects. The observation data made available by Goodacre (VE2AEJ/3 - see below) were also treated with caution. Vidmar and Crawford demonstrated, on the basis of their own observations, that if stricter criteria were applied the supposed radio echoes generally proved questionable. But the comprehensive reports stretching back over the past fifty years ruled out any doubt as to the existence of long delayed echoes.

3. Observations From Radio Amateurs

Radio amateurs have contributed the most comprehensive observational material concerning long delayed echoes. There is no other field of radio wave propagation where radio amateurs' observations have obtained a comparable degree of respect in the scientific literature. The LDE observations listed in the table have been obtained from the QST.

Goodacre (VE2AEJ/3) reported, in a scientific essay, on eight possible LDE effects, which he had been able to pick up between November, 1978 and January, 1979 in the 28 MHz band(9). A five-element Yagi and a 400 W-powered transmitter were used in the experiments near Ottawa. Groups of three to nine pulses were transmitted at a rate of 130 - 150 Hz. The pulses were generated using a continuously switching relay, which was switched by means of a Morse key in series. The radiation was being transmitted towards the Western horizon when ground-to-ground communication in the 10 m. band began to fail, and 10 m. connections were already impossible on other compass bearings. The questionable band points were noted while tape recordings were being made, so that the only observation findings subjected to evaluation were those which had already been considered as suspected LDE's while the experiments were going on (avoidance of false interpretations arising from the known "copying effect" of magnetic tapes). The tape recordings were finally studied using an oscilloscope.

Hardly any attention had been paid to long delayed echoes in the German-speaking world up until then. But it may be assumed that some observations made had not been publicised because the unusual effect was interpreted as an attempt at deception. For example, Schwarzbeck (DL1BU) very probably reported long delayed echoes, in addition to the normal round the world echoes, as a "Morse dot delayed by several seconds" which remained present when the frequency was changed (10).

During an RTTY contest in October, 1986, DJ4ZF and DL6QH received the last 40 to 50 teleprinter characters (45.45 Bauds) of their own transmission (14). The frequency of the echo was app. 300 Hz lower than the transmission frequency. The 20 m. band displayed the typical effect of the "close" before the breakdown of transmission, with the echoes exhibiting a "West Coast or Alaskan character". An output power of 750W was transmitted on a monoband ground plane. The authenticity of the echoes can not be guaranteed. The observers interpreted the phenomenon as an attempted deception by another radio amateur and did not hear of the LDE phenomenon till later.

4. Observations in the UHF Range

The most spectacular amateur observations report long delayed radio echoes in EME connections. Rasmussen (OZ9CR) reported "ghost echoes", in a scientific journal, which he had picked up at 1,296 MHz (7). In a Moon echo experiment on 7. 7. '74 (8 m. dish aerial operating at 500W), it proved possible to receive echoes which arrived about 2 seconds after the genuine Moon echoes. These echoes remained noticeable, even when the aerial was not aligned precisely with the Moon and the usual Moon echoes were absent. The phenomenon lasted for 20 minutes.

Note: doubts were cast on the observation data reported by Rasmussen on the basis of the Moon position specified, and Rasmussen therefore corrected the data on 28. 5. '74 (see (8)).

(8) refers to further LDE observations in connection with EME experiments. The Dubus Magazine also has a short report on long delayed radio echoes which were picked up by YU1AW on 432 MHz (11). The additional echoes followed the Moon echoes with a time delay of about 2 s. and were slightly displaced in frequency.

When the various LDE reports were scanned, a possible common factor in the data from the YU1AW observations in the 70 cm. band and the 10 m. observations of DL1BU (see above) became clear. Unfortunately, the actual observation times could no longer be reconstructed. A survey of long delayed echoes published by the author (see (13)) unfortunately yielded no evaluable results.

5. Interpretations

The attempts at interpretation which accompanied the observations of previous decades can not be summarised here. We should, of course, point out that the boldest attempts at explanations assumed that an extra-territorial space probe was reflecting the terrestrial radio signals (see, for example, (5) and (8)).

Since the abortive scatter experiments on the solar wind, at the latest (see above), there is final agreement that reflections from astronomical objects can not be held responsible for the radio echoes. In near-Earth space, there is only one object with a sufficient back scatter cross-section to cause radio echoes which are observable, even with low-powered transmitters. But radio amateurs know from their own Moon experiments that the echoes are relatively weak, with a delay time of (2.5 ±0.5) s.. The next possible object is Venus, which can approach as close as 0.27 astronomical units to the Earth (1 astronomical unit corresponds to the average distance between the Sun and the Earth). For this special astronomic configuration, a time delay of app. 270 s. can be calculated for the journey there and back.

Finally, the screen effect of the ionosphere on short electro-magnetic waves must be considered. It is generally accepted today that long delayed radio echoes are an effect, the origin of which must be located in the terrestrial ionosphere or magnetosphere.

The observations reported in (10) verify that, in principle, short electro-magnetic waves can go several times round the world. Seven times round the world yields a propagation path with a length of app. 0.97 light seconds, which is 290,000 km.. The estimate made by Schwarzbeck for this example also points out that the round the world echoes may be subjected to path attenuation effects, which are significantly reduced as against free space propagation. However, "normal" round the world effects do not seem able to explain the radio echoes under consideration here. At least, there are no indications that the delay times observable for LDE's are multiples of 138 ms.. Nor do the LDE reports mention any multiple echoes analogous to Schwarzbeck's observations. The delay time of 8 s. which is typical for the LDE's would mean they had to go round the world another 58 times. For a time delay of 40 s., it would appear necessary to go round the world 289 times.

However, the radio echoes picked up must be accepted as experimental facts. If we assume the delay times observed to be identical to the "lifetime" of the transmission signal radiated, and the signal propagation speed to be 300,000 km./s., then we necessarily obtain long propagation paths, irrespective of the geometry of the propagation route (curved propagation path around the world, straight back and forth lines in space, etc.). The resultant difficulties of interpretation can be eliminated if we dispense with one or both of these assumptions.

In a gas, variations in pressure or density can take the form of wave or oscillation conditions (see, for example, sound waves in air). The ionosphere represents a special mixture of gases, for something like a thousandth of the gas particles are ionised, i.e. are present as positively charged ions and negatively charged electrons. The motion of the charged particle, incorporated in the neutral gas, is thus subjected to the effect of additional electrical and magnetic forces. In the partial gas formed from ions and electrons, special wave phenomena can arise ("plasma waves"). Taking ionospheric plasma waves into consideration appears to be an important step forward in the physical explanation of long delayed radio echoes. For example, there can be an interaction between the materially connected plasma waves and electro-magnetic waves, under suitable conditions.

A mechanism is proposed in (4), in the context of a qualitative model, in which part of the electro-magnetic energy is bound in a longitudinal plasma wave. In this context, "longitudinal" refers to propagation along a field line of the Earth's magnetic field. Here, energy-rich electrons, which move around this field line in a spiral, reinforce a plasma wave of this type. The propagation speed of the plasma waves is usually several orders of magnitude below the speed of light. There are thus relatively long propagation times even for comparatively short propagation paths of a few hundred kilometres.

The radio signal is thus, in a way, intermediately stored in a plasma wave until a process analogous to the initial condition creates a new electro-magnetic wave, which can then be observed by the receiver station.

Of course, the authors refer to the circumstance that long delayed radio echoes at high short-wave frequencies can not be satisfactorily explained by this model. This is especially true of amateur observations in the 10 m. band. To wit, with the mechanism described we must assume from the start that the reciprocal effects take place at the height at which the frequency of the radio wave exactly corresponds to the local plasma frequency. This frequency is generally considerably lower than 28 MHz. But the attractiveness of this model lies in the identification of a "natural" time-lag device. A group velocity of 1 km./s. for the plasma waves and a reciprocal effect region of app. 10 km. diameter (4) give delay times of 10 seconds.

The theory is skilfully advanced further in (8) and is used to explain the observations of OZ9CR at 1,296 MHz. Two radio transmitters, at frequencies f1 and f2, are scanning the same region in the ionosphere, unbeknown to one another. The two electro-magnetic waves cause a non-linear reciprocal effect and generate a plasma wave at the differential frequency δf, i.e. f2 - f1, which should simultaneously correspond to the local plasma frequency. If f1 = 1,296 MHz and f2 = 1,303 MHz, for example, the frequency obtained is 7 MHz. After a certain propagation time, the plasma wave again interacts with the electro-magnetic wave, f2, and generates an electro-magnetic wave with a frequency of f1 = f2 - δf, which appears to the puzzled observer to be an echo of his or her own transmission.

6. CONTRIBUTIONS FROM RADIO AMATEURS

With long delayed echoes, we are clearly dealing with an unpredictable and comparatively rare phenomenon. The results of scientific observations indicate that LDE's are not very often traced by deliberate observation. The opportunities for amateur radio enthusiasts to make observations are far less subject to geographical restrictions, or those dependent on local time. In particular, short wave amateurs form a world-wide network of observers always ready for action. The favourable "observation statistics" for amateur radio enthusiasts have conceivably been a decisive factor in the numerous LDE observations in which they have been involved.

The author also endorses the opinion expressed by Budden and Yates, that radiation directed towards the horizon yields better observation results than vertical radiation. True, according to (4) radiation along the local line of the Earth's magnetic field could be more advantageous. The horizontal radiation might possibly increase the probability of observation, since a larger segment of the ionosphere can be scanned by the aerial, by comparison with vertical sounding. The typical radiation characteristic of amateur aerials could thus turn out to be advantageous.

The previous reports confirm that long delayed radio echoes attract attention mainly in non-automated radio traffic, which is connected with the particular capability of human hearing to recognise the acoustic pattern. This state of affairs also corresponds, to a large extent, with the typical conditions for amateur radio traffic.

The experimental conditions for amateur radio enthusiasts thus seem particularly suitable for LDE observations. Radio operators professionally active in the short-wave range also come into consideration as competent observers to the same extent (e.g. marine radio, here especially wireless telegraphy operators). However, there are no corresponding observation reports. It must thus be assumed that some observations are interpreted as attempts at deception and thus do not receive general attention. Conceivably, numerous amateur observations are also not taken into account for the same reason.

It has already been mentioned that the reliable identification of a "natural" LDE presents a difficult task, even if the observer takes great care. Apart from unwanted technical effects, in particular, attempts at deception can in no case be ruled out, and it is to be feared that less serious radio amateurs contribute to deliberate falsification, in view of the fact that the LDE phenomenon is better known in such circles. The continuous self-sabotage should be recalled here which amateur radio circles inflict on themselves in research into VHF radio wave propagation (e.g. by interference in the 2-m. beacon band). Moreover, it can not be ruled out that the exposure of genuine attempts at deception also puts the credibility of subsequent amateur observations in doubt. In that event, scientific institutions could be forced to leave amateur reports out of consideration in future, on grounds of principle. An apparently harmless joke involving a fake LDE can thus do serious damage to the image of amateur radio.

Above all, observers should describe the measures which they have taken in attempting to exclude cheating. Short transmissions using changing frequencies are a relatively simple procedure for excluding potential trouble-makers. Unfortunately, this procedure can be used in practise only when you are re-receiving your own transmissions. If long delayed echoes are received from other transmitters, enquiries should be made as to whether other transmitters on other frequencies are also displaying LDE phenomena. Reports submitted on deliberate or accidental LDE observations should contain the following additional data:

- → Date, start time and end time of observation
- → Location of observation station
- → Observation frequency
- → Echo characteristics (re-receiving of own transmission or observation of another transmitter, duration of echo, time delay, field strength)
- → Transmission power and radiation characteristic, direction of aerial.

Please send appropriate observation reports to the author (address: 68, Hausfeld, 5600 Wuppertal 23). Plottable data will be passed on to the Max Planck Institute for Aeronomy, Lindau/Harz.

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7. LITERATURE

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