UiO : Department of Physics
University of Oslo

Long delayed radio echoes – the illusive secret of the ionosphere

Sverre Holm

LA3ZA

HamSCI Workshop 2021

Ham SCI

March 19-20, 2021 (Virtual)

What has happened to these signals? Where have they been?

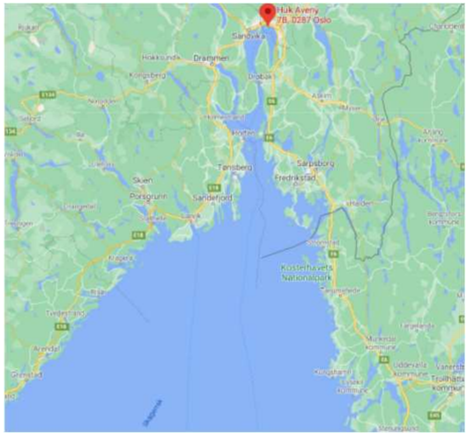
- Larry Horlick, VO1FOG, Newfoundland:
- ~290 ms, 3.5 MHz SSB, 25.01.2019, 22:50 local

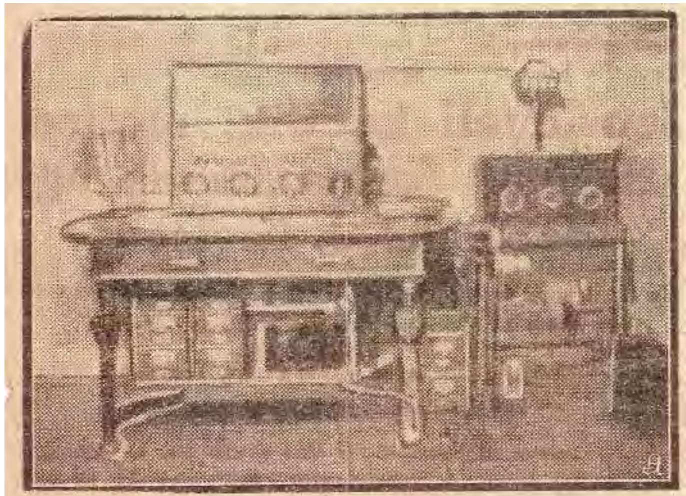
- Poul-Erik Karlshøj, OZ4UN, 2009, Copenhagen:
- 260 ms, 3.5 MHz CW, 10.1.2009 ~20:00 local

Ja det er godt nok mærkeligt … nu er det der igen
Yes it's weird enough … now it's there again

First observation, Oslo, Norway, 1927, Jørgen Hals


Ingeniør Hals.




Jørgen Hals' apparater, som ekkoet blev hørt med.

Aftenposten 20. and 27 Nov 1928

Huk aveny 7b, Bygdøy, Oslo, Norway,
Oslo kommune, byarkivet, fotodatabasen

- http://www.byarkivet.oslo.kommune.no/
- A-20027/Uh/0001/294, from 1950

UiO

Jörgen Hals

TELEGRAMADRESSE „ELEKTROINDUSTRI"
TELEFONER: 3581-18858

~~CHRISTIANIA~~

Oslo, the 29. February 1928,
Sjöfartsbygningen værelse 630.

I had expected a letter in Norwegian …

Jørgen Hals

Professor Carl Störmer Esq.,
Bygdöy.

I herewith have the honour to advise you that in the end of the summer 1927 I repeatedly heard signals from the Dutch short-wale-transmitter P.C.J.J., Eindhoven. At the same time as I heard the telegraph-signals I also heard echo. I heard the usual echo, which goes round the earth with an interval of ca. 1/7 second as well as the weaker echo ca. 3 seconds after the head-signal had gone. When the head-signal was especially strong, I supposed that the amplitude for the last echo 3 seconds after lay between 1/10 and 1/20 of the head-signal in strength. From where this echo comes I cannot say for the present, but I will only herewith confirm, that I really heard this ~~signal~~ echo

Yours truly

Jörgen Hals

C. Størmer, "Short wave echoes and the aurora borealis," Nature, No. 3079, Vol. 122, p. 681, Nov. 3, 1928.

Simultaneous observations, 3-30 sec

- Echoes from PCJJ, Hilversum, 9.54 MHz, 24 Oct 1928,16-17 UTC
- Heard in Oslo, NO and Eindhoven, NL
- Convinced most sceptics that the effect was real
- Measurement campaign: Inconclusive on why

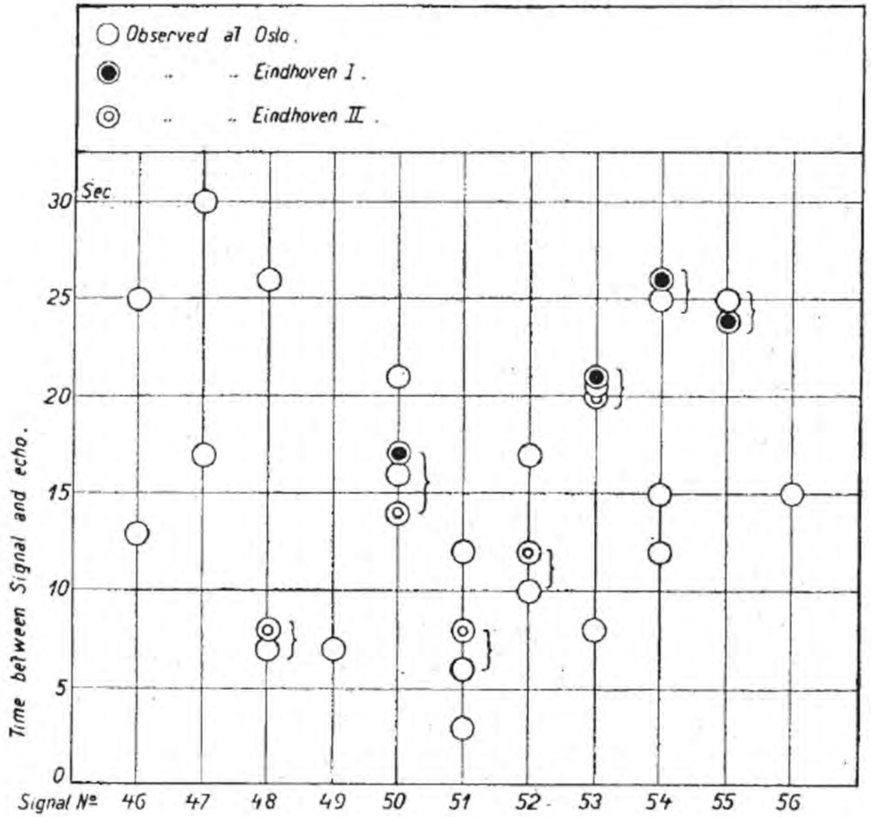


FIG. 1.

- B. v. d. Pol, "Short wave echoes and the aurora borealis," Nature, No. 3084, Vol. 122, pp. 878-879, Dec. 8, 1928.

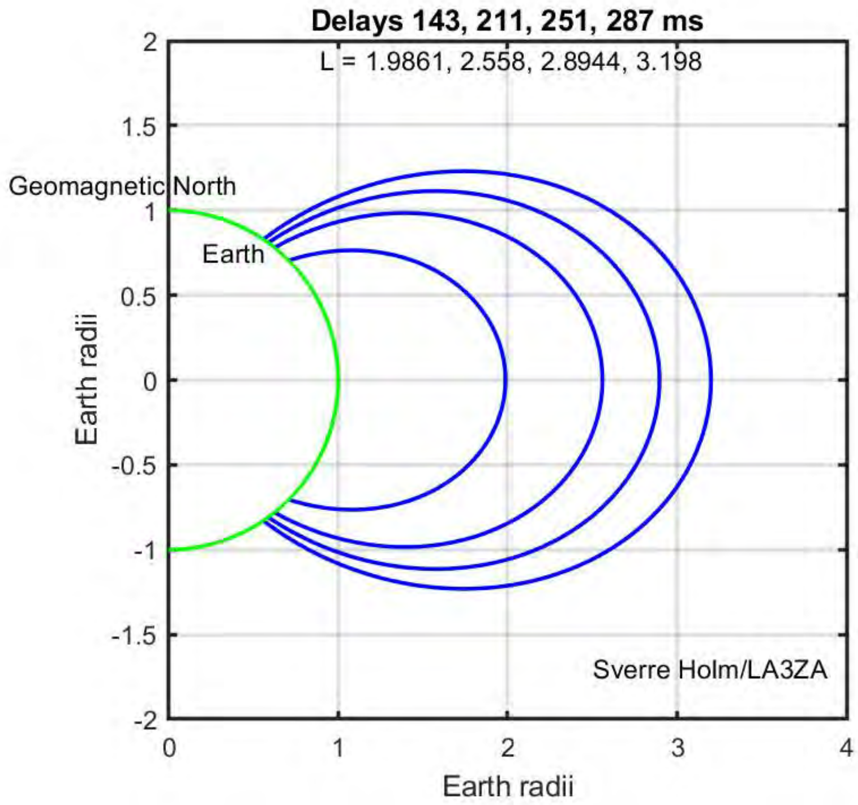
5 mechanisms – only 1 is understood

1. Around the world
2. Distant plasma clouds
3. Mechanical waves in ionosphere
4. Non-linearity and mechanical waves
5. Ducting in the magnetosphere

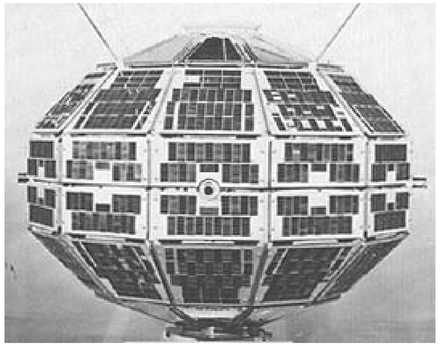
- Wikipedia: Long delayed echo
- The Five Most Likely Explanations for Long Delayed Echoes
  Vidmar and Crawford, "Long-delayed radio echoes: Mechanisms and observations," Journ. Geophys. Res.,1985.
- 15 Possible Explanations for Long Delayed Echoes
  Shlionskiy, "Radio echos with multisecond delays," Telecomm.and Radio Eng., 1989

5. Ducting in the magnetosphere

- ~143 ms: GA, 2006, 3.5 MHz
  - Or round-the-world echo?
- 210-223 (~211) + 438 ms: G3PLX: 2, 2.4, 2.7, 3.5, 3.9 MHz, 59 instances
- 260-270 (~251) ms: Tasmania, 1985/86, 1.91 MHz
- 284-305 (~287) + 590 ms: St Petersburg, RU, 1984/85, 1.8 MHz



UiO : **Department of Physics**
University of Oslo



Alouette 1962 , Explorer XX 1964
(Images: Wikipedia, *NASA Goddard)*

PROCEEDINGS OF THE IEEE, VOL. 57, NO. 6, JUNE 1969 1097

Nonvertical Propagation and Delayed-Echo Generation Observed by the Topside Sounders

D. B. MULDREW

Abstract—Knowledge of the topside ionosphere resulting from studies of nonvertical propagation, such as scatter from ionization irregularities and minitroughs, hemispherically conjugate echoes, combination modes, multiple-hop propagation, unusual Z-wave propagation, and whistler-mode propagation, is reviewed. From these studies there appear to be two major types of magnetic field-aligned ionization irregularities: a thick type and a thin type. The thick type has a thickness of tens or hundreds of kilometers and occurs both near the auroral zone and at latitudes corresponding to the equatorial anomaly. The thin type has a thickness of a few hundred meters and may extend thousands of kilometers along a field line. At high latitudes the thin type has a tubular cross section, may have an electron density either greater or less than the ambient, and may result from fluxes of energetic particles; at low latitudes the thin type has an electron density deviation of the order of 1 percent or less. The thin type of ionization irregularity supports propagation which is responsible, at some distance from the satellite, for two different delayed-echo phenomena. In the vicinity of the satellite electrostatic waves with near-zero group velocity are probably responsible for the f_H, f_T, and nf_H resonance spikes and also for the newly discovered f_{Q} resonance spikes which occur at nonzero and noninfinite values of the wavenumber. A novel spike, called the "floating spike," is believed to result from propagating electrostatic waves.

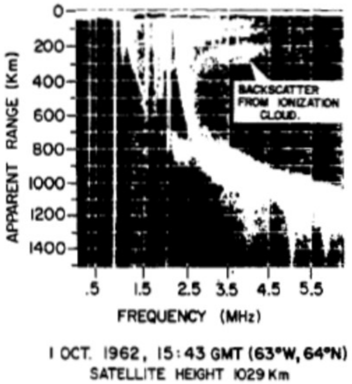


Fig. 1. After Petrie [4]. Alouette I ionogram with a spread trace between 200 and 300 km apparent range and 2.5 and 4.5 MHz resulting from backscatter from a high-latitude field-aligned irregularity.

II. Scatter Propagation

The Magnetospheric Echo Box — A Type of Long-Delayed Echo Explained

Radio amateurs have helped unlock the mystery of LDE signals that have puzzled scientists for over five decades. Continued observations, however, are still needed.

By O. G. Villard, Jr.,* W6QYT, D. B. Muldrew,** and F. W. Waxham, Jr.,*** K7DS

QST, Oct. 1980

Long Delayed Echoes

A Study of Magnetospheric Duct Echoes 1997-2007

INTRODUCTION. On 25th October 1997, at about 19:30 UTC, I was working on 3.5MHz using Hellschreiber, an on-off-keyed facsimile mode in which typed letters are transmitted as patterns of dots which are displayed directly on the screen of a computer. I was experimenting with a 'quick-break' version in which I could listen on the frequency between letters, a technique used by Morse code operators. During this contact, for a period of about 10 minutes, I was aware that I could hear an echo of my own transmission, and therefore see on my screen a double image of the right-hand edges of each of my the resolution of the wide bandwidth. A 100ms pulse swept over 2kHz could be easily transmitted and received by a conventional 100W SSB transceiver. I have previously described, in a *RadCom* article **[2]** how I used this technique to study the signals from swept-frequency ionospheric sounders (Chirpsounders). By switching back to receive quickly and processing the next 500ms of received signal through a special chirp-filter, it would be possible to capture any echoes within the delay range 100ms-500ms, with a resolution of 1ms, and save the results to disc for later analysis.

Peter Martinez, G3PLX, Radcom, Oct. 2007

- The most detailed report there is
- Just made available on [RSGB Propagation: Long-Delayed Echoes]

THE ULTIMATE DX: AN AROUND THE EARTH PATH

◊ During the morning of February 17, 2006, at approximately 0345 UTC, while calling CQ on 3.524 MHz, I heard an interesting echo effect. The echo on my CW signal was strong and delayed so long that I stopped sending to determine if some other station was on my frequency. There was no other station on frequency and the echo appeared to be from my own transmission. Several tests were performed to ensure that there was no digital signal processing (DSP) mode circulating the signal in the transceiver's DSP processor. The effect lasted approximately 30 minutes, which allowed enough time to record the signal using a sound card recording system. Analysis indicates that the signal was most likely

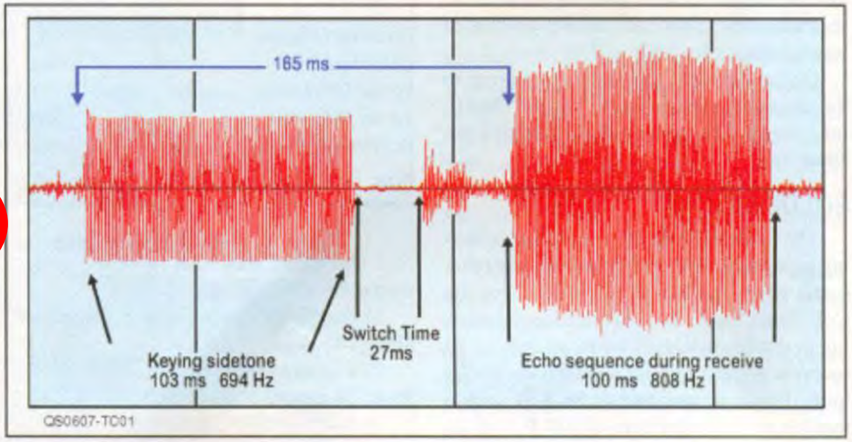


Figure 1 — Keying sidetone followed by change-over switch time and then delayed echo.

QST June 2007, Gene Greneker, K4MOG

characterize the delay properties of my Ten-Tec Orion receiver.[8] The delay time of a signal from the antenna to audio output for CW or SSB and normal filter characteristics was about 14 ms. In his work, K4MOG used a Yaesu FT1000MP-MkV transceiver, which also has DSP filtering. His observation of excess delay compared to an earth circumference may be the result of receiver delay time. — *73, Martin Ewing, AA6E, 28 Wood Rd, Branford, CT 06405*; **aa6e@arrl.net**

MAGNETOSPHERIC DUCTING AS AN EXPLANATION FOR DELAYED 3.5 MHz SIGNALS

◊ Gene Greneker, K4MOG, gave an interesting and well-documented account entitled "The Ultimate DX: An Around the Earth Path" in the Technical Correspondence column, in the June 2007 issue of *QST*. Over a 30 minute period he heard his own signal coming back on 3.524 MHz at a delay of 165 to 168 ms. He explained it as a signal traveling around the earth, possibly along some ionospheric duct, in order to account for the additional delay compared to the usual 138 ms. This is plausible not the least

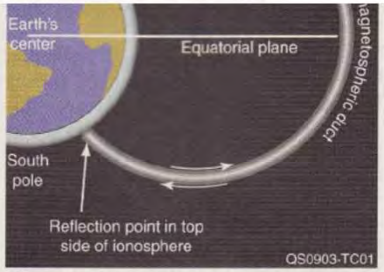


Figure 1 — This sketch shows a magnetospheric duct (with a delay of 0.27 seconds). (Copied from the Oct 1980 *QST* article referenced in Note 10.)

Due to its southern location, the expected delay at K4MOG's location in Georgia is only about 0.15 seconds (see Figure 4 of the Oct 1980 *QST* article by O. G. Villard, W6QYT and others[10]). The delay, however, depends on geomagnetic latitude — the latitude relative to the magnetic North pole. This position shifts with time, and in 2006 his location was at 44.8° North relative to the geomagnetic North pole (**http://modelweb.gsfc.nasa.gov/models/cgm/cgm.html**). This gives a delay of 143 ms, 9 ms less than in 1980 when

midnight local time. K4MOG received his echoes at 0345 UTC, or 2245 local time.

■ The antenna should radiate well in the direction of the magnetic field, as for instance a horizontal dipole oriented East-West would do. K4MOG used a 7 MHz double Zepp oriented North-South at a height of 70 feet (21 meters). Since it was used at half the design frequency, his antenna is probably nearly omnidirectional, as evidenced by his experience with DX both to Europe and to Antarctica. Its height of about ¼ λ should also ensure substantial radiation upwards.

Also, the likelihood for ducting increases near a solar minimum, as indeed 2006 was.[13]

Finally, the value for the critical frequency, fof2, at two nearby sites, Eglin Air Force Base in Florida and Dyess Air Force Base in Texas, show values as low as 3.1 and 2.8 MHz respectively at the time (**http://umlcar.uml.edu/DIDBase/**), indicating that a vertical signal at 3.5 MHz could have passed through the ionosphere and thus entered a magnetospheric duct. — *73, Sverre Holm, LA3ZA, Dæliveien 1, NO-1383 Asker, Norway*, **la3za@nrrl.no**

QST March 2009, LA3ZA

QST, Nov 2009, OZ4UN, Poul-Erik Karlshøj

Observation of Long Delayed Echoes on 80 Meters

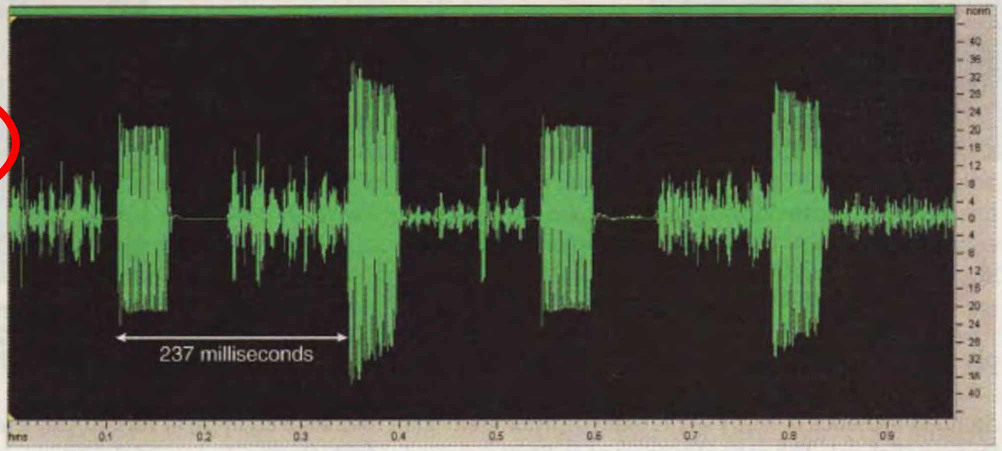
The dit heard 'round the world — twice.

Poul-Erik Karlshøj, OZ4UN

I had an extraordinary experience on the evening of January 10, 2009 on 80 meters. While in a contact with EA2IF on 3512 kHz at 1845 UTC I noticed what I at first thought was another station transmitting on my frequency. But I soon realized that it was the echoes of my own signal.

My Setup

I was using an Elecraft K2 transceiver with 100 W output to an 80 meter circumference loop antenna. The loop is supported by trees in an east-west vertical plane with an irregular somewhat triangular shape. It is fed in the midpoint of the lower wire, that is, the loop is horizontally polarized. The antenna apex



QS0911-Karlshoj01

Figure 1 — This oscillograph shows two dits each followed by an echo delayed 237 ms.

Field-aligned duct or trough

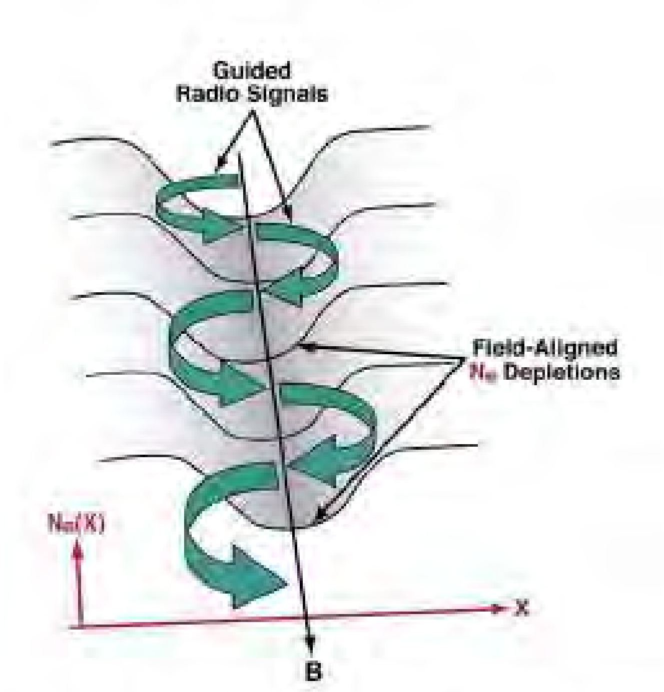


Figure 2. A schematic of ducting of a high-frequency ($f \gg f_{uh}$) electromagnetic wave (green arrows) by field-aligned electron density depletions.

Fung, Green, Modeling of field-aligned guided echoes in the plasmasphere, Journ. Geophys. Research. D. Atmospheres, 2005

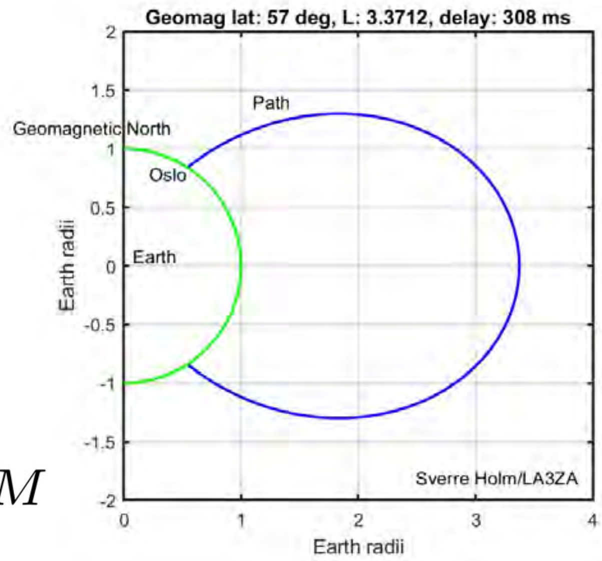
- Related to hemispheric asymmetry of the winds in the ionospheric dynamo region
- Electron density diminished by about 1%
- Diameter 1-2 km, from F-layer of one hemisphere to the other
  - A waveguide if < 10 λ
  - Works up to ~5 MHz
- 40+ dB stronger than free space propagation
  - Platt & Dyson, J Atmos. & Terr. Phys., 1989

Approximate estimate of delay

- Geomagnetic latitude, θ_{GM}, from position, year:
  - http://wdc.kugi.kyoto-u.ac.jp/igrf/gggm/
  - https://omniweb.gsfc.nasa.gov/vitmo/cgm.html
- How far away the field line extends in earth radii: $L = \cos^{-2}\theta_{GM}$
- Path of magnetic field line:

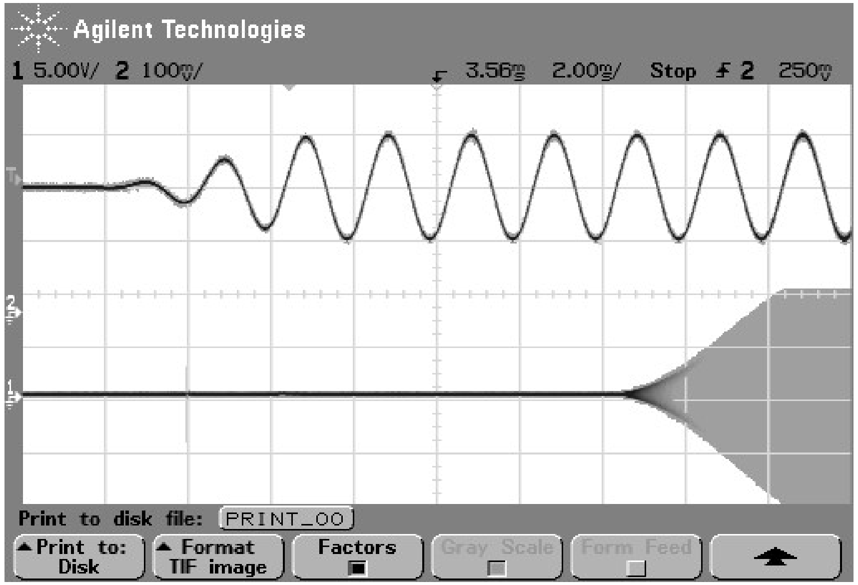
$$r = L\cos^2\theta, \quad \theta = 0 \ldots \pm\,\theta_{GM}$$

- Integrate path to find delay
- Accurate to +/- 5-10 ms

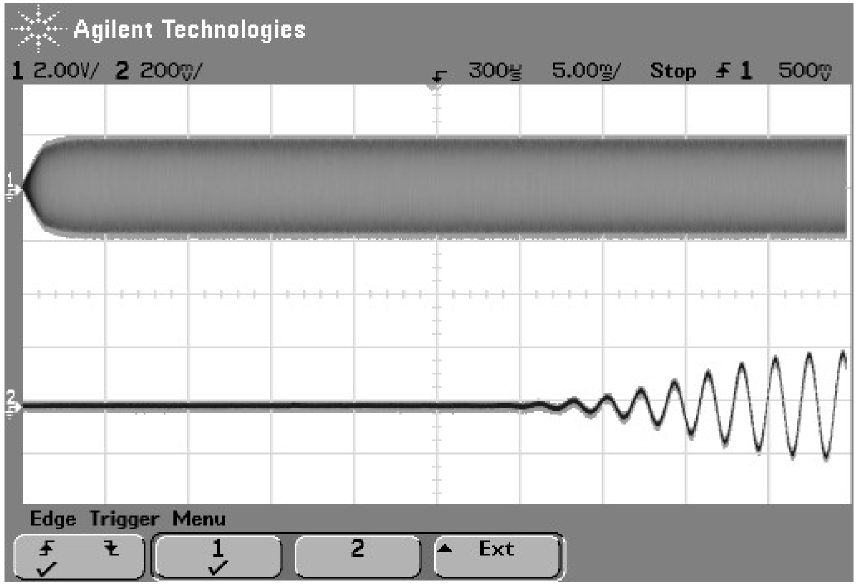


Measurement of AF delay will overestimate RF delay

K3 TX: Sidetone – RF: 15 ms



K3 RX: RF – tone: up to 35 ms



Elecraft K3: by 15+35 = 50 ms (50 Hz bw)
Elecraft K2: by 4+8 = 12 ms (no DSP)

Observations, sorted by delay

W6FB, K6YT, KM6I, N6ZFO, North CA	~126 ms	3.5 MHz	7.11.2015	2300
K4MOG, GA	~143 ms	3.5 MHz	17.02.2006	2245
G3ZRJ, also heard by GW3OQK 100km	~200 ms	3.5 MHz	01.01.2012 08.12.2013	2118-2152
G3PLX	210-220 ms	2 & 3.9 MHz	26.11.2006	21
W2PA, NY	214-219 ms	3.5 MHz	16.02.2008	2222
OZ4UN	~237 ms	3.5 MHz	10.1.2009	1945-2045
Tasmania	260-270 ms	1.8 MHz	1985-1988	
VO1FOG, Newfoundland	~290 ms	3.5 MHz SSB	25.01.2019	2250
St.Petersburg	284-305 ms	1.8 MHz	16.11.1985	2055

All times are local, ~ means predicted delay

Conditions for it to happen

- 1-4 MHz
- Winter. Northern hemisphere: best Dec/Jan, also: Feb/Nov
- 19-24 local time
- More likely during years of low solar activity
- Antenna: radiates up or in direction of magnetic field
- Not too far from duct's entry point
- Signal has to exit the ionosphere, i.e., low F2 critical frequency
- Must reflect at ionosphere on opposite hemisphere, high f_0F_2

Villard et al QST 1980, Ellis, Goldstone, J Geophys Res 1990, http://www.ips.gov.au/HF_Systems/6/5

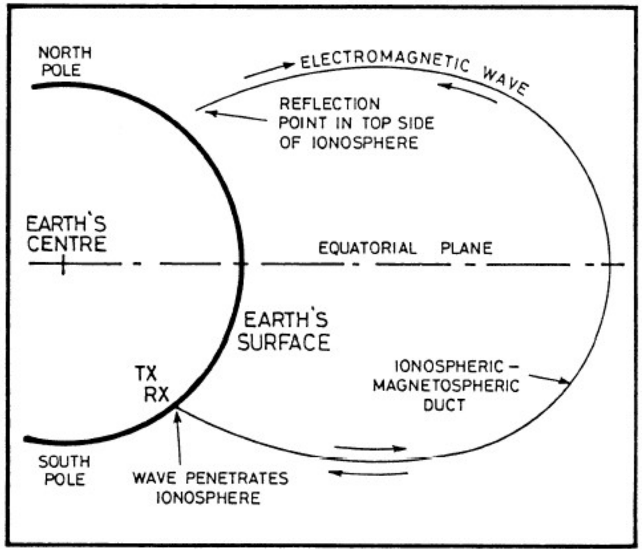
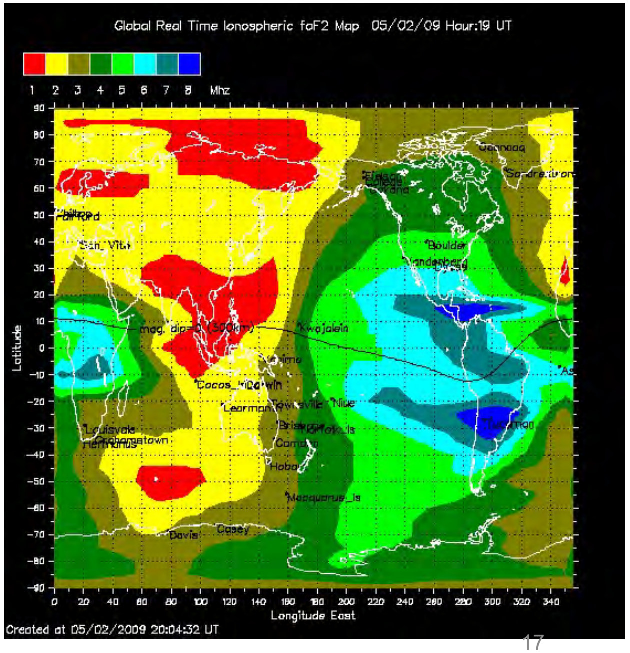


Figure 3 – Geometry of the propagation path.

Low f_0F_2

High f_0F_2



Long Delayed Echoes

- From 1927 until today: up to 30 sec
- From 1.8 to 1296 MHz
- Tests in Norway, Netherlands, France, USA, UK, Soviet Union, …
- Most observations from radio amateurs
- Understood: Magnetospheric duct, 1-4 MHz, < 0.5 sec
  - *G3PLX, 2007: I am tempted to suggest that magnetospheric ducts may never be more than a rare scientific curiosity*.
- *Jørgen Hals, 1928: ”From where this echo comes I cannot say for the present, but I will only herewith confirm, that I really heard this echo”*

Read more

- The Five Most Likely Explanations for Long Delayed Echoes:
  - https://www.mn.uio.no/fysikk/english/people/aca/sverre/articles/lde.html
- 15 Possible Explanations for Long Delayed Echoes
  - https://www.mn.uio.no/fysikk/english/people/aca/sverre/articles/shlionsky15.html
- Wikipedia: Long Delayed Echo, refers to my two pages above
  - https://en.wikipedia.org/wiki/Long_delayed_echo

Thanks:

- National Library, Oslo:
  - Anne Melgård, Nina Korbu
- University Library, Univ Oslo:
  - Knut Hegna
- Radio amateurs who have contacted me over the years with examples of echoes