Measurements of Doppler Shifts During Recent Auroral Backscatter Events.

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Many amateurs have noticed that signals reflected from an aurora are doppler-shifted and that this doppler shift can change with beam heading or time or both. In this article I describe a set of measurements made during relatively weak auroras this year and show some of the interesting effects and their relationship with the ionospheric current system.

The vision carrier of the Greipstad TV transmitter in Norway provides one of the most sensitive means of detecting radio aurora at my location (Surrey, IO91TG). The transmitter is located at JO38 and runs 60kW ERR The carrier frequency shown here as about 800Hz corresponds to a frequency of 48.2524MHz. Not only is Greipstad a strong auroral indicator but it also has a frequency that is not shared with other Band I stations. The next strongest signal via the aurora is that from the transmitter at Orebro in JO79, on 48.23935MHz.

In the analysis that follows I have made use of the Spectrum Lab software from DL4YHF, an excellent program including a very flexible FFT spectrum analyser (Ref. 1). The pictures show a waterfall display in which frequency is along the y-axis and time is along the x-axis. I have found the incidence of auroras that can be detected this way rather higher than expected from this location. This has allowed trends in the behaviour of the signal to be identified and these are discussed below.

The table below lists the dates and times of auroral reception, together with the Lerwick k index (Ref. 2).

Table 1 - Auroral events

Date	*UTC*	*Lerwick k index*
20/03/03	2007	4
28/03/03	2203-2305	6
29/03/03	2328	7
30/03/03	1634-2046	5-6-5
31/03/03	1836-2123	6-5
05/04/03	1800-2000	5
17/04/03	1900- 1910	4
22/04/03	1939-2027	3
23/04/03	2000 - <2040	4
24/04/03	1732-2142	4
27/04/03	1942- 1947	3
29/04/03	1942-2054	5
30/04/03	1749-2151	5
01/05/03	1731-2041	4
06/05/03	1644-2055	4
07/05/03	1912-2120	4
08/05/03	1717-2050	5

Geometry of the path

The map in figure 1 on page 35shows the locations of the stations and the closest location (Ref. 9) for the aurora. The map was produced through an online map creation program (Ref. 3).

The sequence of a typical event

The spectrum obtained on 20th March and reproduced in figure 2 shows at left the direct signal (a mixture of troposcatter

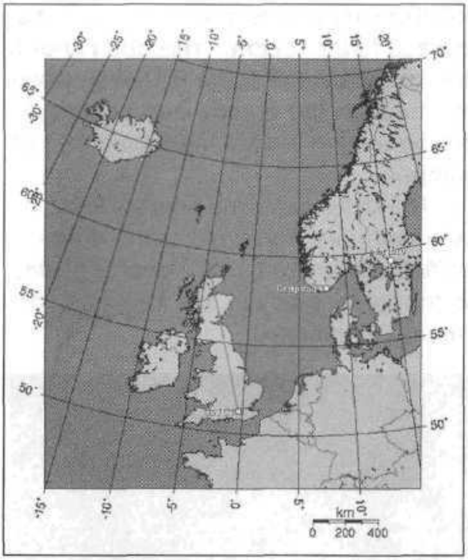

Fig. 1: Illustrative path geometry.

side of the spectrum shows the effect of changing the beam heading to 345° - the aurora appears but centred some 50Hz low of the carrier and about 70Hz wide at -3dB. However there is a return over just about the whole spectrum width from 500 to 1000Hz! The doppler frequency is given by the equation:

$f_d=2vf_0/c$

where f_d is the doppler shift, f_0 is 48.2524 MHz, c is the velocity of light (3.0 E8 m/s), and v is the "phase velocity". The doppler frequency is not **a** measure of the radial velocity as it is for a monostatic radar (transmitter and receiver co-located). For a bistatic geometry, the doppler shift is better described as a rate of change of phase along the total path length from Greipstad via the aurora to IO91.

Applying this equation, we find that the 50Hz peak corresponds with a phase velocity of 155m/s whilst the extreme of the spectrum at 1000Hz corresponds with about 3000m/s.

This negative doppler return will typically continue for quite some time, perhaps with some variation in centre frequency or doppler spread and occa-

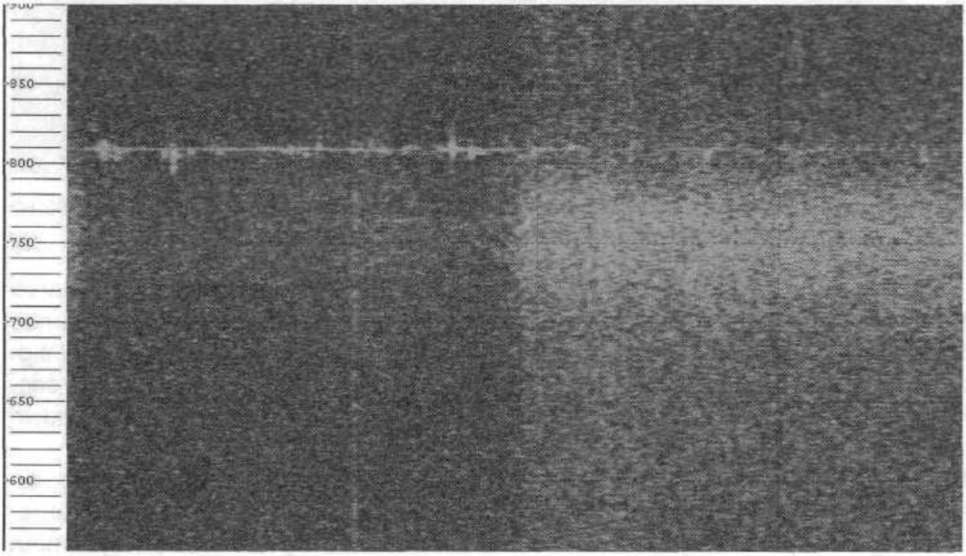

Fig. 2: Spectrum obtained on 20th March, showing at left the direct signal and at the right the auroral signal.

sional fades. Later, it may be joined or replaced by other components. For example, the spectrum shown in figure 3, taken at 2242z on 28th March, shows two quite distinct returns with peaks at about +100 Hz and -50 Hz relative to the carrier. It also shows a distinct skewness of the frequency distribution; i.e. an asymmetric spectral shape, having a sharp cut off at low speeds and a longer tail at higher speeds.

locations may be responsible; this is discussed further below. This chart shows the importance of using RIT when working through the aurora, and continually tuning around in case the frequency has jumped.

The shifts measured here are for a one way path, and if you net to the doppler-shifted station and your signal is shifted in the same direction, the frequency difference is doubled.

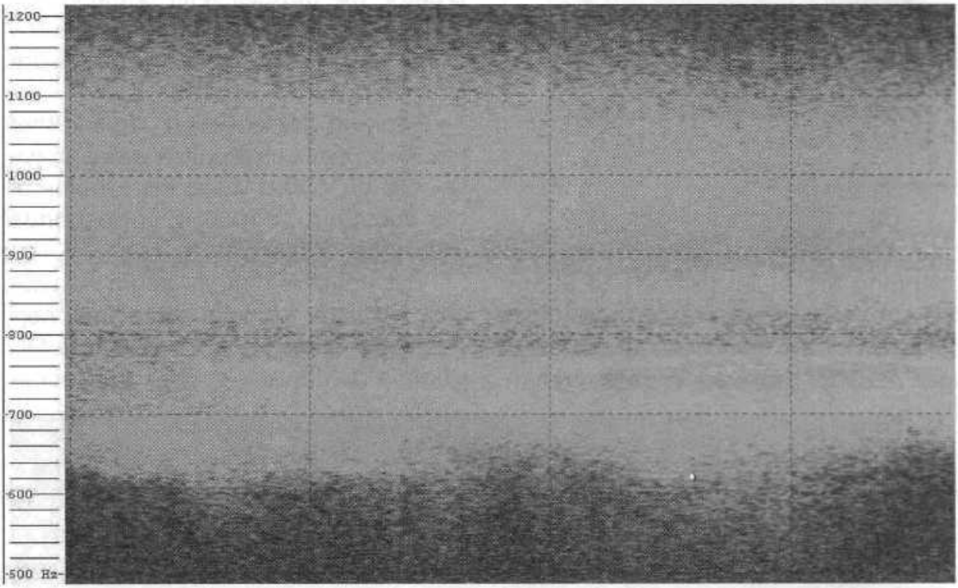

Fig. 3: Spectrum obtained on 28th March showing two distinct returns at +100 Hz and -50 Hz relative to the carrier. ***(See the back cover for a colour copy of Oils picture.)***

In the trace in figure 4, from 30th March, the negative component about 50Hz low of the carrier fades out and the positive one at about +100Hz fades in for about two minutes, then the signal reverts to the negative component again. This is especially interesting because it appears that the motion changes from receding to approaching or vice versa. Of course it may be coincidental and differing relative velocities at different

Another interesting feature captured during some of the openings has been sudden fades or 'stutters' when the signal drops maybe 10 dB for a few seconds only. An example of this is shown in figure 5.

Throughout this series of measurements the beam heading for auroral returns from Greipstad was always about 345°, within about ±10°. If we consider all the possible locations for the aurora

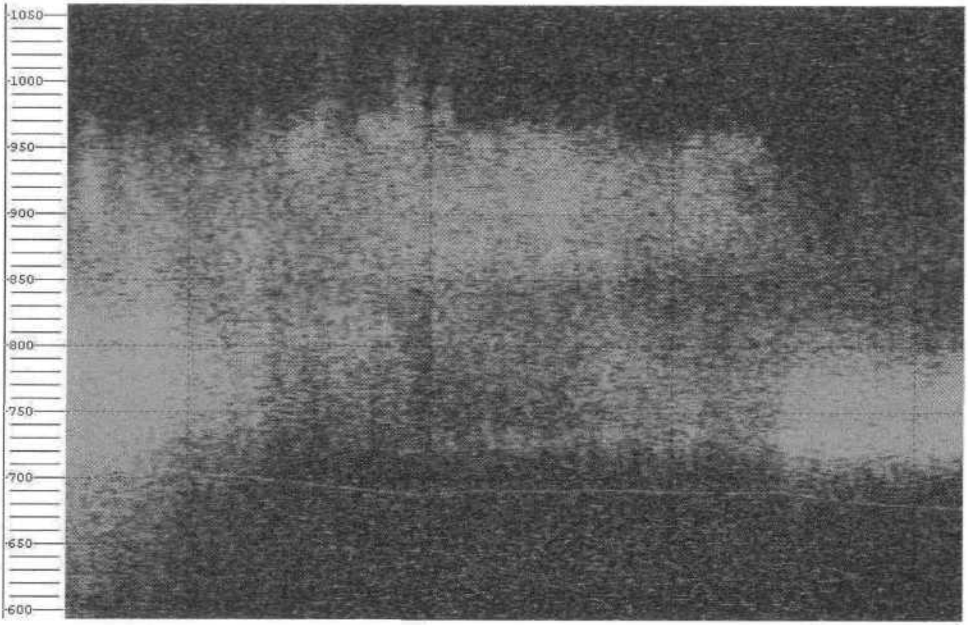

Fig. 4: Spectrum obtained on 30* March showing a switch between negative and positive returns and back. ***(See the back cover for a colour copy of this picture.)***

for this path, it can be shown (Ref. 9) that the backscatter location closest to IO91 corresponds exactly with a heading of 345°. It would be interesting to see results from other observers.

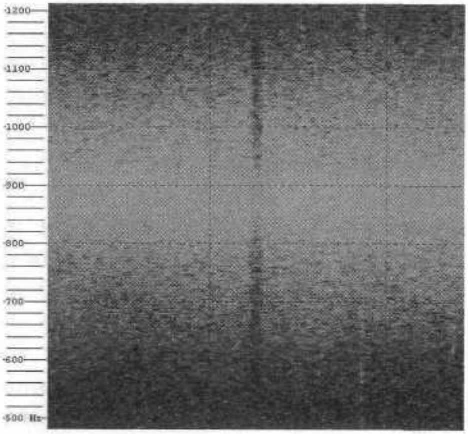

Fig. 5: Spectrum showing a sudden fade or 'stutter' lasting for a few seconds.

Figure 6 on page 38 shows the times at which positive and negative dopplers were detected on each day. It shows that the aurora always starts with a negative doppler shift but that a positive doppler shift may occur later.

Discussion

In the troposphere, the refractive index of the air varies with random changes in pressure, temperature and humidity, resulting in the scattering of radio waves. This effect varies with the wavelength and the scale of the fluctuation in the refractive index. A similar effect can occur in the ionosphere due to random changes in ionisation density in the E-layer. The refractive index depends on the electron density and if this is not uniform, scattering can take place. In an aurora, such irregularities in electron density give rise

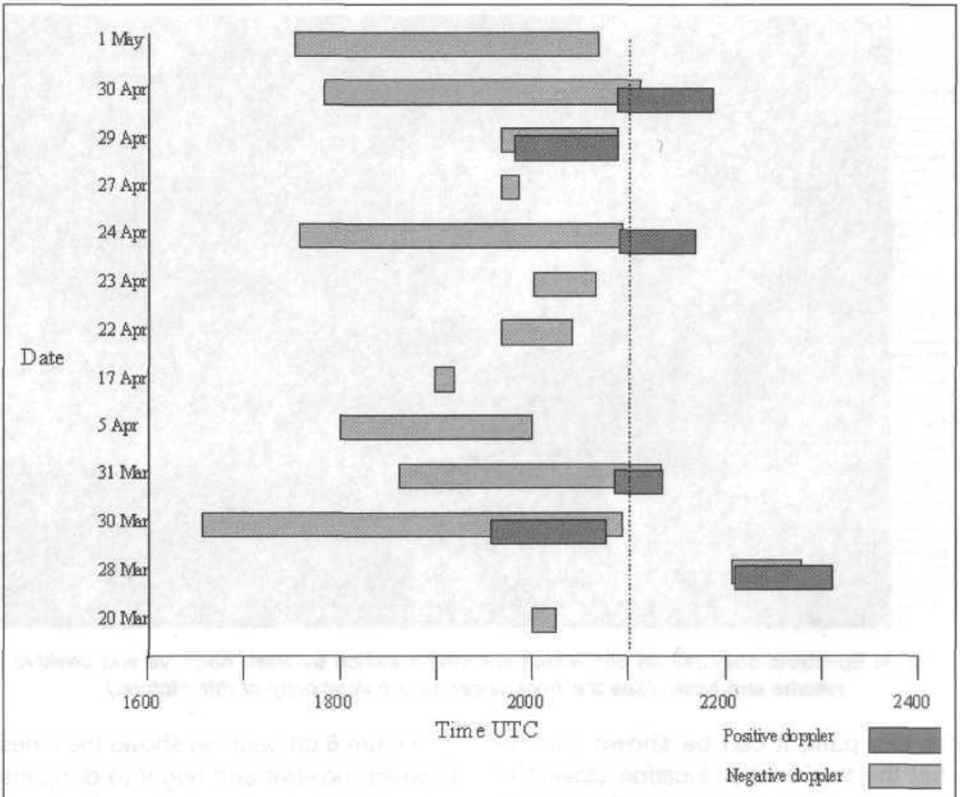

Fig. 6. Illustrating the times of reception of positive and negative doppler around the local magnetic midnight ~2100 UTC

Fig. 6: Times at which positive and negative dopplers were detected on each day.

to the familiar backscatter signals.

The precipitating particles (electrons) that give rise to auroral reflections generally follow the geomagnetic field lines, which at high latitudes will be inclined towards the magnetic pole. The ionisation level required for radio aurora only occurs in the E- layer region, at about 100km altitude. We might at first think that the doppler seen here is due to the motion of the particles down the magnetic field lines. But previous research work at Millstone Hill radar in Massachusetts (Ref. 4) has established that the reflection must be very nearly specular; i.e. the angle of incidence to the magnetic field line is equal to the angle of reflection, within about 10 degrees maximum.

Volker Grassmann, DF5AI has published a paper "Doppler Effect in Auroral Backscatter" (Ref. 5) on this topic in which he analyses the geometry to show that a movement of the reflecting medium along the field line produces no doppler shift, because there is no change of phase along the total path length.

Ref. 5 goes on to develop the concept of doppler shifts arising from the east to west flow of particles. It shows that depending upon the position of the reflecting point relative to the transmitter and receiver, either positive or negative dopplers may arise due to the gross movement in the reflecting point. Where more than one reflecting point exists, both positive and negative Doppler can co-exist.

In 1998, Leif Asbrink, SM5BSZ conducted experiments using a pulsed transmission to locate auroral returns and to measure their doppler shift (Ref. 6). Leif suggests that echoes from the north-east are shifted up in frequency while echoes from the north-west are shifted downwards. He says: "It seems like the aurora is fixed in space (relative to the sun's direction) while the earth is rotating." Other amateurs have also noted that the apparent frequency of an auroral signal can change as they rotate their beam; DF5AI's paper provides a good explanation in such cases.

Whilst this model provides an explanation of doppler shift and the way in which it may change with time or beam heading, it does not provide an adequate explanation for the effects seen here. In particular the beam heading in my measurements remains constant.

One of the major features of the high-latitude ionospheric current system is the Auroral Electrojet. The electrojet is an intense westward flowing current stretching from the early morning sector to just beyond midnight within the auroral belt. The total current in the auroral electrojet is about 10^6A and is driven by the electrical coupling between the high-latitude ionosphere and the magnetosphere. There's a second weaker, eastward flowing auroral electrojet extending from the evening sector to just before midnight. The boundary between the two is called the Harang discontinuity. This is illustrated in figure 7, adapted from Ref. 7.

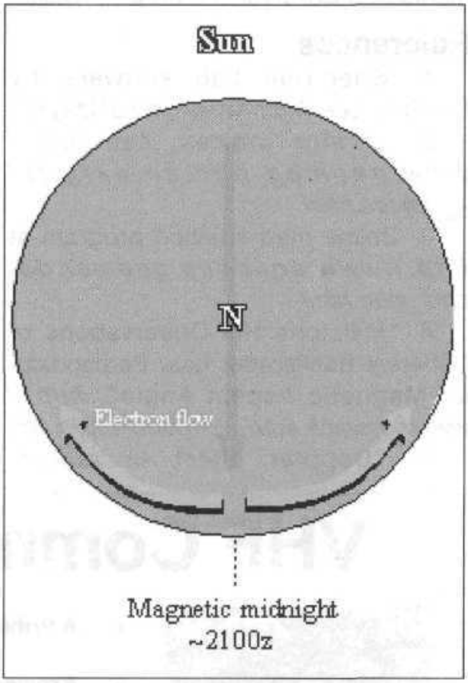

Fig. 7: The Harang discontinuity.

The consequence of this is that the electric field polarity reverses at around local magnetic midnight; the change in the electric vector will result in a change in direction of the electron flow either side of local magnetic midnight (around 2100z at this location). Given the north westward sightline, the change from westward to eastward electron flow will result in a change from negative doppler to positive doppler at about 2100z. The times in figure 6 appear to support this. The simultaneous reception of negative and positive dopplers and the transition from westward to eastward flows around magnetic midnight are both consistent with previous observations (Ref. 8).

Acknowledgements

I would like to thank Volker Grassmann DF5AI for his useful comments and observations on the results.

References

1. Spectrum Lab software by DL4YHF, see *http://www.qsl.net/dl4yhf/*

2. Lerwick indices, see *http:// www.geomag.bgs.ac. uk/gifs/ k_indices.html*

3. Online map creation program at *http://www. aquarius. geomar. de/ oms_intro.html*

4. "Millstone Hill Observations of Coherent Backscatter near Perpendicular Magnetic Aspect Angle", *http:// www.haystack.edu/~jcf/papers/MPI.htm*

5. "Doppler effect in auroral backscatter", Volker Grassmann, Feb 25th 2003, see *http://www.df5ai.net/*

6. "Aurora Echoes With Narrow Band Radar", Leif Asbrink, Feb 15th 1998, *http://antennspecialisten.se/-~sm5bsz/ aurora.htm.*

7. "Radio Auroras", by Charlie Newton G2FKZ, Fig 3.10 (publisher RSGB)

8. "A comparison of velocity measurements from the CUTLASS Finland radar and the EISCAT UHF system", J. A. Davies, M. Lester, S. E. Milan, T. K. Yeoman, Ann. Geophysicae 17, 892 - 902 (1999). See *http://www.copernicus systems, net/EG U/annales/17/ag 17/ 892.pdf*

9. Unpublished communication on the BeamFinder model, Volker Grassmann, 31st May 2003.

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