Natural Radio

September 2005

We've had a severe drought in Northern Illinois this summer with almost no rain for two months. Last week, there was finally some relief with several storms, each producing an inch or so of rainfall. It was nice to finally spend more time picking and eating vegetables than watering them,

With this new weather pattern, I was driving off into the West to meet my wife for dinner one evening and watched a typical anvil shaped thunderhead form from what had been clear sky and a clear National Weather Service radar display a few minutes before. Fortunately for us, the storm passed to the north and our weather remained clear and our outdoor dining didn't get dampened. But unfortunately for the folks to the northwest, the storm I was watching was at the bottom edge of a cluster of storms that spawned of 18 tornados in Wisconsin.

These summer storms are the energy that drives most of the signals in the VLF and ELF bands including the Schumann resonance.

Spherics and Tweeks – Aside from the ever present power line noise and buzz the most common signals in the LF Natural Spectrum are spherics and tweeks. At any given moment, there are several thousand thunderstorms active on the surface of the earth generating on the average over 100 flashes of lightning every second. Lightning can be cloud to earth strikes, intra-cloud lightning between different charged areas in a cloud, and inter-cloud lightning between different storm clouds (this one is relatively rare).

Besides the flash of light and the crash of the thunder, the massive current flow of the lightning bolt creates an intense electromagnetic impulse that radiates energy well up into the megahertz range. Anyone who has tried to listen to a distant AM radio station in the summer can attest to this. However, most of this energy is radiated in the LF spectrum below 30 kHz.

In a typical cloud-to-ground strike, a streamer from the thundercloud may begin to propagate down to the earth. It moves in discrete steps of about 50 meters or so and is called a stepped leader. As it travels downward it creates an ionized path or channel, and by the time it nears the earth there is a large potential difference between the end of the leader and the earth. Usually a streamer propagates upward from the earth and meets the stepped leader. One the connection is made, a return stroke travels up the already ionized path at the speed of light releasing a large amount of energy. (The average peak energy per stroke is about 10^{12} watts.

Lightning flashes are composed of a series of strokes, the average being about four. The duration and length of the strokes vary, but they typically average about 30 μsec.)

In most cases, the discharge is from a negatively charged portion of the cloud and is referred to as a negative strike. Larger thunderstorms called “mesoscale convective systems”, often produce “positive strikes” from a positively charged portion of cloud. These positive strikes are very high in energy and are thought to be the ones that produce sprites and elves, the upward glowing discharges from thunderstorms that were first photographed a few years ago.

Also, it is thought that these positive strikes are more likely to produce whistlers because they radiate more electromagnetic energy.

Inter-cloud lightning (discharges within the same storm cloud), the most common type of lightning, does no produce a return-stroke-like feature. This type of lightning is characterized by slower propagating “recoil streamers”. We watched a storm like this earlier this year on a trip to Maryland. The streamers would crawl across the whole sky, taking a second or two to complete the whole series of flashes. This may account for the long crackling spherics that are often heard.

What about tweeks. Sometimes they are the only interesting Natural Radio signals that we can hear. The tweek sound is the result of dispersion, sort of like a short whistler, but the question as to why tweeks are heard predominantly at night did not seem to have a readily available answer. As a matter of fact, this article was delayed by several months as I tried to find the answer. A 2001 research paper by Porrat, Bannister and Fraser-Smith finally shed some light on the question. (Full reference at the end of the article.)

At frequencies below 30 kHz, the surface of the earth and the bottom of the ionosphere are both very reflective, and the energy from the lightning can propagate long distances, as the space between these two surfaces acts like a waveguide. The attenuation of this earth-ionosphere waveguide is only a few db per 1000 km. Under the right conditions, spherics can be heard around the world.

Trying to explain waveguide theory could fill a book, would probably bore most of you and is well beyond this writer’s knowledge. But in short, there are a variety of modes that allow propagation through a waveguide. In the case of the Earth-Ionosphere waveguide, the TEM (transverse electromagnetic) mode is dominant during the day. This mode of propagation has no cutoff frequency and thus there is little dispersion of the propagated spheric.

During nighttime hours, the QTE_1 and QTE_2 (Quasi-electric) modes of propagation become significant. These modes have a cutoff frequency and thus the waveguide tends to act as a high pass filter. The cutoff frequency in this case is determined primarily by the height of the bottom of the ionosphere, the D layer.

For the QTE_1 mode, this cutoff frequency is at the point where the height of the bottom of the ionosphere is ½ wavelength. For the QTE_2 mode the cutoff frequency occurs at ¼ wavelength. With a typical height of the ionosphere of about 88km above the earth, these two cutoff frequencies occur at about 1.7 kHz. and 3.4 kHz respectively.

Tweeks happen because electromagnetic energy from lightning, propagating through a waveguide, tends to slow down near the cutoff frequency. So the lower frequencies near the cutoff frequency arrive later, giving the tweek its characteristic sound. The longer the tweek, the farther the spheric has traveled. This is similar to what happens in a whistler, although the paths and mode of propagation are entirely different.

Tweeks are usually heard at night because the QTE_1 and QTE_2 modes with their cutoff frequencies and resultant dispersion are enhanced at night. The QTE_1 propagation mode can be enhanced by 25 or 30 db at night making it equal to the TEM mode.

Another spectral feature which also happens during the night, noted by Porrat, Bannister and Fraser-Smith, is semi-periodic fluctuations of the spectrum between the two cutoff frequencies of the QTE_1 and QTE_2 modes. A short period at the low end of the band was observed and a gradual increase of the period as frequency increases. A similar semi-periodic fluctuation is apparent above the cutoff frequency of the second mode. These semi-periodic fluctuations of the spectrum are related to the modal nature of the electromagnetic wave propagation. This may help to explain the different sounds heard on tweeks over the course of a listening session.

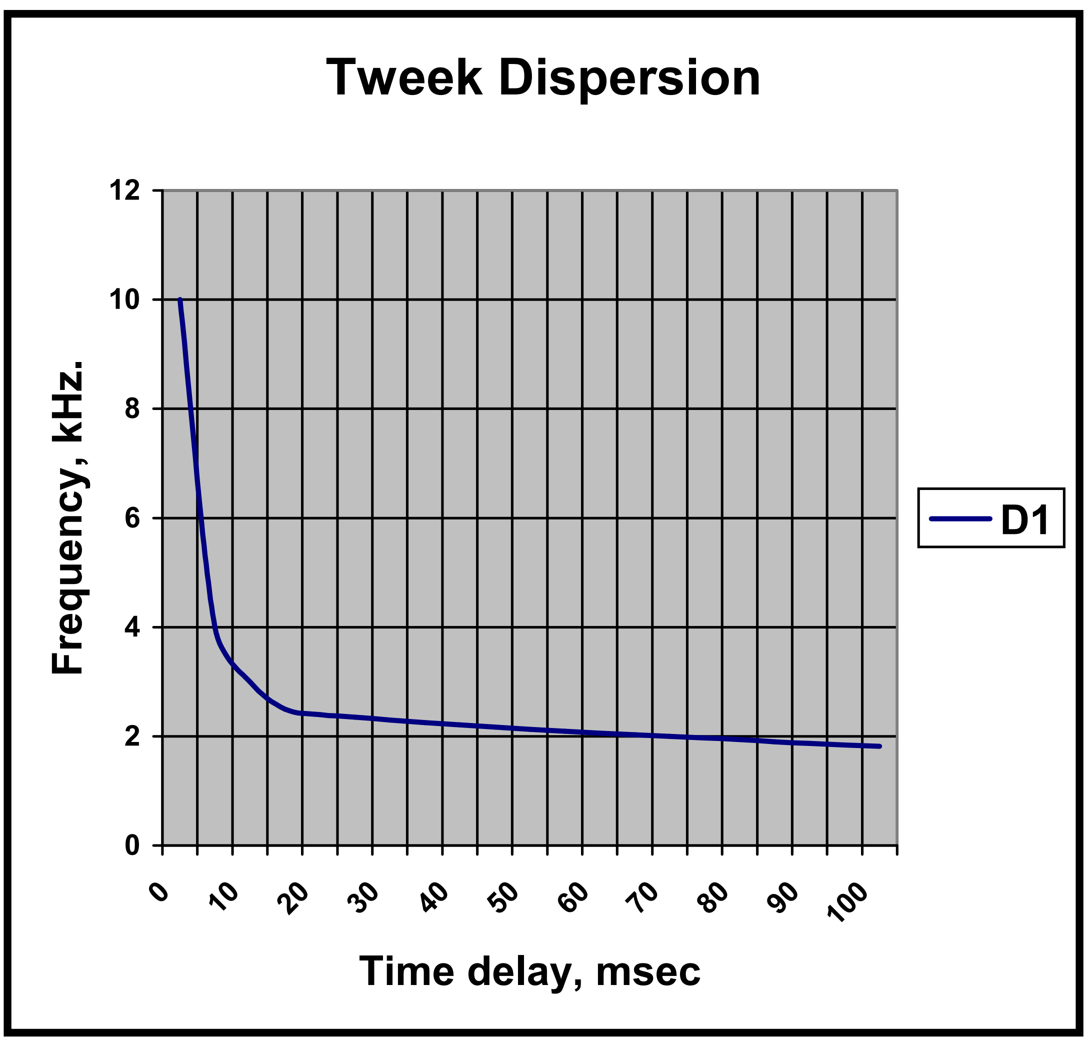

Figure 1

Dispersion can be used to estimate how far away the lightning that caused the tweek is. In *Whistlers and Related Ionospheric Phenomenon*, Helliwell discussed a method of determining the distance of a source producing the observed spheric.

The formula is d=c Δt, where c is equal to the speed of light ($3x10^5$ km/s) and Δt is the difference in seconds, from the leading edge of the trace to the point on the trace where $f=1.16 f_c$.

In Figure 1, shown above, the tweek is approaching a cutoff frequency (f_c) of 1.8 kHz. If $f=1.16 f_c$, then f = 2kHz and Δt =90 ms. Multiplying Δt by the speed of light, (d=c Δt) we find that the distance to the source of the tweek is about 2700 km.

Using Spectran or Spectogram, it should be relatively easy to calculate the distance of the thunderstorm that caused the tweek.

Technical papers that provided the information for this article are *Lightning and Ionospheric Remote Sensing Using VLF/ELF Radio Atmospherics* by Steven A. Cummer, Aug. 1997, at http://www-star.stanford.edu/~vlf/publications/theses/cummerthesis.pdf and *Modal Phenomena in the Natural Electromagnetic Spectrum Below 5 kHz* by Dana Porrat, Peter R. Bannister and Antony C. Fraser-Smith, January 2001, at http://wireless.stanford.edu/~dporrat/radioscience_paper.ps

Low-Noise Amplifier for Loops – If you have interest in building loop antennas and their associated preamplifier, Eric Vogel alerted the VLF_group to a new, low-noise, integrated circuit preamp.

THAT Corporation has released its advanced microphone preamp IC, the THAT1512. Boasting lower noise over a wider range of gain settings than any integrated circuit preamp on the market, the 1512 offers lower distortion, wider bandwidth, faster slew rate, and reduced supply current compared to competitive models.

The 1512 Mic Preamp IC is extraordinarily quiet at both microphone and line levels and its bandwidth is nearly three times wider than that of other ICs. This results in improved distortion and transparency on a par with discrete designs, letting the 1512 deliver discrete performance in IC form."

At 60dB gain, its input noise -- at 1 nV/root-Hertz -- adds only 1.3 dB noise to that of a 200 Ohm microphone. Yet, at 0dB gain, the 1512's input noise rises to only 32 nV/root-Hertz -- matching that of most conventional line-input stages.

The part operates over a wide range of supply voltages – from ±5V to ±20V – and typically draws only 6 mA of supply current.

Parts are available from THAT with a minimum order of 50 pieces, but they are currently providing samples upon request. I have ordered some samples and hope to do some experimenting over the next couple of months both with loop preamplifiers as well as microphone preamps for the studio.

There is also an evaluation board available with all parts and the IC, as well as XLR in and out connectors. The cost of the board is $100. Get all the details on their website at http://www.thatcorp.com/press34.html