Flare Detection using VLF Radio signals

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The detection of Solar Flares can be achieved by continuously recording the signals from some of the Military radio transmitters on VLF (Very Low Frequency) radio. In the radio field these events were given the name Sudden Ionospheric Disturbances (SID) early on, and Flare detection is sometimes referred to as SID detection. The effect depends upon the response of the ionosphere to the burst of solar radiation, and the mechanics of the radio propagation mechanism.

The Ionosphere

The Ionosphere is a region of the Earth’s atmosphere where the gas density is low enough for atoms that become ionised to exist for a significant period of time before meeting and colliding with another atom and becoming neutralised again (collisional recombination). This region is at an altitude of between 50 km and about 600 km above sea level. The ionising energy arises mainly from the Sun in the form of particles and electromagnetic radiation from the visible spectrum right through to gamma rays.

Flare Detection Mechanism

The part of the Ionosphere that interests us from the point of view of Flare detection is referred to as the ‘D-layer’ (at 50 km to 90 km altitude) and the ‘lower E-layer’ (90 km to 150 km altitude). In the radio field the D-layer is known mainly as an absorbing blanket that stops long distance propagation at lower “short wave” frequencies. At VLF and LF, which are defined as frequencies below 300 kHz, the D-layer provides the means by which these frequencies could reach world-wide before the short-wave bands were opened up in the 1930s. It is often explained as forming a “waveguide” with the Earth’s surface that guides the waves round the curvature of the Earth. Although the simpler analogy of a mirror “reflection” can be used to describe the propagation mechanism, the physical mechanism is actually ‘refraction’, the same mechanism that is responsible for the “bent pencil in the tumbler of water” effect. The term ‘reflection’ is used here in quotes when describing the ionosphere returning an upward radio signal back towards the Earth.

The Ionosphere is characterised by an increasing electron density from about 50 km altitude upwards. At low electron densities and the higher air pressures around 50 km, the incoming radio wave loses energy to the free electrons, which recombine before they have chance to return energy to the wave. However at higher altitudes the electrons have a chance to interact with the wave for longer, in a way that apparently speeds up the wave, bending its direction back towards Earth again. These two mechanisms, absorption and “reflection” are vital to the understanding the SID detection mechanism.
Ionospheric Layers

- **Topside**
  From F2 layer to 500/1000km transition O+ less than H+ and He+

- **F Layer**
  Above 150km, reflecting F2 layer, ions NO+ (lower) to O+ (upper)

- **E Layer**
  95 – 150km, ions are mainly O++ , also thick E2, thin sporadic E

- **D Layer**
  75 – 95km, weak ionisation, absorbs HF

**Normal Quiet VLF Propagation**

At relatively short distances, less than 1000 km, the radio signal from the VLF transmitter reaches the receiver by two paths. One of these hugs the ground and is called, unsurprisingly, the “ground–wave”; the other is via “reflection” from the ionosphere, called the Ionospheric–wave, often colloquially known as the “Sky–wave”. These two paths are of different lengths, and lead to the formation of an ‘interference pattern’. In this case the term ‘interference’ is used in the optical sense and not meaning unwanted noises and lightning static as in the radio sense. The different path lengths for the two signals means that the phases of these signals will differ at the receiver. If the path difference is an even number of half wavelengths the signals on the two paths will reinforce and if the number of half–wavelengths is odd there will be some cancellation. The same kind of effect is obtained by listening to a steady sound from a loudspeaker in a sparsely furnished room and moving slowly around. You will find places whether the sound you hear is reduced and other where it is enhanced. The difference in distance between these points is one half wavelength of the sound–wave. If the amplitudes of the signals on the two paths are the same and they are out–of–phase there will be perfect cancellation. However the reflected wave is usually attenuated so it arrives weaker than the direct wave so there is less than complete cancellation. If, as in the case of the ionosphere, the “reflector” moves up and down there is a continuous change in the received signal which is normally referred to as ‘fading’.

In daytime the Sky–wave is attenuated by the absorbing part of the D–layer, but the amount of absorption is dependent on the amount of penetration. High angle waves penetrate deeply and are severely attenuated, but waves at low angles of incidence penetrate more shallowly and are less attenuated. The ground–wave component of the signal progressively weakens as the receiver becomes further from the transmitter. At about 700 km range the ground and sky waves are approximately the same strength.

After dark the D–layer, which is mainly ionised by Solar Ultra Violet rays, quickly disappears and with it all the absorbing ionisation. "Reflection" now occurs from the lower part of the E–layer at around 90 km to 100 km altitude. The result of this is
that once the mid point of the path is in shadow at 100 km altitude, the signal strength will usually increase significantly, while the ground wave signal stays exactly the same strength. Thus night-time reception is marked by large and rapid swings in signal strength as the two, now more nearly equal strength, signals swing in and out of phase. This is of little interest to the SID observer as there can be no Solar Flares detected in the Earth shadow, but it may help to set up the Receiver levels correctly, so that you do not miss or corrupt a flare-induced signal.

Changes due to Solar Flares

A Solar Flare is caused by the sudden collapse of the very highly strained magnetic field in the region of a Sun–spot. Electro–magnetic waves are generated by changing magnetic fields, and the size and strength of the field in a Sun–spot are enormous. When the twisted and strained field snaps into a lower energy condition, vast amounts of energy are released as high energy electro–magnetic radiation. This can be detected from microwaves right up to gamma–rays. This radiation travels in a straight line at the speed of light and takes about 8 minutes to reach Earth. If we had no atmosphere we would be fried!! Fortunately our atmosphere and the Earth’s magnetic field protect us from the worst of the radiation blast. The UV penetrates to the D–layer and the higher energy waves create an avalanche of particles in the very outer regions of the atmosphere. When the radiation reaches the D–layer it produces a very high level of ionisation, pushing the “reflection” level right down through the normally lightly ionised absorbing layer. In effect we have a “mirror” at 50 km and no attenuation of the Sky–wave signals. Hence the usually displayed “shark–fin” response on the signal strength plots. The height of the trace is related to the strength of the flare (see the NOAA web site for a tutorial) though a very strong flare may saturate. From experience it is unlikely that a flare of below Class–C1.0 will be reliably detected. In solar quiet conditions it may be possible in retrospect to relate deviation in signal strength to flares of B5.0 or higher. Detection sensitivity depends upon many factors including the distance from the VLF transmitter and the time of day. It may be useful to monitor several stations to determine which gives the best sensitivity.

Abnormal Results

It is not unusual for an observer to get strange results that are difficult to understand at first. A common one is a negative going “shark–fin” at a flare. This has been written off by some as an equipment fault, but it is a function of the distance from the transmitter of the monitored signal. Remember the fading effect mentioned earlier; if the ground wave is much stronger than the normal quiet Sky–wave and they are out of phase, then an *increase* in Sky–wave strength will *reduce* the level of the composite signal. This can be complicated by some flares which cause the signal to go one way at first and then the other before the signal returns to the undisturbed level.
If you are a great distance from the station (when monitoring LF beacon stations at 2000 km the flare effect will always be upward because the ground wave is very weak at this range) then there are some special effects that take place at sunrise and sunset. These are often referred to and the morning and evening “dips”. These are caused by the daytime Sky-wave being wiped out by an unexpected effect. At sunrise and sunset the ionospheric “reflection point” is actually illuminated from underneath, by weak rays that have grazed the ground at the edge of the darkness shadow. These produce weak ionisation levels that strongly absorb radio signals but are not enough to “reflect”. They totally cloak the E-layer that will soon take up the reflection of the night-time Sky-wave, thus virtually removing the daytime Sky-wave. The composite signal level at this time correlates well with calculations of ground-wave only signal strength, which are based on transmitter power, range, and ground conductivity.

Detection Summary

**Quiet Sun**

*Low level of Sky-wave signal received vs. ground-wave.*
At Night

Erratic level of Sky-wave signal vs. constant ground-wave.

Active Sun

High Sky-wave signal level received during a flare.