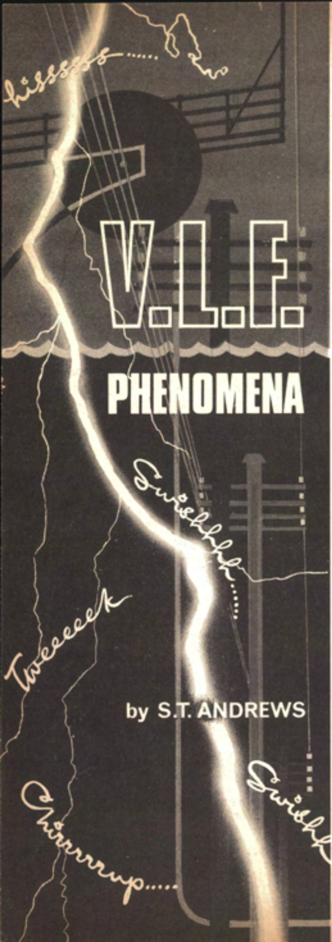

V.L.F. PHENOMENA

by S.T. ANDREWS

WHEN considering radio waves and radio reception it is customary to think in terms of frequencies of megahertz or at least hundreds of kilohertz per second. There are, however, certain radio emissions which do not fall into this category; these are naturally-occurring radio signals of extremely low frequency and correspondingly long wavelength, which are appropriately called Very Low Frequency (v.l.f.) signals.

V.L.F. signals have been the subject of sporadic investigation for a long time, in fact for most of the time during which radio communication has been known and developed. Some problems in this field are still unsolved and, perhaps because of the unusual—and at times quite mysterious—forms which v.l.f. waves take, the subject is extremely interesting.

The purpose of this introductory article is to give a description of some of the types of these signals, together with some theories on their generation. It should be added that v.l.f. waves can be man-made as well, nuclear weapons, and missile and rocket exhausts all producing signals in the same frequency range. However, this article deals only with the naturally-occurring types of v.l.f., so these artificial sources will not be mentioned again.

EARLY HISTORY

The first indication of the existence of v.l.f. signals is to be found in the early part of this century. These were the days when telephones were becoming widespread but the large-scale national electric grid system had not been started and there were far fewer electrical machines of all types. Under these circumstances there was little in the way of man-made interference and in theory long-distance telephone wires should have remained silent when no actual messages were being sent.

In practice, however, the operators soon built up a list of strange and unidentified noises which appeared on their lines and which included chirps, warbling sounds, hiss, whistles of varying pitch and numerous other sounds often known only by suitably-invented onomatopœic names—tweeks, chinks, clicks, etc. Although it was soon realised that the noises were some form of natural radiation no explanations were immediately forthcoming and for a time the causes were quite unknown.

SUBMARINE CABLES

Telephone lines were not the only form of communication to be affected by v.l.f. pick-up, and in 1929 investigations were made into similar phenomena in submarine cables. The signals picked up from such cables were of various types, one common form being a low-frequency, low-amplitude voltage "kick". The occurrence of these kicks was very variable, their frequency being low during daylight, rising progressively as evening passed, and maintaining a high level throughout the night. As soon as dawn broke the kicks rapidly diminished in number to the low daytime level.

Other forms of interference appeared as signals in the range 500 to 1,500Hz, and when applied to a loudspeaker after amplification these came out as roaring or rustling sounds. Also noted were "swishes", signals characterised by a narrow bandwidth, the centre frequency of which rapidly changed, typically from 700 to 2,000Hz over a period of ¼ to 1 second. Such swishes were heard both with ascending and descending centre frequencies.

TWEEKS

Another form of v.l.f. phenomena observed from submarine cables were "tweeks". Their waveform was characteristically a damped oscillatory waveform of approximately constant frequency, the whole thing lasting ⅛ second and being in the frequency range 6 to 20kHz, see Fig. 1. Tweeks were apparently always preceded by a static "kick" and were never heard in daylight. They always appeared at dusk with a low repetition rate and heavy damping. Later in the night the rate often rose to three to 30 tweeks per minute and the damping was greatly reduced. Just before dawn the rate increased briefly before falling to the daytime zero level.

It is reasonable to accept the theory that tweeks are caused by the multiple reflection of a pulse between the earth and the lower levels of the ionosphere, or possibly between layers within the ionosphere (see Fig. 2), and it is also reasonable to assume that a similar explanation may well account for at least some of the sounds heard on the telephone wires.

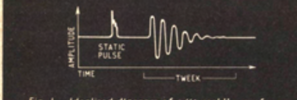

Fig. 1. Idealised diagram of a "tweek" waveform

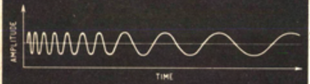

Fig. 3. Idealised diagram of a "whistler" waveform

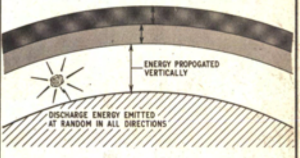

Fig. 2. Formations of "tweeks" (idealised and not to scale)

Tweeks, and also "chinks", had also been heard on telephone wires, again only at night, and they were found to have a duration of $\frac{1}{20}$ to ½ second and a frequency in the range 1·6 to 4kHz. Taking the approximate height of the bottom of the ionosphere as 100km and $c = 3 \times 10^5$km per second, we get about $2{\cdot}5 \times 10^3$ complete bounces per second—so if some signal is reflected by the ionosphere at each bounce we would get a damped waveform of frequency 2·5kHz which is in fair agreement with observation, at least with the telephone wire tweeks.

LIGHTNING DISCHARGES

The ultimate source of energy for a tweek appears to be the static pulse which precedes it. This initiating pulse, or click, is typically radiation from a lightning discharge, and lightning discharges figure very largely in discussions and explanations of v.l.f.

A considerable amount of research has been done into lightning strokes and their effect. Everyone is familiar with the sounds emitted by an ordinary radio receiver when lightning occurs nearby—an initial crack, followed by a sizzling or swishing sound lasting ½ to 1 second. The actual energy dissipated in an average stroke is 1,000 megawatts, all released in 0·1 millisecond or less, so this represents a truly colossal release of energy. It is hardly surprising that some curious effects, for example tweeks, should result from such an energy release and it will soon become apparent that several other phenomena are also the result of energy liberated by thunderstorms.

WHISTLERS

Possibly the commonest, and certainly the most recognisable, type of v.l.f. signal is the whistler. A typical whistler will be heard as a high-pitched audio note, often initially at the upper limit of hearing, which rapidly (0·3 to 5 seconds) falls in pitch and finally dies away at a frequency many octaves lower, see Fig. 3. Sometimes several whistlers will occur in succession, with progressively decreasing amplitudes. Whistlers with frequencies varying from 30kHz to 350Hz have been measured but the spread is usually less in a given instance.

Various theories were put forward to account for the properties of whistlers, in particular their comparatively pure note and the smooth fall in frequency. One suggestion was that whistlers were formed by multiple reflections between the ground and the Heaviside Layer. With a changing angle of reflection a wave would need a different number of bounces to reach a given receiver and since time delay was proportional to the number of bounces, some "sorting out" of frequencies would occur if the maximum angle of reflection was in some way related to frequency.

Another idea was that whistlers were of solar origin and that a group of ionised particles from the sun hit the outer atmosphere and gave rise to a pulse in the shape of an expanding torroidal ring of radiation in the ionosphere with some frequency-selective properties.

The mystery was finally solved by Storey who noted that whistlers could be grouped into two categories depending on the rate of fall of the frequency. One group, with a rate of fall approximately twice that of the other group, generally had the whistler by itself, whistlers in the other group were very often preceded by a pulse of atmospheric noise.

IONOSPHERIC NOISE

Storey showed that this initial pulse came from a lightning discharge and formed his theory that some of the intense energy liberated interacts with free electrons in the ionosphere to give a broad band of radio noise. Some of this noise travels out into space following the lines of force of the earth's magnetic field and ultimately hits the ground again when the line of force goes underground, approaching the other pole. In the case of lightning in Britain this bounce will occur in the neighbourhood of South Africa. After the bounce the waves re-trace their path, following the same lines of force, back to their starting point, see Fig. 4.

A reflective system such as this exhibits dispersion, that is, short wavelengths corresponding to high frequencies are diffracted the most, and so follow a path which is always nearer the surface of the earth than the path taken by a signal of longer wavelength. Since the wave-velocity is constant it follows that shorter wavelengths will arrive back first, followed progressively by longer and longer wavelengths. Thus at a receiving point the effect is a steady lengthening of the received wavelength, hence the regular fall in pitch and the explanation of whistlers.

The degree of dispersion of a whistler will obviously increase with each passage from ground to ground, so whistlers originating from lightning discharges in Britain should have a slower rate of frequency change after two "hops" than those originating from storms in South Africa which have only made one hop, see Fig. 5. Also, one would expect some of the radio noise from the discharge itself to be heard before the whistler in the case of a British-originated whistler. This, of course, is just what is observed, the slower-falling frequency class of whistler generally being preceded by a click.

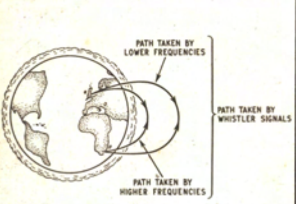

Fig. 4. The formation of "whistlers"

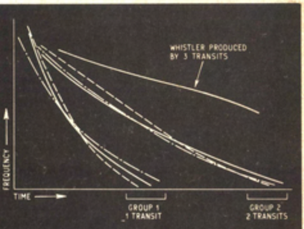

Fig. 5. Graph of fall of whistler rate v. time

THE DAWN CHORUS

If whistlers are the most recognisable part of the v.l.f. repertoire then the upper atmosphere's "dawn chorus" is undoubtedly the weirdest and most unearthly, especially when the observer happens to be on a lonely mountainside in northern Scotland at 5.30 a.m. The dawn chorus is a complex sound and is composed of a mixture of short rising whistles, of duration 0·1–0·2 second, and longer warbling tones; it has been likened to the sound of a distant rookery.

The intensity of these signals varies very greatly during the day and in Britain it is at a maximum around sunrise with, sometimes, a smaller peak at sunset. In Alaska the daily peak comes nearer 2 p.m. and at latitudes nearer the equator the daily peak may be as early as 2 a.m. When plotted graphically the relation between latitudes and time of peak signal is a good approximation to a straight line.

Other properties noted include the apparent similarity between the signals received at stations far apart, implying a widespread source, rather than a localised one, and the absence of any audible precursors. There is certainly no connection between whistlers and the dawn chorus and the lack of any initiating trigger (unlike the click preceding locally-produced whistlers) seems to indicate a source high in the ionosphere.

EXTRA-TERRESTRIAL

Theories on the formation of the dawn chorus all agree that the ultimate source is extra-terrestrial and is in fact ionised particles shot out by the sun. It is possible that the dawn chorus is initiated by the arrival over the geomagnetic equator of positive particles of solar origin, such particles would excite ions already present in the outer atmosphere and these would re-emit excess radiation as electromagnetic radiation at their natural resonant frequency. This frequency would rise as the ionising cloud penetrated to lower levels. Referring momentarily back to the previous paragraph, it was shown that the time of peak dawn chorus activity was progressively later as latitude increased. It is interesting to note that a graph of

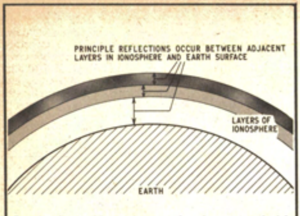

Fig. 6. A possible explanation for the origin of v.l.f. signals in the ionosphere is suggested in this diagram

latitude *v.* peak activity time is also the locus of positively charged incoming ions travelling in an equatorial plane and being deflected by the earth's magnetic field.

TRAVELLING-WAVE THEORY

Another theory, due to Gallet and Helliwell, suggests a different action entirely. Their theory is somewhat complex but basically it suggests that in the upper atmosphere an effect occurs similar to that in a travelling-wave tube.

According to this theory the slow-wave circuit (corresponding to the helix in a normal travelling-wave tube) is formed by the ambient ionisation of the outer ionosphere in the presence of the earth's magnetic field. The energy for amplification is provided by the streams of in-coming particles which have velocities in the range 0·1 to 0·01c (c = velocity of light). The particle stream is assumed to travel along the lines of force of the earth's magnetic field and there will be a component of the electric field parallel to this direction. Under these conditions travelling-wave amplification is possible.

According to Gallet and Helliwell the incoming particles arrive in bunches and as these travel along the lines of force of the earth's magnetic field travelling-wave amplification is possible and will occur at a frequency determined by the size and velocity of the bunch. As the bunch loses energy these parameters change so the frequency of amplification, and of the resulting note, change, giving the characteristic rising tones of the dawn-chorus signals.

FINAL THEORETICAL COMMENTS

There is still a lot to be learned about naturally-occurring v.l.f. radio waves and much remains unknown. There is no doubt that some of the strange noises, for example the whistlers, have been successfully explained but the exact method of generation of, for example, the dawn chorus is still controversial.

Some pure research goes on into the nature of v.l.f. and information is also being obtained as a by-product of other work dealing with the propagation of man-made low-frequency transmissions.

Experiments on the nature of the ionosphere are continuing. It is certain that a lot of v.l.f. signals are generated in the ionosphere and the more detailed is the information about it the easier it will be to decide on a mechanism for v.l.f. signal generation.

Ionisation is known to alter greatly in the ionosphere at sunrise and sunset. At sunrise the ionisation and electron density rapidly increase with corresponding changes in the permeability to, and polarisation of, low frequency radio waves. Nuclear explosions at high altitudes also have the effect of increasing electron and ion densities. Another form of v.l.f. radiation, plain hiss, is often heard and this was observed to increase sharply after a heavy cosmic ray shower in 1956.

PRACTICAL NOTES

Theoretically, v.l.f. radio reception is simple, one merely connects an ordinary aerial to an audio amplifier instead of the aerial socket of a radio receiver. In practice, of course, this usually fails due to the pick-up of man-made interference. Fairly high audio gains are required for efficient v.l.f. reception, although whistlers and the dawn chorus are often detectable with quite simple systems.

There are two chief difficulties. The first lies in getting rid of broadcast transmissions which can "break-through" if the v.l.f. receiver has any non-linearity in its amplifying stages. This may be avoided by using a low-pass filter in the aerial circuit and keeping amplifier linearity as high as possible. The second is interference, which comes from almost anything from an electric razor to an electric train, and also the 50Hz hum which is picked up from every power cable.

Since it is not usually possible to reduce the interference at its source v.l.f. experiments frequently have to be performed in open areas away from towns, hence the earlier reference to the lonely mountainside in Scotland.

TYPICAL V.L.F. AERIAL

A typical v.l.f. aerial may consist merely of a hundred or more feet of ordinary wire hung above ground in the traditional "crystal-set" style. One aspect of v.l.f. which is well worth some experimental time is the design of the aerial. Obviously dipoles are quite impractical when dealing in wavelengths measured in terms of miles, and some other criteria must be found which specify the efficiency of the aerial.

A certian amount of "devotion to the subject" is necessary when studying v.l.f. especially for experimenters who live in towns and who wish to study the dawn chorus! However, with a little care both in building the equipment and in laying out a suitable aerial, good results are usually quite obtainable and the audible results alone from a v.l.f. receiver are almost always very interesting.

Next month our Constructional Projects will include a V.L.F. "Whistler" Receiver