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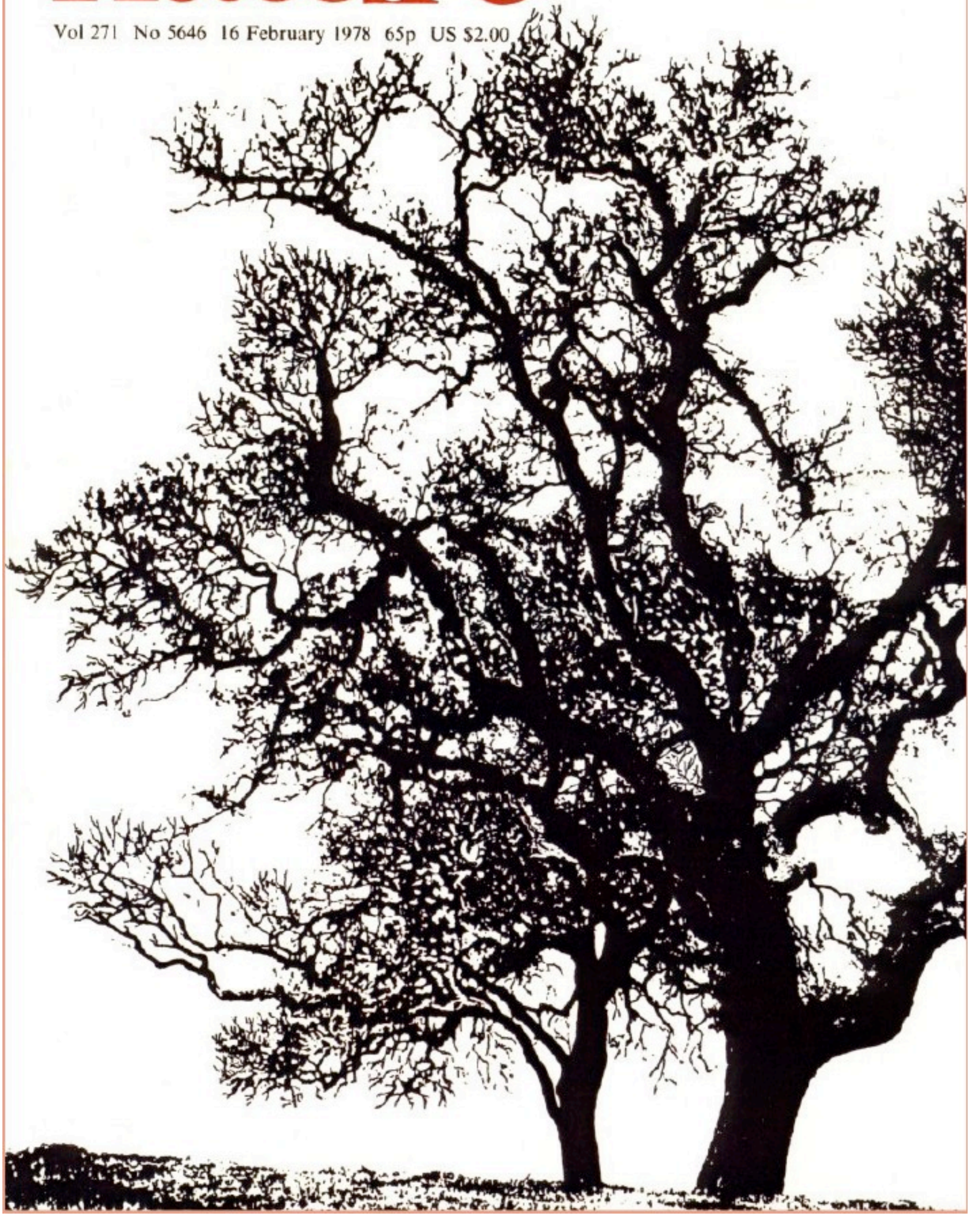

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ULF tree potentials and geomagnetic pulsations

HIGH-SENSITIVITY measurements of ultra-low-frequency (ULF; frequencies less than 5 Hz) geomagnetic pulsations[1] usually require elaborate receiving antennas ranging from large air-cored coils[2] through multi-turn steel, or mumetal-cored solenoids[3–5] to small superconducting loops immersed in liquid helium[6]. Pairs of electrodes inserted in the ground have also been used as antennas[7,8]. The need for a large spacing between the electrodes (varying from hundreds to thousands of metres) and the difficulty of calibrating the measurements absolutely have resulted in the almost universal use of the more compact and easily calibrated coil-type antennas in recent years. I describe here a new method for measuring ULF geomagnetic pulsations, which requires a minimum of elaborate equipment. The method is based on the use of trees, or, more specifically, on the use of pairs of electrodes inserted into trees, as ULF receiving antennas.

There are several reasons that this new method of measurement may be of interest. The equipment is simple and thus the method could lead to more widespread observations of ULF geomagnetic pulsation phenomena. The method of measurement also provides new information about tree potentials, that is, it shows that some, and perhaps all, of the ULF components of these potentials are induced by ULF geomagnetic field fluctuations and do not originate in the trees themselves. Finally, although it is not clear at present what effect induced ULF electric fields may have on the growth and other vital processes in a tree, the link between these ULF electric fields and geomagnetic field fluctuations suggests that some environment-related changes in trees could also be influenced by changes in geomagnetic activity. These changes may have a natural origin (for example, the changes that occur during a solar cycle[9]) or they may be caused by a variety of human activities (by modern d.c.-powered mass transit systems, which can produce large amplitude ULF electromagnetic fields[10]).

The ULF measurements reported here were stimulated by the work of Burr on relatively steady-state tree potentials[11]. Burr recorded these potentials for more than a decade using a pair of specially-designed non-polarisable electrodes inserted in the cambium of an unspecified tree (which was probably a maple). The electrodes were about a metre apart along the long axis of the tree and Burr observed diurnal, 27-d, and seasonal variations, as well as a suggestion of a correlation with sunspot activity, in their potential difference.

Most of Burr's observations were at frequencies far below the frequency range for ULF geomagnetic pulsations. One series of measurement obtained, however, during an electrical storm suggested that ULF variations of tree potentials might occur on occasion. I therefore began a search for variations with frequencies predominantly in the Pc 1 geomagnetic pulsation range (0.2–5 Hz). These frequencies correspond approximately to the delta regime for human brain waves.

The measurements were made using a large native oak, *Quercus lobata*, that was located near conventional ULF recording equipment at a site on the Stanford University campus. This latter equipment uses 20,000 turn steel-cored solenoids as ULF antennas and it operated continuously throughout the interval during which the tree measurements were made. Thus, simultaneous measurements of ULF geomagnetic pulsations using both conventional loop antennas and a tree 'antenna' were obtained at the one location.

Two steel nails were used as electrodes. Following Burr's configuration, they were inserted about 0.05 m into the tree along the long axis, with a spacing of 0.76 m. The lower electrode was approximately 1 m above the ground, and the two electrodes faced toward the geomagnetic west. Because the tree was not completely vertical, a line joining the two electrodes would have been inclined approximately 20° toward the geomagnetic east. The diameter of the tree midway between the two electrodes was 0.65 m.

A resistance of about 5 kΩ was typically observed between the electrodes, increasing to about 10 kΩ if polarisation was allowed to occur. A d.c. potential difference was also observed that varied from day to day but whose absolute value was usually in the range 10 to 100 mV, with the upper electrode positive. The electrodes were connected to a low-frequency high-gain amplifier through an *RC* filter (R= 22 MΩ, C=50 μF). The amplifier was usually set for 50 db gain, and its output was filtered (0.02–7 Hz) before being recorded, generally without additional amplification, on a chart record and on analog magnetic tape.

The ULF signals measured by this system were undoubtedly induced in the tree 'antenna' and not in the shielded cabling between the electrodes and the recording system: when the electrodes were disconnected from the tree and connected to an equivalent 5 kΩ resistor, without any other change in the wiring or configuration of the system, only a steady low level of white noise (typical resistor thermal noise) was observed.

Similarities between the ULF signals recorded conventionally and with the tree 'antenna' were immediately apparent on the chart records. More detailed analysis confirmed that Pc 1 pulsation events recorded by the two systems were very nearly identical in all their important characteristics. Figure 1, for example, shows spectrograms of a sequence of four Pc 1 pulsation events that occurred during the interval 1200 to 1500 UT on 17 January 1976, and which were received by the tree 'antenna' (*a*) and the conventional north–south solenoid antenna (*b*). With the exception of a lower signal-to-noise ratio for the tree measurements, the two Pc 1 pulsation records are closely alike. It will also be noticed that the lower frequency Pc 2/Pc 3 geomagnetic activity (frequencies in the range 0.02 to 0.2 Hz) is recorded similarly by both systems. The amplitude of the ULF pulsations in the tree potentials is very small. For the Pc 1 pulsations shown in Fig. 1, the maximum amplitude of the potential fluctuations was about 0.1 mV.

The nearly identical occurrence and spectral characteristics of ULF events measured by the tree electrodes and by the conventional ULF equipment indicated that the tree potentials were largely induced by ULF time variations of the geomagnetic field. To investigate this possibility, a portable planar search coil powered by a 1 Hz signal generator was moved around the tree near the electrodes. It was found that a 1 Hz oscillation of the potential difference between the tree electrodes was produced only when the search coil was orientated with its moment vector in the north–south direction. When the two electrodes were moved to the north face of the tree, a response from the electrodes could be obtained only when the search coil moment vector was orientated in the east–west direction. These results, and the observations of natural Pc 1 pulsa-

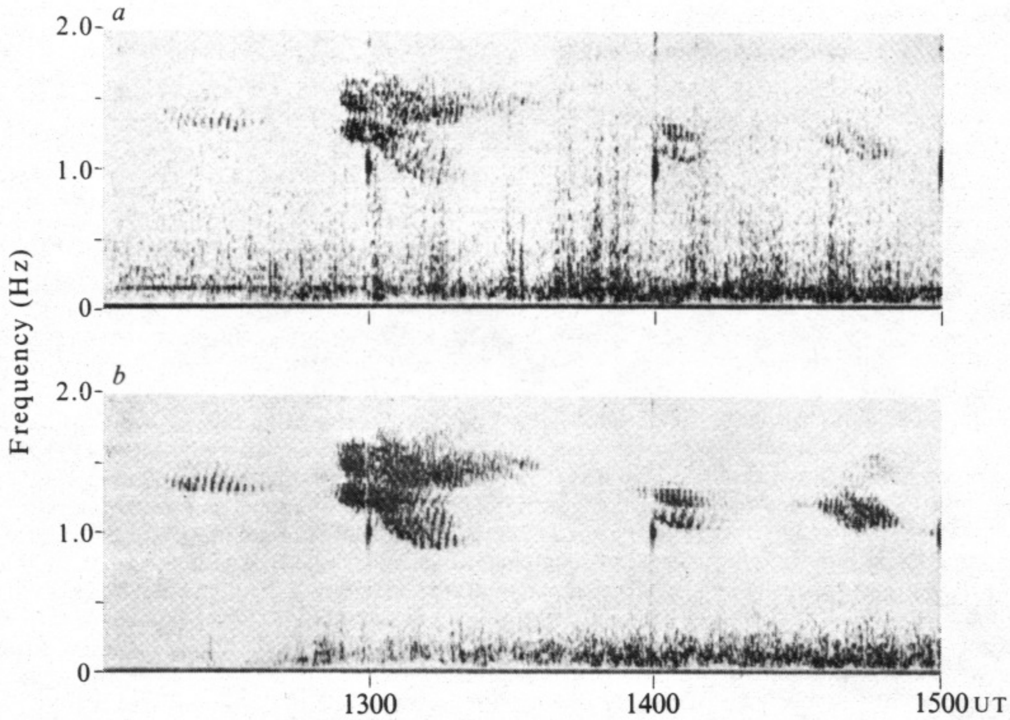

Fig. 1 Spectrograms of a series of Pc 1 geomagnetic pulsation events recorded at Stanford, California, using tree potentials (*a*) and a conventional solenoid antenna (*b*). Short intervals of a 1 Hz calibration signal appear at the start of each hour. The vertical lines in the upper spectrogram are caused either by local electromagnetic transients or by natural sferics; similar lines occur in the lower spectrogram, but they are not as obvious because the background noise is comparatively suppressed.

tions, can possibly be best understood by considering the tree/electrode pair combination to form a collection of conducting loop antennas in which e.m.fs may be induced by magnetic field fluctuations in the appropriate direction. The conducting paths are provided by the conducting material of the tree (and the cambium in particular[11]), and, for field fluctuations in a particular direction, the area of the relevant loop antenna is defined by the intersection of the tree with a vertical plane perpendicular to the particular field direction and passing through the two electrodes. Thus, in the measurements reported here, the Pc 1 pulsation events observed in the tree potentials were produced by Pc 1 pulsations of the north–south component of the geomagnetic field.

Further tests showed that the tree potentials could only be detected in a living tree. Thus, when a tree dies, the potentials gradually disappear as the wood dries and loses its conductivity.

In conclusion, measurements with tree electrodes show that trees may be used as 'antennas' to detect ULF geomagnetic pulsations. The measurements also show that ULF tree potentials are largely produced by ULF fluctuations of the geomagnetic field (the remaining component of the potentials is probably thermal noise). Presman[12] noted that electromagnetic fields usually have an adverse effect on living processes. If the ULF geomagnetic pulsations have any adverse effect on the growth of trees (and, as we have seen, they must induce electric currents in the living material) these effects could possibly be observed in tree ring data. Pc 1 geomagnetic pulsation occurrences vary markedly over a solar cycle[9] and thus, if these particular pulsations effect tree growth, a solar cycle in tree ring data could occur. LaMarche and Fritts[13] searched unsuccessfully for a relation between tree ring data and sunspot numbers. The phase of the Pc 1 pulsation solar cycle, however, differs by several years from the sunspot cycle and, assuming the two cycles affect tree ring data, they may tend to obscure each other's effects. Furthermore, other geomagnetic pulsations and higher-frequency electromagnetic signals have their own cycles of occurrence, and their effects on tree ring formation, if any, could add further to the complexity of the tree ring data. Studies of these possible effects are desirable, because the tree ring data could provide a unique record of past ULF and higher-frequency geomagnetic activity.

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