With regard to those rules, at least in theory, the scientist has been given a rather tightly circumscribed role. One reason for this is an apprehension, not unjustified, of abuse of the system. Courts are indeed plagued by the "instant expert," who, whether out of a misguided eagerness to earn his fee or an overreaction to his own self-described credentials, may expound quite far-reaching opinions. An unfortunate consequence of that phenomenon has been, on a limited number of occasions, a refusal on the part of the manufacturers of breath alcohol instruments to make their manuals available to anyone other than official government agencies. That, of course, is a bit like the Emperor Caligula inscribing the laws upon pillars so high that none of the citizens of Rome could read them.

Clearly, there can be no such thing as an "official" science. The potential for governmental abuse is not as great as it may seem, however. The prosecutor is bound by the duty to see that justice is done and that the innocent go free. On the other hand, the defense attorney, with respect to his own client and as long as his own actions are lawful, has no duty to see that the guilty are punished. Within this context, it must be remembered that the prosecution and defense do remain as adversaries under our system of law and are obligated to conduct themselves accordingly.

To find those under this system who are not adversaries and who have a duty to remain objective, one must go to the legislature or, in the courtroom, to the judge and jury. To ensure that the *science* is objective and fair, one can only go to the scientists themselves. If the particular encounter discussed has any value as a model for relations in general between science and society, it is this last feature that might earn first consideration. The role intended for science is that of handmaiden to society, not prostitute.

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Project Sanguine

James R. Wait

The United States Navy has announced (*1*) that it has been conducting research and development on extremely low frequency (ELF) communications. The early part of the research program was known as Project Sanguine. The Navy has claimed that the research proved the feasibility of ELF communications as early as 1963.

The Sanguine system, as envisaged by the Navy, is a single transmitter complex able to communicate with American submarines while they are submerged in the ocean at operating depth (*1*). Currently, messages are sent at very low frequency (VLF) by using high-power (megawatt) transmitters with massive aerial structures. Sanguine is supposed to provide the capability of communication (one-way) to submerged submarines from a single buried transmitter site, located in Wisconsin. The technical objective of Sanguine is to launch electromagnetic energy into the free-space cavity formed between the earth's surface and the lower edge of the ionosphere. Such signals will then penetrate below the surface of the sea when the operating frequency is sufficiently low. In this sense, the energy path from transmitter to receiver is up, over, and down, rather than directly through the earth. The attenuation for a path through the earth is prohibitive, even for frequencies of the order of 50 hertz.

The frequencies in the range relevant to Sanguine are extremely low, below 100 hertz. At 45 hertz, which is a designated Sanguine frequency, the free-space wavelength is 6660 kilometers. Thus, an antenna several hundred kilometers in length is still a small fraction of a wavelength. Such ELF signals, if radiated, will penetrate to great depths in the ocean without appreciable attenuation.

Pre-Sanguine History

Historically, it is interesting to note that Tesla (*2*) proposed the use of such signals for worldwide communication in 1899. His experiments were conducted in Colorado Springs, under the sponsorship of J. Pierpont Morgan. On one occasion, his huge spark-gap transmitter drained off the whole output of the 60-hertz power supply from the city—to the chagrin of the residents.

The current Sanguine transmitting antenna is to be powered by a series of generators located along a parallel array of insulated cables buried at depths of the order of 2 meters. These cables are to be up to 200 km in length and "grounded" at their end points. In order to achieve omnidirectionality, a second array is envisaged, located at right angles to the first. The principle of operation of such ground-type antennas has been known for a long time. The basic theory goes back to Sommerfeld (*3*), who in 1926 published a treatise on the exact integral solutions for the fields of dipoles. Of course, the Sanguine antenna is not a hertzian dipole, but it can be conceived of as a superposition of such dipoles laid end to end. Actually, the radiation from such a structure was demonstrated by Beverage and his colleagues in the early twenties, and their results were published in an important but often overlooked paper (*4*). Contrary to simple intuition, such a grounded dipole radiates predominantly vertically polarized ground waves. In the "Beverage wave antenna," the excitation is of the nature of a traveling wave, so the pattern is directional. For a center-fed structure, the familiar figure-of-eight pattern results. The horizontally polarized radiation, while always present, is orders of magnitude smaller than the vertically polarized radiation—at least, this is the case for VLF and ELF. An interesting feature of these grounded antennas is that they radiate best over poorly conducting ground. In fact, the radiation field varies approximately as the inverse square root of the conductivity.

In the Sanguine system the ionosphere plays a dominating role. The vertically polarized radiation from the grounded antenna structure couples into the terrestrial wave guide formed by the earth's surface and the lower portions of the ionized layers in the upper atmosphere. As envisaged by Schumann (*5*), the whole air-earth-ionosphere space acts as a resonant cavity. The fundamental frequency is approximately 8 hertz when account is taken of all the complicating influences.

The propagation characteristics of ELF waves were exhibited in a study by Chapman and Macario (*6*), who used the audio-frequency electromagnetic signals from lightning as their source. Such signals, when received at a distance, are known as atmospherics, or simply "sferics." The manner in which the frequency spectra change with distance can be used to ascertain attenuation rates. Chapman and Macario found, for example, that at 100 hertz the attenuation rate was only of the order of 1 decibel per 1000 km of path length: Such signals will envelope the globe and lead to cavity-like resonances. Using more refined techniques involving observations at several stations, Jean *et al.* (*7*) confirmed these results. Only simple wave-guide theory was used to interpret these early data, but even then it was recognized that a model of a homogeneous, sharply bounded isotropic ionosphere was not adequate. Thus, Wait (*8*) introduced exponential models for the electron density and considered the influence of the earth's magnetic field and antipodal focusing effects. A more refined exponential model was then considered by Galejs (*9*), and related investigations followed in the next decade (*10*). A major advance in our understanding of the propagation phenomenon is due to Jones (*11*), who provided definitive information based on careful measurements of the field strengths of naturally occurring signals in the ELF range. He has established the validity of the simplified single-mode wave-guide theory that has been so widely used.

Project Sanguine History

The extensive engineering development of the Sanguine system to exploit the characteristics of ELF radio waves was unknown to the public (and to me) until 1971. On 14 May of that year Senator Gaylord Nelson of Wisconsin reported to the Senate that the Navy had begun work on the Sanguine project in 1959. A description of the system and its objectives appeared in the *Congressional Record* on 17 May 1971 (*12*). Appended was a digressive analysis by A. W. Biggs, who called into question the technical feasibility of the system. Since that material has appeared, the criticism by Biggs has stimulated a good deal of discussion. At this juncture I would like to point out that, because of a misquotation from my work (*12*, reference 37) Biggs's estimates of field strength were low by a factor of about $\lambda/(8h)$, where λ is the operating wavelength and h is the height of the ionospheric reflecting layer. At 45 hertz this factor is approximately 10 (or a factor of 100 in power). In addition, he chose a pessimistic estimate of the effective ground conductivity that could easily change the factor of 10 to one of 40 or more.

A strongly worded criticism of the whole Sanguine project then appeared. McClintock, Rissman, and Scott (*13*) claimed to have shown that a communication system of the Sanguine type would have an excessively slow message rate, or would require an excessive amount of input power. Also, they argued that the power required to jam a Sanguine system would likely be less than the power needed to operate such a system.

Presumably in response to these criticisms of the Sanguine system, the Navy Department, in accordance with Senator Nelson's recommendations, asked the National Academy of Sciences (NAS) to conduct an impartial study. A summary report of the study has now been released (*14*). On the basis of evidence supplied by the Navy, the NAS panel concluded "that the Sanguine system contemplated by the Navy would work substantially as they anticipate." This endorsement was somewhat qualified by the following three recommendations:

1) A generally acceptable theory of the propagation of ELF waves is needed. It should be capable of assessing the worldwide distribution of field strength for a graded ionosphere under the influence of the earth's mag-

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netic field, taking account of day and night effects and of the effects of polar and other disturbances. The theory should also be capable of assessing the degree to which energy leaks into the magnetosphere.

2) There should be systematic, long-term studies of the variability of ionospheric properties likely to influence ELF propagation of signal and noise.

3) A paper should be published describing the application to Sanguine of the theory of buried long-wire antennas.

It is unfortunate that some of the crucial unclassified Navy documentation was not included in the NAS report. For example, Burrows and Niessen of Lincoln Laboratory at Massachusetts Institute of Technology have supplied the panel with a summary of the design principles (*15*). In particular, they replied to criticisms dealing specifically with (i) the signal propagation, (ii) the atmospheric noise level against which the system must operate, (iii) the reliability (error rate) of the messages, and (iv) the susceptibility of the system to jamming. Of special interest in the Lincoln Laboratory report is the summary of the extensive ELF propagation data obtained from the Sanguine test facility in Wisconsin. The propagation attenuation rates here, unlike those connected with the "sferics" studies, could be obtained without assumptions about source spectra and the nonreciprocity of the propagation. I was gratified to see that the "Wait model" held up so well. The Lincoln Laboratory report also contained a cogent discussion of the theory of propagation along buried insulated antennas.

The NAS report also contains a supporting discussion of the relevant quasi-static antenna theory. Many of the basic ideas go back to the pioneering investigations of the mutual impedance of grounded circuits, carried out at Bell Telephone Laboratories during the 1930's. An excellent summary of this work has been given by Sunde (*16*), who himself contributed greatly to the subject. The NAS panel emphasized this basic reference in spite of the fact that Sunde was not specifically concerned with radiation and propagation.

In disagreement with the conclusions of the NAS panel was C. W. Harrison, one of the original panel members, whose dissenting opinion appeared in the *Congressional Record* (*17*) before the NAS report was released. An account of this episode also appeared in the *New York Times* (*18*), where it was reported that Harrison "questions the adequacy of the studies thus far made regarding the feasibility of the Sanguine antenna. . . ." Harrison is concerned about some of the basic premises, such as the assumption that the earth is a homogeneous half-space, with conductivity of the order of 10^{-4} mho/m. He is also worried about the shunting effect of the insulation capacitance of the antenna wires. In general, he thinks that the present test facility, where elevated wire conductors are employed, is not representative of the contemplated system involving a massive buried array of insulated wires.

Many of Harrison's criticisms are answered, at least in part, in the unclassified series of Lincoln Laboratory reports, which were presumably made available to the NAS panel members. Certainly, a rigorous theory to account for all the second-order effects is not yet available. Contrary to the conclusions of the NAS panel, I believe that much more theoretical analysis is needed before we understand the operation of finite insulated antennas immersed in dissipative and inhomogeneous mediums. For example, the problem has been shown to be complex for even a two-dimensional model (*19*), and this is only a prelude to what needs to be done for structures of finite length with specified terminal conditions. Analytical studies of finite insulated structures in lossy mediums of infinite extent have been considered by King (*20*) and his associates at Harvard. This work deserves special attention in the context of Sanguine.

Other Unresolved Technical Issues

Another technical controversy has to do with the proper method of analyzing the ELF propagation for a realistic ionospheric model with a diffuse lower boundary. A report by Johler and Lewis (*21*) appears to lead to predictions of field strengths of the order of 20 db less than those obtained in other similar analyses. Since Johler and Lewis used a zonal harmonic series method, it is difficult to compare their steps with those of others. Galejs (*22*), however, concludes that the calculations of Johler and Lewis for a sharply bounded model are consistent with other results. But he argues that discrepancies arise for the stratified model when they introduce a complicated sequence of reflection and transmission coefficients for the various layers. Moler (*23*) independently comes to similar conclusions (*24*). I also questioned the results of Johler and Lewis when I found that their attenuation rate was consistent with results for similar models, whereas, for the stratified model, the field strength was reduced by about a factor of 10. Curiously, their graph of field strength as a function of distance (*21*, figure 8) suffers a very rapid decrease for very short ranges. It is possible that here the summation errors in the zonal harmonic method may be greatest. I suggested (*25*) that the Johler-Lewis formulation be converted, through a Watson transformation, to a residue or modal series representation. Terms of the latter can be more readily compared with terms obtained in other analyses. This might be a worthwhile task, although the prediction formulas currently in use, which are based on the simpler models, agree well with experiments.

I also believe that the ground conductivity question has not really been resolved. While the bedrock of Wisconsin is primarily a Precambrian metamorphic-igneous complex consisting of granites, there may also be more conductive rocks, such as schists, in addition to localized mineralization. Also, the surface layers may become quite conductive after heavy rains and spring thawing. While an effective conductivity may be measured and interpreted by a conventional geophysical probing method, the result may not be directly applicable to Sanguine. What seems to be needed is a deep-probing technique involving the measured time-domain fields from a long pulse-excited cable, or some equivalent method involving a controlled source. Such techniques have enjoyed considerable success in explorations for deep mineral and oil deposits, particularly in the Soviet Union (*26*). In the interpretation of the results, account should be taken of the lateral inhomogeneities of the crustal structure. In fact, it may well be that the deep, highly resistive layers in the crystalline basement will be overlooked in conventional probing methods, such as four-terminal resistivity and magnetotelluric techniques. Some of these problems are summarized in two monographs (*27*), and in a survey of the literature on the electrical properties of the earth's crust (*28*). Recent technical developments and detailed descriptions of the design approaches of Sanguine have been published in the proceedings of a symposium (*29*).

In discussing the technical issue, I

have said nothing about the strategic value of such a system. The interested reader may wish to examine the arguments put forth by Scoville (*30*), who points out that a demonstrated ability to retaliate is the clue to a stable strategic balance. The specter of the Sanguine project has raised the ire of environmentalists and conservationists in Wisconsin. The environmental aspect is not the subject of this article, but it is safe to say that the envisaged field strengths, even within 100 km of the antenna, will not be harmful, although it may be necessary to mitigate interference with power and communication lines. This subject was discussed at the Newport symposium (*29*).

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Electronic Characterization of Solid Surfaces

Determination of the energy levels of electrons at surfaces is now possible over a wide energy range.

Homer D. Hagstrum

The essentially two-dimensional surface of a solid may reasonably be thought of as a distinguishable phase of matter. Although attached to a bulk solid, its characteristics may depart considerably from those of a simple termination of the solid lattice. When certain strongly bound foreign atoms, for example, are present on a surface, the surface can resemble an ordered array of molecule-like structures. On the other hand, weakly held adsorbates will, at sufficiently high temperatures, be very mobile over the surface.

This is a time of increasing interest in fundamental studies of surfaces. Many new experimental tools needed for the basic characterizations of solid surfaces have been devised within the last decade. Such an increase in surface studies is clearly justified since many phenomena which occur at solid surfaces are of very great importance to mankind. Heterogeneous catalysts, corroding solids, as well as many solid-state electronic devices and biological systems will be understood in a fundamental way only insofar as we understand basic surface phenomena. Furthermore, the conceptual structure that is emerging from basic surface studies, in addition to specific facts, should be of great value in the characterization of more complicated phenomena in which solid surfaces play an important role.

Surface Definitions and Terminology

The surface of a solid may be defined as the outermost atomic layer including foreign atoms absorbed into it and those adsorbed to it (Fig. 1). The surface is attached to what has been called the selvedge (*1*). This is the near-surface region of the solid, and it differs from the deeper, bulk solid by virtue of its proximity to the surface. According to common nomenclature, the attachment of a foreign atom to the surface monolayer of which it is not a part is termed surface adsorption. I shall use the term surface absorption to mean the incorporation of the foreign atom into the surface monolayer either substitutionally where it replaces an atom of the host lattice, or interstitially, where it lies between but in approximately the same plane as the surface substrate atoms. Moreover, foreign atoms can be absorbed into the selvedge or bulk either substitutionally or interstitially as shown in Fig. 1. The atomic "traffic" in both directions between surface and selvedge is often very important in surface studies.

If one views a surface face-on, its two-dimensional structure becomes apparent. In Fig. 2 the surface atoms of the (100) face of a face-centered cubic crystal are shown as open circles. The

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