"Electromagnetic Pollution Measurement"

Almost overnight, pollution has become a common household word. Although water and air pollution have received the lion's share of attention, electromagnetic pollution is an area that is also of great potential importance, but that is as yet largely undefined. Ultimately, control of electromagnetic pollution is certain to become necessary. However, before it can be controlled, we must first be able to measure it.

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Pollution of our rivers, lakes, and atmosphere has occurred gradually during a period of many decades. The utilization and pollution of the electromagnetic spectrum, however, is a phenomenon of only the past two decades. Although one may argue about the current extent of electromagnetic pollution (EMP), few would disagree that, at the rate at which spectrum users (and abusers) are proliferating, electromagnetic pollution has become a very real problem.

Before proceeding further, let us define our use of the term "pollution". As employed here, "pollution" is taken to mean any disturbance of the natural environment that may produce an adverse effect upon some portion of the total ecological system. In this context, that which may be considered as pollution depends upon the specific area of concern, and upon one's particular viewpoint. Thus, the FCC may consider as pollution any unauthorized electromagnetic radiation that lies within its spectrum of assigned frequencies. A biologist, on the other hand, may regard perfectly legal and authorized electromagnetic radiation as pollution, if it has an effect upon the organ or organisms with which he is concerned.

"Electromagnetic pollution" (EMP), then, can have a variety of meanings to different people, depending upon the particular aspect of EM radiation that may have some effect upon their specific area of concern. Moreover, with our present limited knowledge of the subject, that which may properly be termed EMP is the subject of some very lively—and often heated—discussion, debate, and argument.

Electromagnetic Pollution

There are, in general, three basic areas of concern associated with electromagnetic pollution. Heretofore, they have been separated from the standpoints of management, measurement, and abatement. The first area, that has received the most discussion and study, is that of spectrum conservation and frequency measurement. Those who are concerned with spectrum conservation have long advocated strong management concepts and principles in the areas of frequency assignments, suppression of unintentional radiators, and maximum usage of the available telecommunications spectrum.

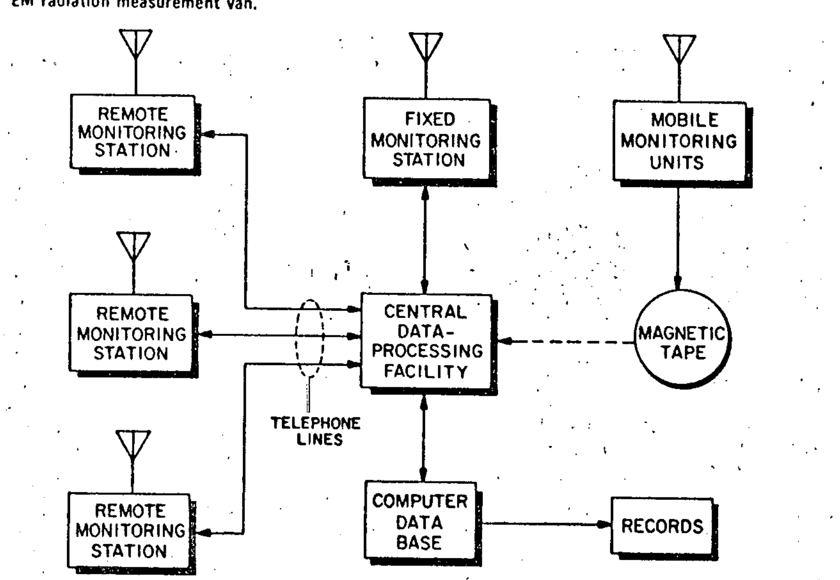
Although there is—as there should be—great concern for spectrum conservation, this represents only one aspect of the electromagnetic pollution problem. Another aspect is that of electromagnetic energy levels. In general, we are concerned with electromagnetic energy in free space, and we may thus discuss power density. Those who have been active in areas that deal with problems such as radiation hazards and electromagnetic compatibility have concerned themselves with the power densities associated with electronic and electrical equipment.

The third aspect of concern with respect to EM pollution is that of exposure, or time. In general, electromagnetic radiation as a function of time is expressed in terms of frequency, and these relationships have been thoroughly studied and are well known. However, the question of long-term exposure to EM radiation has not been explored to nearly the depth of the spectrum-occupancy and power-density investigations.

Who Is Concerned with EMP?

Among those who have been involved with EMP measurements during the past decade are both government agencies and private organizations. It was a natural extension of the Department of Defense's electromagnetic compatibility program, that has been in effect for a number of years. Much of the technology and know-how that is being applied and will be applied to the EMP problem was developed as a result of DoD electromagnetic compatibility programs. One DoD division, the Electromagnetic Compatibility Analysis Center (ECAC), maintains a detailed data base of electromagnetic emitters from which a number of problems relating to known EM energy sources can be solved. ECAC has supported the Department of

Fig. 1. Basic block diagram of an electromagnetic pollution-monitoring system. This system includes remote, unmanned monitoring stations, a central data-processing facility, a fixed station, and a mobile EM radiation measurement van.



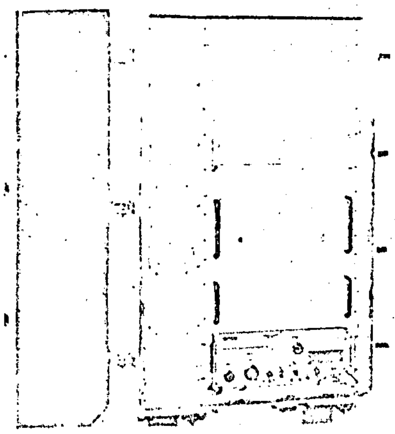


Fig. 2. Remote monitoring system developed for NASA by Fairchild/Electro-Metrics Corp., used to monitor EM environment at the John F. Kennedy Space Center. The calibrated system measures the local EM spectrum, and transmits data to a remote monitoring station via telephone lines. It selects the proper antenna and pre-selection shoulder for the frequency range of interest automatically.

Health, Education, and Welfare, Bureau of Radiological Health, in its studies program on electromagnetic or non-ionizing radiation effects.

The Bureau of Radiological Health (HEW) has conducted a number of studies and funded a study for EM environmental ambient measurements. These studies have included measurements on microwave ovens, power-density measurement instrumentation, radio transmitters, etc.

The Federal Communications Commission (FCC) has long been concerned with sources of electromagnetic energy—both intentional and unintentional. It has the regulatory power both to control the manufacture of electronic devices that emit electromagnetic energy, and to deny the right to operate those devices that encroach upon the lawful use of the electromagnetic spectrum. The FCC has funded a number of studies concerned with spectrum management, and has recently pursued actively what is termed "channel occupancy management", which relates to the percentage of time that assigned frequencies are utilized. A currently prevalent belief holds that there is a tremendous waste of electromagnetic spectrum, because many assigned frequencies are in use for only a small percentage of the available time.

The automobile manufacturers have also conducted studies and funded programs [1] to evaluate the contribution of automobiles to the overall electromagnetic environment. As a result of these studies, the amount of electromagnetic energy emanating from an automobile has been reduced to the point where most new vehicles conform to SAE standard No. J551a—a self-imposed standard on radiation from vehicular ignition systems. [2].

Recently, the medical community has also shown much interest in electromagnetic energy, due largely to:

- Problems associated with electronic heart pacers;
- Reports concerning the effects of EM radiation upon humans, published by Russian scientists [3]; and
- EMI problems associated with hospital equipment.

In the U.S., it has generally been considered that only the thermal effects of electromagnetic radiation are of biological significance. However, in the U.S.S.R., the non-thermal effects are believed to be most significant, and they have been investigated in some detail. It has been found, for example, that radio frequencies can have a depressing action upon the central nervous system, resulting in fatigue, headaches, and sleepiness. In addition, it has been found that preparations such as blood tissue, cultures, and micro-organisms, that exhibit higher coefficients of microwave absorption than other media, may be subjected to micro-heating effects, when macro-heating of the entire medium is not noticeable.

Standards and Legislation

Volume 35, No. 100 (Friday, May 22, 1970) of the *Federal Register* [4] contained a new standard on microwave ovens. Under paragraph 87.212, "Performance Standard for Microwave Ovens", it is specified that ". . . the power density of the microwave radiation emitted by microwave ovens shall not exceed 1 milliwatt per square centimeter at any point 5 centimeters or more from the external surface of the oven, measured prior to sale or purchase, and thereafter, 5 milliwatts per square centimeter at any point 5 centimeters or more from the external surface of the oven". Although this standard deals with only one device—the microwave oven—it does represent a beginning of legislation concerned with electromagnetic energy radiation.

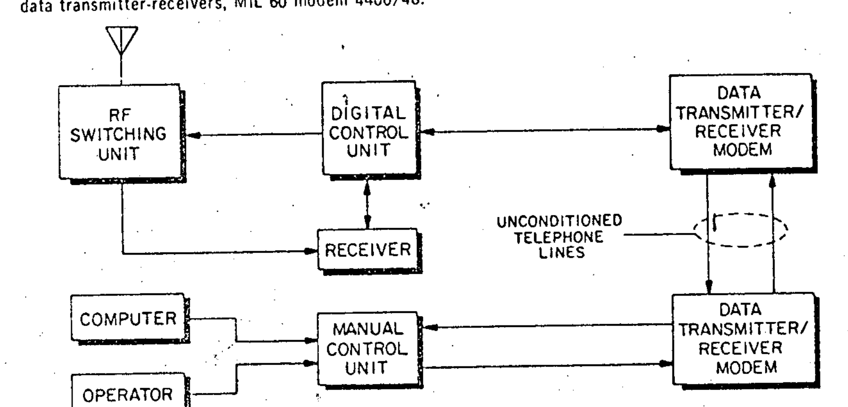
Another important piece of legislation dealing with electromagnetic radiation—Public Law 90-602 [5]—amends the Public Service Act to provide for the protection of the public health from radiation emanating from electronic products. This act gives the Department of Health, Education, and Welfare the authority to regulate the manufacture and use of electronic products that radiate electromagnetic energy that can endanger the public health. It includes "development and administration of performance standards to control the emission of radiation from electronic products, and the undertaking by public and private organizations of investigation into the effects and control of such radiation".

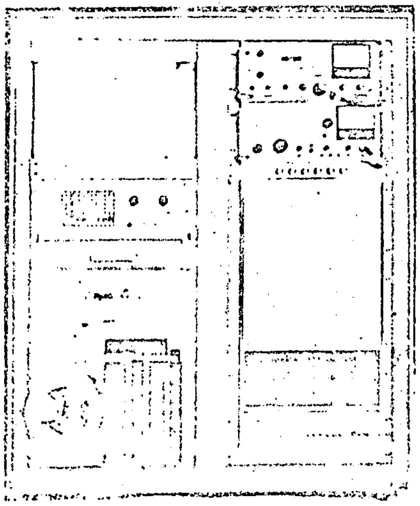
Monitoring Requirements

Electromagnetic energy in free space is measured in terms of power density (in MKS units), expressed as watts per square meter. Although the term "peak power" is sometimes used to represent instantaneous power, it is more appropriate to identify instantaneous values in terms of field intensity, expressed in volts per meter. By definition [6], the power of radiated electromagnetic energy is its equivalent heating value (in watts), and field intensity is the electric force per unit positive charge (newtons per coulomb).

To define an electromagnetic field adequately, one must determine both the power density and the peak field intensity. Both are important. For instance, some devices and/or human organs are affected primarily by the long-term-power effects of electromagnetic radiation—e.g., the classical examples of cataracts, sterility, and burns. Conversely, other devices, such as heart pacers and artificial hearts, as well as or-

Fig. 3. Block diagram of the remote monitoring system shown in Fig. 2. In this particular system, the specific units used were: computer, Hewlett-Packard 2116B; manual control unit, Fairchild MCU-25; digital control unit, Fairchild DIU-25; receiver, Fairchild EMC-25R; RF switching unit, SU-125; and data transmitter-receivers, MIL 60 modem 4400/48.

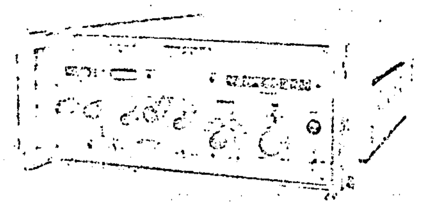




gans and nerve systems, may be affected adversely by less than so-called "hazard-level" fields. They are sensitive to non-heating effects, which are a function of peak field intensity. Therefore, any monitoring system intended to assess the effects of electromagnetic pollution must provide data concerning both power density and peak field intensity.

Knowledge of the time-dependence of the EM environment is equally important. The ideal EM pollution measurement system, then, would assess the entire frequency range of interest—from sub-audio frequencies to millimeter waves—and would provide a total field-intensity and power-density measurement. Practically, however, it is difficult to perform measurements over frequency ranges of even one octave, although some relatively insensitive systems have been built to operate over decade ranges of frequency.

To circumvent the problem, one can break the total spectrum into a number of discrete sectors. Then, from a knowledge of the power density and field intensity in each sector, one can determine not only the power-level environment, but can also assess another aspect of the EMP problem—i.e., spectrum occupancy.



◄ Fig. 4. Computer-controlled, fixed-station installation, used for spectrum-surveillance and EMC purposes. The system employs two Fairchild/Electro-Metrics receivers—an EMC-10 and an EMC-25—and a Hewlett-Packard 2116 computer. Fig. 5. The Fairchild/Electro-Metrics Model BRT-35 receiver, that is the heart of the mobile measurement van. This broadband, digitally controlled receiver is intended to provide a wide range of amplitude information, and to perform accurate frequency measurements as well. ▲

Breaking the frequency spectrum into discrete portions affords two measurement choices: one may scan a window across the spectrum, as is normally done with conventional receivers; or, one may detect all frequency windows simultaneously in real time. The latter approach, which is prohibitively expensive, is currently neither practical nor economical for a measurement system that must operate throughout the entire frequency range of interest.

A more practical and interesting compromise is to use several receivers that scan the spectrum randomly, employing variable bandwidths. Using a statistical approach with a system of this type, the intercept probability becomes usefully significant, so that measurement accuracies can be improved and errors reduced by orders of magnitude over those achieved with conventional receivers and spectrum analyzers. Thus, a monitoring system that measures power density and field intensity in randomly selected bandwidths, and at random frequencies, will enhance significantly the information-gathering capability of the system.

Instrumentation Requirements

One of the principal requirements of any pollution-monitoring system is that it be both controllable by and compatible with computers—both small and large. To conceive of a manually operated and controlled pollution-monitoring system would be a ridiculous mistake. The huge amounts of data accumulated in only a few days of measurements would, without computer assistance, require many months of effort merely to reduce the data—which would completely defeat the purpose of the system. To be useful, the system should be capable of providing semi-real-time data (i.e., with only a short processing delay) concerning the EM environment, and should include the ability to detect undesirable radiation.

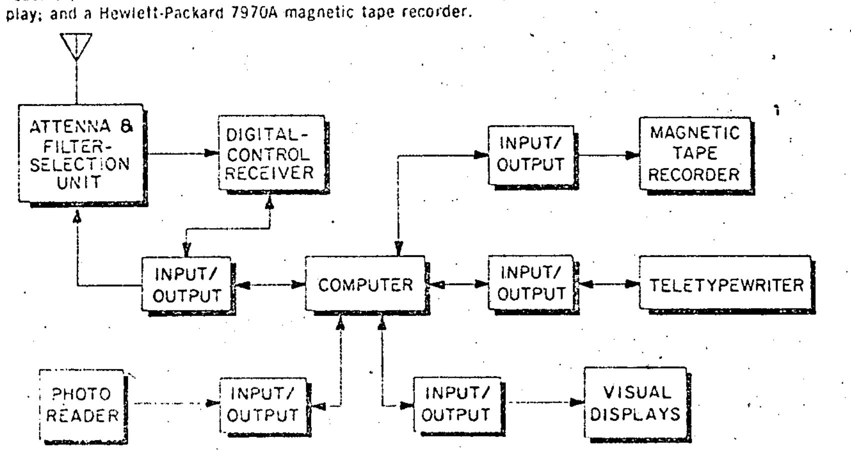
An important feature of an EM radiation monitoring system is that it be able to monitor radiation at remote locations, and to transmit its data (either "raw" or pre-processed) back to a central processing facility. Figure 1 shows the block diagram of a basic system that includes a central data-processing facility, a fixed monitoring station (that may coincide with the processing facility), several remote monitoring stations linked by means of telephone lines, and a mobile monitoring unit that stores its data on magnetic tape for later processing by the central facility. In this case, all monitoring stations are capable of measuring the total local EM environment.

A considerable amount of work has been done under government contracts funded by the Department of Defense, NASA, and other agencies, that is applicable to the EMP monitoring system described. For example, Fig. 2 shows a remote monitoring system [7] used by NASA at the John F. Kennedy Space Center to monitor the electromagnetic environment at a launch complex from a remote site, such as a van or a launch control center. Figure 3 shows the block diagram of the remote monitoring system of Fig. 2.

Figure 4 shows a computer-controlled, fixed-station installation that is in common use for spectrum surveillance and electromagnetic compatibility work. Representative of the current generation of computer-operated ground stations, it can be adapted readily to the monitoring of electromagnetic pollution. In this system, all receiver functions are under direct control of the computer.

For mobile-measurement purposes, the Federal Communications Commission recently entered into a contract with Fairchild/Electro-Metrics Corp. for the design and construction of a mobile measurement van, capable of monitoring spectrum occupancy in the land mobile communications bands. The system, as constructed, consists of

Fig. 6. Block diagram of a mobile electromagnetic radiation measurement system. Included among the components of the particular system described in the text were: a Fairchild BRT-35 digital-control receiver; a Hewlett-Packard 2116B computer; an ASR-33 Teletype unit; a Fairchild CXY-300 visual display; and a Hewlett-Packard 7970A magnetic tape recorder.



a broad-range, variable-bandwidth receiver (shown in Fig. 5), an on-board computer, a magnetic tape unit, and video display systems.

The block diagram of the system is shown in Fig. 6. All system components are controlled by a computer that functions as the system supervisor. The system automatically selects the appropriate bandwidths, antennae, and displays for the frequency range to be monitored. It operates over the frequency range from 5 kHz to 1 GHz—which can be extended to 40 GHz. Data are stored on magnetic tape, and then taken to a batch-processing facility for later data reduction and analysis.

Displays are provided for both channel occupancy and channel spectrum. System operation is controlled by means of either a Teletype unit or a paper-tape reader. Programs stored on paper tape can be entered into the system readily, to effect rapid changeover of operation. The entire system is installed in a mobile camper-type vehicle. In the SCAN mode, the system detects and records the peak signal amplitude in each channel as it is sampled. Since processing time is available, channel occupancy is readily determined, and the data recorded.

Channel-occupancy data can be updated during each scan through a block of assigned channels. As each is sampled, its occupancy is determined, and a number corresponding to either an occupied or unoccupied channel (as appropriate) is added to the occupancy record for that channel. These stored data can then be normalized, by means of scan number, to produce a record of percentage occupancy for each channel during the time interval when it was being observed. These occupancy data, stored in the computer working memory, are then recorded on the magnetic tape, following completion of the last scan for a particular block of frequencies. Thus, a scan for a given five-minute period, for example, produces a record on the magnetic tape that consists of a relatively long profile of amplitude as a function of channel and of time, followed by a relatively brief profile of channel-occupancy data.

In the MONITOR mode of operation, the system monitors a single channel at a high sampling rate. This optional mode of operation can be implemented quite easily by means of minor programming, and is very useful for determining precisely the percentage of time that a particular channel is occupied. Such information can be especially significant for certain specific channels, such as emergency channels and, or channels that exhibit or are subject to unusual occupancy conditions.

Suitable central data-processing facilities are already available and in operation. It remains, then, only to interconnect building-block units—i.e., remote monitoring stations, fixed monitoring facilities, and mobile units—into a complete EM pollution monitoring system. Once such a system is fully operational, a suitable data base can be developed, and the system modified accordingly to provide an adequate safety margin.

Future EMP Needs

Since electromagnetic pollution is a relatively new addition to the overall environmental ecology problem, it has not yet been adequately studied, nor has it received the funding necessary for intensive investigation. From only a cursory examination of recent electromagnetic-energy-source proliferation, one must conclude that the most desirable first step toward EMP control would be an abatement program. However, such a program can be of value only if a sufficiently defined end goal is envisioned. At the present time, it would be virtually meaningless to establish purely arbitrary limits for electromagnetic energy levels, although some limits have already been established in certain areas—such as hazardous heating levels—where more information and experience are available.

The area that most needs to be investigated and defined at this time is that of the non-thermal effects of electromagnetic energy upon the human body. Another related question deals with the possible hereditary effects of EM energy. Since the population has been exposed to high levels of such energy over broad ranges of frequency only since slightly before World War II, we have no real multi-generation data files for comparison. A study based upon animals—particularly those that reproduce rapidly—might help to provide data in this area.

Currently, engineers and designers working in a number of disciplines—such as the design of biomedical elements (e.g., heart pacers, artificial hearts, limb stimulators, etc.), electric automobiles, police communication networks, power-distribution systems, etc.—must work without the support of even a first-order approximation of the electromagnetic environment in which their equipment must "live" and operate. Computer users often complain about loss of memory caused by what they term "spikes" on their power lines, policemen complain about a lack of communications during riots, and hospital technicians report "arcs" when they interconnect equipment.

Although these problems are not necessarily as catastrophic as that of the heart-pacer user who suffers fibrillation because his pacer is overridden or loses control, they are, nonetheless, very real EMP problems. They will have to be solved if we are to continue our pace of development in the electronic age.

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