NATIONAL BUREAU OF STANDARDS

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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Proceedings of the 1978 Electromagnetic Interference Workshop

NATIONAL BUREAU OF STANDARDS

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[1]Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington,D.C. 20234.
[2]Some divisions within the center are located at Boulder, Colorado, 80303.

The National Bureau of Standards was reorganized, effective April 9, 1978.

Proceedings of the 1978 Electromagnetic Interference Workshop

Proceedings of a Workshop held November 2-3, 1978
at the National Bureau of Standards,
Gaithersburg, Maryland

Edited by:

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EDITOR'S PREFACE

The National Bureau of Standards sponsored the second Electromagnetic Interference Workshop at its Gaithersburg, Maryland, laboratories on November 2 and 3, 1978. This proceedings is a report of that workshop.

The objective of the 1978 Workshop was to address current and future EMI technical problems and regulatory actions, and to explore potential solutions and what is needed for progress. To do this effectively required the meeting together of decision-makers from both industry and government. A workshop format was chosen as the best way to encourage dialogue among those who produce and experience electromagnetic interference, those who attempt to control and regulate interference through legislative and technological means, and those who write standards of various types that impact the problem of interference.

The workshop program was divided into two broad categories: Plenary sessions and working-group sessions. Plenary sessions were characterized by overview speakers selected to cover the main concerns of the workshop. Working-group sessions were characterized by the concurrent but separate meeting of five topical groups in a less formal setting. The five topic areas were: Communications, transportation, consumer products, industrial, and medical.

Altogether, 206 persons registered for the workshop. A wide range of organizations and disciplines were represented.

To what extent the workshop was successful has yet to be determined. Certainly, the objective of providing a forum for discussion was met. Some attendees expressed satisfaction with the endeavour; others expressed mixed feelings of various kinds. In any event, herein is a record of what transpired, as provided by the summary materials of the overview speakers and working-group chairmen.

ACKNOWLEDGMENTS

The 1978 Electromagnetic Interference Workshop was organized at the suggestion and with the support of Dr. John W. Lyons, Director, National Engineering Laboratory, NBS. The workshop committee consisted of the following persons:

C. K. S. Miller, Chairman
Wilbur J. Anson, Vice-Chairman
Dee Belsher, General Arrangements
JoAnn Lorden, Local Arrangements
Frederick P. McGehan, Publicity
Robert E. Nelson, Finances
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Myron L. Crawford, Program Development
Harold E. Taggart, Program Development
Shirlee A. Brubaker, Workshop Secretary

Special acknowledgments go to the overview speakers and the session developers who carried out the plan of the program.

Photography is provided by the editor.

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   Washington, D.C.

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Organizer: John P. Murray
National Telecommunications and Information Administration
Boulder, Colorado

Panel Members:
D. D. Crombie, National Telecommunications and Information Administration
N. N. Hankin, Environmental Protection Agency
Jeffrey Krauss, Federal Communications Commission
R. J. Matheson, National Telecommunications and Information Administration
Jeff Young, Federal Communications Commission
J. A. Zoellner, Electromagnetic Compatibility Analysis Center

2. Transportation

Organizer: Ronald J. Wasko
Motor Vehicle Manufacturers Association
Detroit, Michigan

Invited Speakers:
Session I: Warren Kesselman, Department of the Army
Joe Kindermann, General Motors Corporation

Session II: Fred Bauer, Ford Motor Company
Myron Crawford, National Bureau of Standards

Panel Members, Session III:
Comprised of the above speakers

3. Consumer Products

Organizer: W. Thomas Collins
RCA Corporation
Indianapolis, Indiana

Panel Members:
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Harold Anderson, Litton Microwave Products
Sally Browne, Electronic Industries Association
Robert Grant, Magnavox Company
Erika Jones, Federal Communications Commission
Paul Ruggera, Bureau of Radiological Health
Art Wall, Federal Communications Commission

Session II (joint with Industrial Working Group):
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4. Industrial

Organizer: George H. Hagn
SRI International
Arlington, Virginia

Panel Members:

Session I:

George Hagn, SRI International (chairman)
Frank Garlington, Sprague Electric Company
Hal Gauper, General Electric Company
Heinz Schlicke, Interference Control Company
Lou Shulman, Foxboro Company
Al Visek, Sperry Univac Company

Session II (joint with Consumer Products Working Group):

Ralph Showers, Univ. of Pennsylvania (chairman)
Tom Collins, RCA Corporation
Lou Schulman, Foxboro Company
Al Visek, Sperry Univac Company
Art Wall, Federal Communications Commission
Panel members from Consumer Products Working Group

Session III:

Mike Crawford, National Bureau of Standards (chairman)
Frank Garlington, Sprague Electric Company
Larry Middlekamp, Federal Communications Commission
Lou Shulman, Foxboro Company
Ray Vincent, Systems Control, Inc.
Al Visek, Sperry Univac Company

5. Medical

Organizer: James C. Toler
Georgia Institute of Technology
Atlanta, Georgia

Invited Speakers:

Session I:

Don Justesen, Veterans Administration
Leslie Hamilton, Health Industries Manufacturers Association

Session II:

Saul Rosenthal, New York Polytechnic Institute
Bob Flink, Medtronic, Inc.

Session III:

Bob Jenkins, Georgia Institute of Technology
Fred Cain, Georgia Institute of Technology

Abstract

This report is a summary of the overview talks and session discussions at the 1978 Electromagnetic Interference Workshop, held at the National Bureau of Standards, Gaithersburg, Maryland, on November 2 and 3, 1978. These discussions addressed the following questions: What are the significant Electromagnetic Interference (EMI) problems? How serious are they? Which should be tackled first? What solutions are practical? Who is responsible for solutions? What new standards or changes in present voluntary standards are needed? What is needed for progress? Impacted areas featured at the workshop included communications, transportation, consumer products, industrial, and medical. Workshop speakers and attendees represented a broad segment of decision-makers in both industry and government.

Key words: Electromagnetic bioeffects; electromagnetic compatibility; electromagnetic immunity; electromagnetic interference; electromagnetic radiation; electromagnetic susceptibility; electronic smog; home entertainment electronics; industrial electronics; medical electronics; microwave electronics; non-ionizing radiation; radiation hazards; radio regulations; radio standards; RFI; spectrum management; standardization organizations; telecommunications; TVI; vehicular electronics.

CHAIRMAN'S INTRODUCTION

Charles K. S. Miller
National Bureau of Standards
Boulder, Colorado

NBS organized the 1978 EMI Workshop to provide a forum by which managers and/or decision makers overseeing technical work within regulatory agencies, manufacturing industries, and users of electronics could be exposed to factors influencing their decision making. A large complement of the problems related to EMI are caused by decision makers not being aware of the extent of the problems that are caused by regulation, constrained by technical limitations, or affected by user practice. This fact was amply portrayed by several remarks made in the 1977 EMI Workshop (to which, unfortunately, there was no proceedings) that followed such patterns as: "I had no idea that regulations caused such problems," or "I had no idea there were so many new consumer products that could be affected by electromagnetic radiation," or "whose job is it to measure the EM environment and publish the results so that products can be made compatible to local environmental conditions?"

It is the purpose of this Workshop to establish dialogue between various groups and to surface problems that could be openly addressed. Through this process, we hope to uncover whether the constraints to technical progress are real or imaginary, negotiable or cast-in-concrete, economically viable or limited through legal constraints, etc. To this end we will address such questions as: What laws are pending that will affect decisions? What are our sacred cows? Do we have too much or not enough regulation of EMI? Can voluntary standards approaches replace regulation successfully? Do we need to establish an organization that could coordinate EMI laws, regulations, voluntary standards, and technical solutions? Do we have the technology (at least the measurement technology) to solve our EMI problems?

We deliberately decided not to rely on the DoD experience in this matter since they have a reasonably closed system in that they are their own regulator, specification writer, testing authority, and user. The civilian sector has a much more complex task because there is less unified control in the system. Presently, the civilian sector responds to Federal and state laws, regulatory authorities, voluntary standards groups, unknown or poorly defined environmental conditions, rapid changes in technology, public pressure, marketplace competition, unexpected or unintended applications of their products by users, and stockholders who demand a profit for their investment. In this setting, the EMI problem is often not accorded much attention until it becomes a pressing issue. It is now fast becoming a very pressing issue because of the proliferation of electronic hardware in a multitude of technologies, the increasingly costly or dangerous consequences of equipment malfunction, and the steadily increasing levels of non-ionizing electromagnetic radiation which can and does in some cases cause malfunction.

NBS sponsored this workshop because it is a neutral government agency and therefore has the ability to draw these various factions together. We expect to learn the measurement technology deficiencies inherent in regulation, manufacturing, and user applications. In this way, a more effective NBS program can be planned to address the national EMI measurement needs.

THE EXTENT OF TODAY'S EMI PROBLEMS
and
PRIORITIZING EMI PROBLEMS

Chris M. Kendall
Private Consultant
Running Springs, California

I am impressed and concerned with how enormous the electromagnetic interference (EMI) problems are at the present time, but the problems are still in their infancy by comparison with what they are going to be by the late 1980's. We are at the verge of the electronics revolution which, according to Business Week magazine, "... increasingly is being recognized as a force that will have a far greater impact on society than the industrial revolution had 200 years ago."[1] If this is true, the problems we will face in the 1980's will be more significant than those we now face.

Most of today's problems are solvable through education. The main reason products are produced today with potential compatibility problems is mainly a lack of education and understanding of the basic principles of crosstalk and rf transmission/reception by those who are designing many of the new microprocessor-controlled products for the consumer market and to some extent those making products for the commercial business sector. Most companies do not want to generate emission levels that could disrupt communication systems nor be susceptible to the same. However, through ignorance or inexperience, products are manufactured that do result in electromagnetic incompatibility. Fortunately, most manufacturers will take immediate action when it is discovered their equipment is generating a compatibility problem.

Under the heading of communication problems, we find that high effective radiating power levels do cause situations that can be classified as nuisance, as well as a potential hazard to life and property. High effective radiated power levels have resulted in electric toasters playing music and ungrounded steel structures causing electrical shock.

Under the heading of transportation systems are the well-known problems associated with anti-skid brake control systems. Rf radiation from citizens band (CB) equipment, taxi, police and fire department transmitters, and other commercial mobile sources becomes rectified to dc or is rf coupled into the anti-skid processor/logic circuitry causing either partial or complete brake disruption in the vehicle. There is also concern over the expected increased use of digital logic in the automobile for control of engine functions, and perhaps safety devices. The engine ignition and alternator, along with increased use of communication equipment such as CB VHF equipment and car telephones, do pose a significant interference potential if not adequately designed.

With regard to consumer products, the increased use of microprocessor-controlled home appliances and control systems together with home or personal

[1] Business Week, "Special Report," September 18, 1978, p. 69.

computers is a significant potential threat to home entertainment equipment. Interaction of processor equipment and television/stereo systems is fully expected. Harmonics of the clock frequency oscillator often fall precisely on a TV receiver frequency making it impossible to protect the TV set from the emitting source. The addition of filters on the TV set will suppress both the intended signal as well as the unintended signal of the computer.

The industrial world, including office and business equipment, has many areas of electrical interference concern. The broad use of distributed processing and processor-controlled equipment makes them susceptible to power line transients and external electric field radiation. The cable lengths involved are long and resonant at relatively low frequencies. The cables transmit the received power to the processor at levels above normal logic thresholds causing disruption in the equipment they control.

In medical electronics, the radiation levels, especially in hospitals, can be quite high, perhaps on the order of 15-20 volts per meter. Such levels, when picked up by the remote sense leads used to monitor body functions, can transmit this energy into wide bandwidth logic circuits, resulting in their malfunction. If the instrument is life supporting, personal injury could result. Better awareness of the levels expected, together with design guidelines, is needed as a supplement to any standards issued to insure maximum compliance.

The problems cited above all have technical solutions that would add little or no cost to the recurring price of the products if EMI suppression was considered in the design phase. Analysis techniques do exist that can predict both the amount of emission and the degree of susceptibility of a given product before it is committed to production. As a consultant, I have been using such analysis techniques for many years and recently have completed a systematic computer analysis approach called EMCad, standing for Electromagnetic Compatibility Analysis and Design. EMCad has reduced the cost of computer analysis for a given product to under a thousand dollars. Whether analysis or test methods are selected, the potential electromagnetic characteristics of a new product can be determined and solutions implemented.

As to priorities, our first concern should be with the intense radiation problem, especially where people can be injured. Second are those areas where huge numbers of electronic devices will be used such as consumer products and transportation systems using computers and microprocessors. But perhaps ahead of both of these comes the need for better education and understanding of the interference problem and how to design electronic equipment to bring the problem under control.

BIOLOGICAL ELECTRO-MAGNETIC INTERFERENCE (BEMI)

Don R. Justesen, Ph.D.
Veterans Administration Medical Center
Kansas City, Missouri

The controversy over biological effects of microwaves and other rf radiations has erupted from the laboratory to invade the public domain and is fomented by a curious mix of fact, speculation, and unfounded fancy. The fact: Soviet limits of occupational exposure to radiofrequency energy are three orders of magnitude more stringent than those recommended in the United States. The speculation: Soviet physicians have reported that a mild and reversible neuropsychiatric syndrome -- "neurasthenia" -- occurs in workers who labor for long periods in proximity to power lines, to sources of rf energy, and to generators of ionizing radiation. While any of a host of environmental (including physical, psychological and sociological) factors may be responsible for the headaches, insomnia, irritability, and impotence that symptomatically define neurasthenia, attempts have not been made to determine which of these factors is (are) responsible. Rather, the blame has been laid solely to electromagnetic radiation. The fancy: Some contributors to the popular media, who are scientifically and technologically naive but are highly skilled in communicating with and arousing the public, have unaccountably lowered thresholds and have raised the ante of morbidity. In pronouncements that leave even the most accepting Soviet pathologist perplexed and unaccepting, these authors are claiming that cancer, heart disease, blindness, and birth defects are the toll of electromagnetic fields at intensities that are well below those permitted in the Soviet Union.

One result of these developments has been to sharpen the boundaries--and the acrimony--that divide the two largest camps of radiobiological scientists: Those who opt for a traditionalistic, brute-force, unless-you're-burning-up-you're-safe approach, and those who entertain the possibility of weak-field interactions but are at a loss to specify the <u>modi operandi</u>. Ignorance of mechanisms of interaction militates against assessment of whether weak field effects are hazardous or not.

The boundaries between the scientific camps could be dissolved and their efforts more profitably directed toward real solutions by adoption of a two-fold working hypothesis:

1. <u>In simple and in complex organisms, biological receptors exist that are sensitive to weak electric and magnetic fields.</u> An abundance of data indicates that organisms that range from single-cell to the highest evolved are sensitive to properly modulated electric and magnetic fields. For example, bacteria migrate and fish and birds navigate in consequence of "signals" generated by the earth's natural fields. Other evidence indicates that natural fields regulate the biological clocks of mammals, including those of man. Since known (visual and acoustic) receptors are sensitive to energy transitions on the order of photon capture and Brownian movement, the assumption of EM receptors of rf quanta carries no burden of large-order

kinetic energy. The burden of Receptor Theory is the isolation and identification of sensitive substrates both anatomically and physiologically.

2. Artifically generated fields might constitute sources of BEMI. If the earth's natural electromagnetic fields provide signals that not only enable avian navigation but synchronize the mammal's biological clocks, it stands to reason that the coupling of artificially generated fields from power lines, and from radio and TV broadcasts, could act as a source of biological electromagnetic interference (BEMI). Desynchronization of biological rhythms--alteration of the electroencephalogram, upset of thermal tides, etc.--might be the physiological correlates of the neurasthenic syndrome.

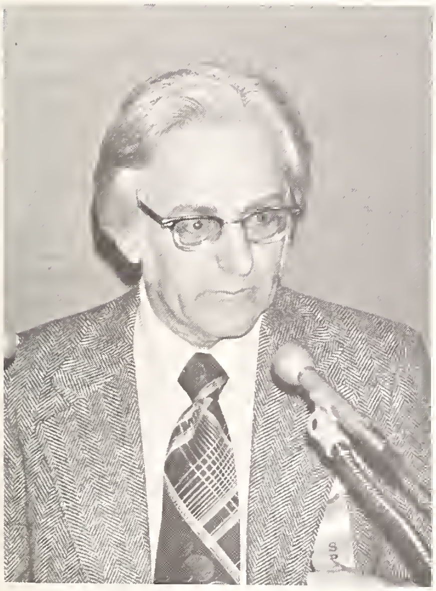
This two-fold assumption is not a conclusion, but a speculation; it is not a solution to a problem, only a paradigm that provides a rational means of attacking it. By placing biological experimentation on natural and artificial electromagnetic fields in the contexts of sensory physiology and signal-and-noise analysis, a new and more successful approach to an increasingly perplexing problem may be realized.

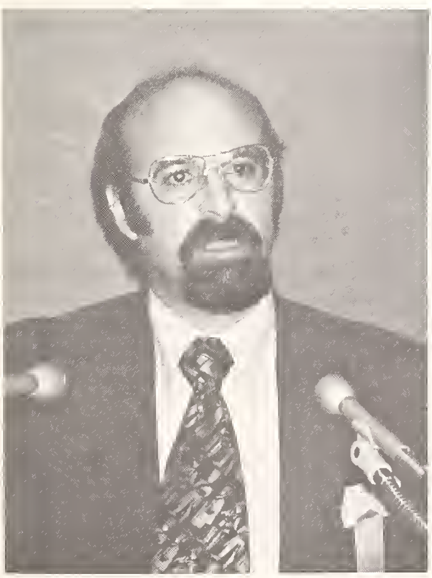
FCC ACTIVITIES REGULATING ELECTROMAGNETIC INTERFERENCE

Alvin W. Paul
Office of Chief Engineer
Federal Communications Commission
Washington, D.C.

and

Jeffrey Krauss
Office of Plans and Policy
Federal Communications Commission
Washington, D.C.





The compatibility of radio frequency emitters and electronic devices is a matter of prime concern to the Federal Communications Commission. Under the Communications Act of 1934, the FCC has statutory authority to minimize the electromagnetic interference caused by emitters, but has little control over non-emitters that are susceptible to EMI.

The FCC establishes performance standards for emitters as opposed to design methods or standards. Hopefully, this approach does not inhibit the diversity of supply, technological innovation, or the competitive structure of the electronic industry. Part 2 of the FCC Rules (47 CFR Part 2) defines parameters such as power, bandwidth, spurious emissions, frequency stability, and modulation characteristics. The actual limits prescribed in the Rules will vary, depending upon the specific requirements of each type of radio service.

Part 2 of the Rules contains the procedures for obtaining an FCC authorization for an emitter. There are three types of authorizations: Type approval, type acceptance, and certification. The specific kind of equipment determines which type of authorization is needed. For example, type approval is needed for microwave ovens, marine radar and wireless microphones that operate in the FM broadcast band. Type acceptance is generally required for transmitters intended for operation in any of the licensed services. Certification is required for field disturbance sensors, receivers designed to operate between 30 and 890 MHz, and CB receivers that operate at 27 MHz.

Type approval is the only form of equipment authorization requiring measurements performed at the FCC laboratories at Laurel, Maryland. Type acceptance and certification are both bilateral procedures that require manufacturers to submit measured data to support each application for an authorization. Our laboratory then performs an engineering evaluation of the data to determine compliance. In addition, we can request that the equipment be submitted to the laboratory to assure validity of the submitted data.

While the FCC has authority to establish standards for radio emitters, it does not have comparable authority to establish standards for electronic equipment generally. In particular, it does not have authority over electronic equipment that, through inadequate design, is susceptible to interference from legally designed and operated emitters. It is extremely difficult to convince a consumer that the interference he receives may be due to his own receiver, rather than a faulty transmitter.

Although there has been legislation introduced that would give the FCC authority to establish standards of interference immunity for electronic equipment generally, there is some concern that mandatory government regulation in this area might stifle technological innovation, adversely affect equipment performance, and result in inflationary price increases. Consequently, the FCC staff has developed a proposal for an Inquiry* into the entire problem of electromagnetic interference to non-emitters, which will examine alternative regulatory approaches. It is intended that this Inquiry be a formal FCC proceeding, to gather information to support possible regulatory or legislative initiatives in this area. The Inquiry will deal with five main areas: Consumer education, government regulation, economics, engineering, and manufacturing.

The area of consumer education appears to be critical. Will improved information help consumers make better purchasing decisions? Do consumers want a choice between more susceptible equipment and less susceptible equipment, and are they willing to pay higher prices for less susceptible equipment? We can speculate that manufacturers would build less susceptible equipment if consumers demanded it, and we hope the Inquiry will supply information either confirming or refuting this.

In the area of government regulation, we are seeking alternative approaches to assure electromagnetic compatibility. Such approaches might include voluntary industry self-regulation, mandatory government regulation, or some combination. We are seeking information on other programs that involve the establishment of performance standards for consumer products, to see whether those programs can be adapted to our needs. We are asking other government agencies to submit their views on matters of interagency coordination in areas such as research and development, and enforcement of "truth in labeling" laws.

Economic issues deal with questions of cost, pricing and industry structure. We are concerned not only with the cost impact of designing and building more immune electronic equipment, but also the cost impact of various alternative regulatory approaches. Do the administrative costs of regulation, associated with filling out and submitting forms and similar recordkeeping, constitute a significant burden? We are also concerned with whether alternative regulatory programs--mandatory or voluntary--will affect innovation, competition or diversity of supply in the electronic equipment industry.

Engineering issues deal primarily with characterizing the environment, developing performance standards, and developing equipment and methods to measure compliance. While the importance of modeling the electromagnetic environment is self-evident, it is not clear how detailed such models must be

* Editor's note: This became General Docket No. 78-369, adopted November 14, 1978, and released November 21, 1978.

or what organizations should have the responsibilities to develop these models. We are also interested in whether simple and inexpensive testing methods can be developed to test the susceptibility or immunity of electronic equipment.

In the area of manufacturing, we seek the estimates of equipment manufacturers as to the impact of immunity standards upon their products. For example, will more immune equipment perform its intended function better or worse than susceptible equipment? What methods, if any, do equipment manufacturers now use to reduce equipment susceptibility to interference? Is this area considered an important selling point to consumers in terms of advertising of immunity?

This Inquiry will ask some complex and far-reaching questions. It will itself serve as a vehicle for a consumer education program since it will be based on a document that will be widely distributed through public service groups, radio clubs, and retail stores. It is only through gathering information in this manner that the FCC can intelligently decide among the alternative regulatory approaches that have been suggested.

EMI/EMC LEGISLATION IN THE 95TH AND 96TH CONGRESSES

Dr. Charles L. Jackson
House Communications Subcommittee
Washington, D.C.

EMI/EMC legislative proposals surfaced twice during the 95th Congress. The first proposal to rise into sight was Senate Bill S.864 offered by Senator Goldwater. S.864 would have amended the Communications Act to allow the FCC to regulate the interference susceptibility of consumer electronic equipment.

Representatives Benjamin, Vanik, and Fisher all introduced similar legislation in the House. The Vanik and Fisher Bills differed slightly in wording from S.864. They would give the Commission the power to establish minimum performance standards for interference susceptibility. In contrast, the Goldwater/Benjamin language would allow the Commission to require protective components in consumer electronics equipment. This slight, but important, language difference should not obscure the fact that these bills serve the same policy objective--the elimination of interference from radio transmissions, mainly CB transmissions, to televisions, radios, and Hi-Fi systems.

The Senate Communications Subcommittee held hearings on S.864 on June 14th of this year. The Senators heard from a wide variety of government, industry, and citizen group representatives. Every major point of view seems to have been represented.

Senator Goldwater's opening statement explained both the technical and policy problems created by EMI and susceptibility legislation. In a personal aside, the Senator noted that as a radio amateur, he had been aware of this problem for a long time, and that the problem had gotten worse since the introduction of tubes, transistors, and integrated circuits! His statement made it clear that he wanted to see the EMI/EMC problem resolved, preferably without recourse to federal regulation, and that he hoped that the hearings would get manufacturers on the road to providing improved equipment.

The lead-off witness was FCC Chairman Charles Ferris who explained the FCC's views on both the legislation and on the susceptibility problem more generally. He pointed out that there are both technical and economic problems involved. He also touched on a number of other issues: Standards, characterization of the EMI environment, the impact of improved consumer awareness, and the possibility of recent changes in the susceptibility of newly designed consumer products.

Chairman Ferris concluded with the statement, "Whether or not the Congress decides to confer this authority at this time, the Commission will independently pursue, under its existing authority, the significant problem to which S.864 is addressed."

One week before the Senate hearing, Chairman Lionel Van Deerlin and ranking minority member Lou Frey of the House Communications Subcommittee introduced a bill, HR13015, the "rewrite" of the Communications Act of 1934. This major legislative proposal dealt with EMI and susceptibility issues with four non-traditional proposals.

Section 412(9) would require the regulatory commission to prescribe rules governing the interference potential of equipment. This language does not restrict the commission to regulating only the external effects of equipment. Thus, in essence, it is very similar to the proposals by Senator Goldwater, et al.

Section 412(10) would allow the regulatory commission to regulate the performance characteristics of television receivers. This language would subsume the 1962 All Channel Receiver Act and would eliminate the possibility of any law suits challenging the commission's authority to regulate TV receivers. It also includes, redundantly in light of 412(9), authority to regulate the susceptibility of TV receivers to EMI.

Section 707(b)(1) requires the director of the National Telecommunications Administration (NTA) to conduct a study to characterize the electromagnetic environment in the United States. And Section 707(c)(1) requires the director of the NTA to conduct a two-year study of problems and issues relating to the susceptibility of consumer electronics to EMI. HR13015 would authorize ten million dollars to be expended for those studies.

Thirty-three days of hearings were held this last summer and fall on HR13015. Four hundred and eighty-four witnesses appeared. However, relatively few of the witnesses commented on the EMI/susceptibility language. Predictably, television set makers opposed section 412(10). Radio amateurs supported the language of 412(9) and 412(10). The Motor Vehicle Manufacturers Association was, to the best of my recollection, the only group to comment on and support the EMI environment survey.

Current plans call for a "rewrite of the rewrite" to be prepared for introduction in late January or early February of 1979. So far, the EMI provisions of the rewrite seem to have stood up relatively well. I would be surprised if there were major changes in this area. However, the process is still open for suggestions, comments, and further input. Nothing is cast in stone. Your thoughts would be welcome!

VOLUNTARY STANDARDIZATION FOR ELECTROMAGNETIC COMPATIBILITY

Dr. Ralph M. Showers
University of Pennsylvania
Philadelphia, Pennsylvania

1. INTRODUCTION

The voluntary standardization effort in the electromagnetic compatibility field is extensive. The purpose of this presentation is to describe the scope of the effort, indicate what it has accomplished, and provide suggestions as to where it may lead in the immediate future. Because of the limited nature of this discussion, it is not possible to give complete details on the program. The details will be furnished to interested persons by the author upon request.

2. AMERICAN NATIONAL STANDARDS INSTITUTE

In many respects, the American National Standards Committee C63, Radio-Electrical Coordination, acts as a central coordinating body for the voluntary standardization effort in electromagnetic compatibility. The following are three of the purposes of the Institute as quoted from its Constitution:

"(1) To serve as the national coordinating institution for voluntary standardization and certification activities in the United States of America through which organizations concerned with such activities may cooperate in establishing, improving and recognizing standards, based on a consensus of parties-at-interest, and certification programs to the end that such activities remain dynamically responsive to national needs; that duplication of work is avoided; and that individual enterprise and initiative are encouraged.

(2) To represent the interests of the United States of America in international nontreaty standardization and certification organizations with which it is or may become affiliated.

(3) To serve as a clearinghouse for information on standards and standardization and certification work in the United States of America and abroad."

It carries out these purposes primarily through the authorization of "American National Standards." With regard to this approval procedure, it should be noted that, "The approval of a standard by the Institute implies a consensus of those substantially concerned with its scope and provisions. In standardization practice a consensus is achieved when substantial agreement is reached by concerned interests according to the judgment of a duly appointed authority. Consensus implies much more than the concept of a simple majority, but not necessarily unanimity." The organization of the Institute includes a number of councils representing, for example, organizational members, company members, consumers, various standards boards and committees, and the International Standards Council which oversees the operation of the United States National Committees for the International Standards Organization and the International Electrotechnical Commission.

3. SECTIONAL COMMITTEE C63

The scope of C63 is as follows:

"Development of definitions and methods of measurement of noise and signal strengths, determination of levels of signal strength, levels of interfering sources, limiting ratio of noise to signal and development of methods of control of influence, coupling, and susceptiveness."

As can be seen, this scope is quite broad and generally covers all aspects of EMC. Participation in the activities of C63 is generally by member organizations who designate delegates. The current list of member organizations is shown in Fig. 1. It should be noted that except for a limited number of members-at-large, individuals are not members of this committee. The administrative work of the committee is carried out by the sponsor, who presently is the Institute of Electrical and Electronic Engineers, Inc.

4. INTERNATIONAL VOLUNTARY STANDARDIZATION

Work is carried out both in the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). The major committee concerned with this activity is the International Special Committee on Radio Interference (CISPR) which is affiliated with the IEC and which has six subcommittees covering the following areas: Instrumentation and Measurements; Industrial, Scientific and Medical Equipment; High Voltage Lines and Equipment; Ignition; Receivers; and Appliances. It has issued many reports, recommendations, and specifications in the field and its recommendations and specifications are being adopted by many countries as part of their national regulations. Other committees of IEC concerned with electromagnetic compatibility problems include TC 9, Electric Traction Equipment; TC 12, Radio-Communications; SC 17D, Low-Voltage Switchgear and Controlgear; TC 18, Electrical Installations in Ships; TC 22, Power Electronics; TC 34, Electric Lighting; TC 44, Electrical Equipment of Industrial Machines; TC 57, Power Line Carrier Systems; TC 64, Electrical Installations of Buildings; TC 65, Industrial Process Measurement and Control; TC 75, Environmental Conditions; and TC 77, Electromagnetic Compatibility between Electrical Equipment Including Networks. In addition, in ISO, TC 20 is concerned with EMC aspects of aircraft and space vehicles, and TC 97 with EMC aspects of computers and information processing. Also, there are other international committees concerned with EMC matters. As an indication of the extent of the interest in EMC standards in the IEC, a survey of the 180-odd technical committees and subcommittees of IEC was recently made. More than 50 of these technical committees and subcommittees indicated a direct interest in EMC.

5. THE VOLUNTARY STANDARDIZATION EFFORT

In carrying out its responsibility, American National Standards Committee C63 has made a survey of its activities, not only nationally but on a worldwide basis in the EMC field. Of the 11 pages of items which are either specific standards or work related to the development of specific standards, nine of these pages are concerned with voluntary standards activities. Approximately two pages are concerned with military or government standardization activities. ANSI itself has a number of projects underway. The three most important are:

C63.2 - Specifications for Radio-Noise and Field-Strength Meters, 0.015 to 30 Megahertz.

C63.4 - Methods of Measurement of Radio-Noise Voltage and Radio-Noise Field Strength, 0.015-25 MHz.

C63.12 - Recommended Practice in System Electromagnetic Compatibility: Part 1 - Rationale for Developing Limits.

A revision of the first of these has recently been accepted as an approved national standard and is presently being printed. The second is out for ballot as an approved revision of a current national standard. The third is a new document, which has been approved for trial use for a period of one year. It is currently in the galley-proof stage.

In order to place these documents and other documents which have been developed in the voluntary standards effort in some sort of perspective, Table I has been prepared. The first item in the table is definitions, and indicates several of the more important publications. The remainder of the table identifies for each EMC phenomenon, for example, emission or susceptibility of a specific source, related standards or standardization efforts that can be identified as being concerned with instrumentation, techniques, or limits. Table II shows those standards pertaining to EMC control techniques.

6. PRESENT PROGRAM

Figure 2 shows a concept of a program for bringing many of these standardization efforts together. It is clear that the several documents containing definitions should be examined for consistency with the objective of trying to produce a single vocabulary. Many of the terms presently being used are common in several vocabularies but a significant number are not. Presumably, these differences can be reduced, but probably not eliminated because of the different purposes for which each vocabulary serves.

There is no real reason why we should not have a common instrumentation standard. Recently, ANSI has taken a major step in this direction in adopting standards that are not ony consistent with practice in the United States but also that are followed in the CISPR. In this concept, one has a choice of instrumentation depending upon his immediate needs, but when he makes the choice he uses an instrument of agreed upon specifications.

In the techniques area, the concept is that many of the devices can be measured using a standard technique; however, it will be necessary to recognize certain variations of the standard technique in order to accomodate special types of equipment. Hopefully, variations will not be so extensive as to invalidate the concept. Certainly, in developing this concept, one of the fundamental rules of the game should be to bring civilian and military practices together. Many have suggested a civilian MIL-STD-461. Hopefully, we can do better than that and actually have an American national standard that is acceptable, in so far as techniques are concerned, to both military and civilian sectors. In developing such a standard, one of the objectives would be to try to improve the realism of test procedures with regard to their ability to measure basic parameters; that is, parameters which are significant for the application of limit criteria in so far as conduction, induction, and radiation phenomena are concerned.

With regard to the area of limits and limit guidelines, we hope that in the very immediate future many users of EMC standards will make a careful review of document C63.12. This document is admittedly not as comprehensive as we hope it will be finally, since at the moment it deals only with narrow-band emission and susceptibility. However, the criteria which are discussed in the document seem to be very basic, and if the principles used there can be accepted, one can then proceed to expand the scope and usefulness of this document. In the establishment of limits (and their associated measurement techniques) participants in the standardization effort will have to take into account such factors as cost of suppression and shielding, the cost of efficient circuit design, the value of hazards removal (hazards being defined as having to do with health, safety, and comfort), and the establishment of valid statistical parameters which are significant in the computation of probability of interference.

If the basic documents can be prepared, then work can go forward with specialized documents to the extent that they are needed, but which will hopefully be quite consistent with the basic documents.

7. CONCLUSIONS

In considering these matters, it is important to recognize that many significant changes in technology are taking place on a regular basis. Such changes include the following: Increasing use of digital techniques for replacing analog techniques, optical techniques, electronic power conversion, satellite communications, new medical devices, and ground transportation systems.

Clearly, it is not anticipated that EMC problems will disappear. There will always be a conflict between undesired emission levels and sensitivities of systems to desired emissions. In order to promote the electromagnetic compatibility of these systems as they develop in the most efficient manner, we must have standards which are relatable to basic electromagnetic emission, coupling, and susceptibility phenomena, and an approved body of technological know-how which will enable efficient application of the available techniques.

Finally, the contributions of the voluntary standards effort should be recognized. It is obvious that the development of a more uniform set of standards than currently exists is a desirable objective and will be achieved. Steps currently being taken should accelerate the process.

Figure 1

ORGANIZATIONS REPRESENTED BY DELEGATES TO C63

Aeronautical Radio, Inc.

American Radio Relay League

Association of Home Appliance Mfgrs.

Association of American Railroads

Canadian Standards Association

Computer Business Equipment Manufacturers Association

Department of Agriculture, Rural Electrification Administration

Department of the Army, Development and Readiness Command

Department of Commerce, National Bureau of Standards

Department of Commerce, National Telecommunications and Information Administration

Department of Energy, Bonneville Power Administration

Department of the Interior, Bureau of Reclamation

Department of the Navy Naval Electronic Systems Command

Department of the Navy Naval Sea Systems Command

Department of State

Electric Light and Power Group

Electrical Testing Labs., Inc.

Electronic Industries Association

Federal Aviation Administration

Federal Communications Commission

IIT Research Institute

Institute of Electrical and Electronic Engineers, Inc.

Motor Vehicle Manufacturers Association

National Association of Broadcasters

National Electrical Manufacturers Association

Society of Automotive Engineers, Inc.

Society of the Plastics Industry

Telephone Group

Western Union Telegraph Company

Figure 2

EMC PRACTICES AND STANDARDS

1. The Electromagnetic Environment
   - Description - characterization and levels
   - Natural and man-made
2. Instrumentation
3. Techniques and Limits
3.1 Emitters
   - Transmitters (including handi talkies)
   - ISM
   - Ignition
   - High voltage lines
   - Appliances - fluorescent lights
   - Systems
3.2 Susceptors
   - Receivers
   - Audio systems
   - ISM
   - Telecommunications
   - Appliances
   - Systems
4.0 Hazards
5.0 Methods of control
   - Filtering, shielding, bonding, calibration

Table I - Relationship Between Various EMC Standards Activities

Definitions

IEEE 100
MIL-STD-461
IEV Publication 50 (902)(CISPR)
(TC 77, WG 1)

EMISSION	INSTRUMENTATION	TECHNIQUES	LIMITS
EM Environment (natural and man-made)	ANS C63.12 CCIR	ANS C63.12 EIA (Site Survey) IEEE, CISPR, CCIR	ANS C63.12 EIA (Designers' (Guide) CCIR
Transmitters (incl. radar)	SAE AIR 1225, 1255	IEC 244 FCC Parts 2,15 ITU MIL-STD-462,449 469 IEEE 284	FCC Part 15 (Docket 19356) ITU MIL-STD-461 OTP (radar)
Industrial, Scientific, Medical	CISPR Pub. 16 ANS C63.2 IEC 65 (ionizing radiation) SAE AIR 1225, 1255	IEEE 54,139,140 FCC Part 18 CISPR Pub. 11 MIL-STD-462 ANS C63.4	ANS C63.12 MIL-STD-461 CBEMA (EDP/OM) FCC Part 18 IEC Pub. 9 CISPR Pub. 11
Receivers (inc. CATV)	ANS C63.2 CISPR Pub. 16 SAE AIR 1225, 1255	CISPR Pub. 13 IEC 106,107 IEEE 187,214, 213,263 EIA RS 378 FCC Part 15 MIL-STD 462	ANS C63.12 CISPR Pub. 13 FCC Part 15 IEC Pub. 9
Ignition	CISPR Pub. 16 ANS C63.2	CISPR Pub. 12 SAE J551 MIL-STD-462 EIA TR 8.12	CISPR Pub. 12 SAE J551 IEC Pub. 9 MIL-STD-461
High Voltage Lines and Equipment	CISPR Pub. 16	CISPR Pub.( ) IEEE 430 NEMA 107 and Bushing Tap Msmts.	CISPR Pub.( ) IEC Pub. 9
Appliances	CISPR Pub. 16 ANS C63.2	CISPR Pub. 14,15 ANS C63.4 FCC OCE 20 (microwave ovens) Part 15 (Garage door opener) NEMA WD2 MIL-STD-462	CISPR Pub. 14,15 IEC Pub. 9 FCC Part 15 NEMA WD 2 NIL-STD-461 MIL-STD-1337
Power Equipment		IEC:(TC 77) 34-1 (Turb. gen. harm) (TC 17,Switch-gear) (TC 22, Power supplies) IEEE 469 (Transf. Noise)	MIL-STD-745

Table I (cont.)

EMISSION	INSTRUMENTATION	TECHNIQUES	LIMITS
Systems	CISPR Pub. 16	IEC 533(SHIPS) MIL-E-6051 RTCA DO 160 SAE ARP 937 (jet engine) SAE ARP 1147 (aircraft) STANAG 3516	IEC 533(SHIPS) MIL-STD-704 MIL-STD-442 (telemetry) MIL-S-13715 transients(veh) MIL-E-6051 RTCA DO 160 STANAG 3456, 3614 SAE AIR 1261
SUSCEPTORS			
Receivers		CISPR Pub. 13 IEC 315-3,5,8 IEEE 184,185, 294 EIA TR 8 SAE AIR 1209 MIL-STD-462, 449	MIL-STD-461
Audio Systems		CISPR SC E MIL-STD-462 SAE AIR 1209	CISPR SC E MIL-STD-461
Industrial, Scientific, Medical		TC 65(Ind. Cont) MIL-STD-462 SAE AIR 1499 1209 NEMA (Pacemaker) SAMA AAMI (Pacemaker)	MIL-STD-461 SAE AIR 1499 SAMA
Telecommunications		CCIR IEEE 455 (L.B.) 367 (Gnd PR) 368 (Induced Noise) SAE AIR 1207 MIL-STD-462	CCIR EIA TR 41
Appliances		SAE AIR 1207 MIL-STD-462	
SYSTEMS		MIL-STD-442 (telemetry) SAE (gnd trans) IEC TC17 (swgr-surges) IEC 533 (SHIPS)	IEC 533 (SHIPS)

Table II - Standards Pertaining to EMC Control Techniques

CONTROL METHODS	INSTRUMENTATION	TECHNIQUES	LIMITS
Shielding		IEC 169-1 TC 46 (connectors) MIL-STD-285 IEEE 299 SAE ARP-1173 (gaskets)	IEC 169
Filters		IEC 161 MIL-STD-220 SAE ARP 936(cap) SAE AIR 1172(filters)	
Bonding, Grounding		MIL-STD-5087 MIL-STD-1310	
Antenna Calibr.		SAE ARP 958	
Impulse Strength and Bandwidth		SAE AIR 1267 IEEE 376	
Hazards	C95 (proposed) IEEE (GIM)	IEC TC 61, 74 MIL-STD-1512 MIL-STD-1377	IEC TC 61, 74 ANS C95.1 ANS-C105 (Blast) MIL-P-24014

WHAT IS NEEDED FOR PROGRESS IN EMC?

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1. THE PROBLEMS AND THEIR BASIC CAUSES

There is a growing need for electromagnetic compatibility (EMC). But, simultaneously, there is widespread dissatisfaction with conventional approaches to achieving EMC. It is hard to apply to the burgeoning, modern, microprocessor- computer- controlled (non-communications) systems as, e.g., industrial and process control, transportation, health care, etc. By extracting the real reasons for such justifiable complaints about established EMC, we can develop clear guidelines for a new EMC permitting very satisfactory, cost-effective solutions for civilian electromagnetic interference (EMI). To distinguish this new approach patently from the conventional (military-oriented) electromagnetic compatibility, we shall call it ELECTRO-MAGNETIC COMPOSSIBILITY, the much-needed new, adaptive technique. It is principle- (not spec-) oriented, results and cost- (not documentation-) directed, and stresses systematic co-planning of EMC. But let us first marshal the key complaints and the real reasons behind them.

a) Complaint: "EMC often does not work." Reason: Conventional EMC was developed essentially for communication systems. There we have narrow-band senders, defined channels, and tuned receivers. In contrast, in control systems we have broadband sources of noise (transients) and field concentrations; untransparent, "spread" transfers; exposed receptors, some often quite unsuspected. Hence, in view of the basically different operating conditions, we cannot apply many of the methods, essentially developed for communications systems, to control systems.

b) Complaint: "Often eliminating one problem creates another problem." Reasons: Three major reasons are involved: (i) The nonlinearity inherent in feedback systems; (ii) many a misconception and the many antinomies imparted by mandatory safety measures and by spread (in space and frequency); (iii) see c) below. Things cannot be taken out of context with impunity.

c) Complaint: "EMC is unscientific, unpredictable, and often 'brute-force'." Reason: Because of the indeterminacy of boundary and operation conditions, standards are often grossly oversimplified. This results in worthless convenience. One must use realistic models and simplifications. Theory can be a very practical thing (as will be shown).

d) Complaint: "I would like to have simple step-by-step rules." Reason: EMC is not for cookbook engineers. Such unimaginative, rigid people are costly. Cost- effective EMC is not a routine affair. You must use the code and your head!

e) Complaint: "EMC is costly." Reason: Only if approached incorrectly. But what is the correct approach?

2. THE SOLUTION: ELECTRO-MAGNETIC COMPOSSIBILITY

First, we must accept the impact of a) mandatory safety codes (safety first!), consequential for both normal and abnormal operating conditions, including the 'oozing' of 60 Hz throughout the whole system; b) the spatial spread of large, fast systems (quasi-static considerations are inadequate); and c) the unavoidability of exposed receptors which must operate in very noisy places to do their job. We cannot permit presumptive simplifications pretending that such conditions do not exist.

Next, system planning and EMC planning must go hand in hand. EMC planning requires continual feed-back and feed-forward between analysis and control. Hereby we must allow the right hemisphere of the brain (holistic thinking) to participate in the optimization process which is both generic and specific.

For cost-effective decriticalization of the system, we must plan along three generic lines:

a) Partition of the system into (i) quiet spaces containing the low amplitude fast logic; (ii) semi-quiet spaces, interfaces, containing high amplitude, slow I/O devices; and (iii) noisy spaces where the sensors and actuators are exposed to noise.

b) Isolation. (i) Shielding and filtering quiet and semi-quiet spaces; (ii) isolation of control elements by electro-optic isolators; and (iii) isolation of exposed receptors by use of non-contacting sensors, isolation amplifiers (all three ports), and/or fiber-optics.

c) Redundancy of data handling systems. Large scale integration makes affordable duplication or triplication of whole critical sub-systems, going beyond error-correcting coding. For power handling systems, redundancy is replaced by subdividing in power aggregates.

This generic approach is very much facilitated by solid state developments still very much in flux:

* Electro-optics (limited linearity; use V/F conversion if needed).
* Microprocessors, partly replacing hardware by software.
* CCD's, permitting great reduction in hardware; most important: non-contracting, self-scanning, fast image sensors.
* Solar cells for complete isolation of power in hazardous areas.

Specific remedies can be classified as nullification (localized suppression or cancellation) and differentiation. Differentiation of noise and signal can be direct or indirect. Direct differentiation means staying with the same FATTMESS criterion (Frequency, Amplitude, Time, Temperature, Mode, Energy, Size or structure, Statistics). For instance, staying with F: Use a filter to separate low frequency signal from high frequency noise. Indirect differentiation is more sophisticated filtering, using several other FATTMESS criteria to handle one criterion that is difficult or costly to control directly. Typical are slew rate limiting, averaging, etc.

Finally, we must finish off some sick sacred cows. Some of the most blatant cases of misleading simplifications happen with the supposedly most simple EMC measures--grounding, shielding, and filtering. Unfortunately, such unrealistic simplifications seem to be sanctioned by long usage. They are nevertheless wrong and cause much frustration. These misconceptions and their corrections are as follows:

a) The concept of "control common" is a wishful myth for large, fast systems. Calling something a ground does not make it so. But electro-optic isolators eliminate much of the grounding problems.

b) The unrealistic plane-wave concept of shielding is replaced by equivalent spheres, cylinders, and/or pairs of finite-distance planes. Size is also important for low frequency magnetic shielding and saturation effects.

c) Probably the most flagrant case of EMC error is the insertion loss measurement of powerfeed line filters in 50/50 ohm interfaces (or other totally uncritical methods). This does not guarantee that the filter will work in real interfaces which are mostly variant and indeterminate. Filter dysfunction, in the form of ringing, insertion gain, and/or poor stopband performance, is often quite consequential and not improved by brute-force overdesign. If the filters are made multi-section and lossy in the pass-and transition band, they will meet the coming IEC (CISPR) worst-case standards. Two alternate test methods are involved; the simplest is replacing the 50/50 ohm by 0.1/100 and 100/0.1 ohm. The method is based on a broad data base of 60 Hz interface impedances as boundary conditions for a new matrix theory of severely mismatched filters. The modified method has only to be applied for 2 kHz to 200 kHz. If the filter works in this range, the 50/50 ohm method is acceptable for higher frequencies.

Naturally, the information presented here can be only cursory. The IEEE Educational Activities Board is presently offering a Continued Education Course on ELECTRO-MAGNETIC COMPOSSIBILITY, by the author. For more details on this call H. Schlicke at 414-352-7085 (for obtaining the text) or V. Giardina (IEEE Service Center) at 201-981-0060 (for arranging the course).

COMMUNICATIONS WORKING GROUP SUMMARY

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1. INTRODUCTION

Although the communications working group sessions generally followed the topics suggested for the workshop as a whole, a number of special interests consumed most of our time and not all of the topics were raised. The group was too small to represent a cross-section of all the affected community, although issues raised were of a character that appeared broadly applicable.

In the communications context, we suffer from definitional problems with the term "Electromagnetic Interference." For communications planning and engineering, EMI is a general term that encompasses the effects of very low-level signals, as well as the higher levels which were also of concern to the workshop. To many people, including the majority of those attending the working group sessions, EMI means high-level signal influences on non-communications equipment and biological systems.

In my judgment, the high-level situation should be treated as a logical subset of the more general problem. By so doing, we can expect to realize symbiotic benefits in the various special interest subjects. As a minimum, dialog between interested parties is less ambiguous and the chances for complementary work are much improved.

But the high-signal-level distinction continues. In this report, I have tried to reflect the views of the working group rather than my own prejudices. Accordingly, emphasis is on interference effects to non-communications equipment and, to a limited degree, on living systems.

2. PROBLEMS

Problems of concern to this group included:

a) The lack of a single source of administrative authority;
b) the lack of a source of environmental definition;
c) adverse effects on industry or mandatory controls and regulations;
d) the lack of awareness of EMI effects on the part of many people who are being affected;
e) interference from systems not intended to radiate (such as arc-welders).

A strong consensus developed around the argument that trends in the evolution of the U.S. economy are spectrum intensive and that EMI problems will continue to grow both in number and complexity.

3. SOLUTIONS

In general, the group felt that the principal barriers to solutions of a broad range of problems were economic or institutional rather than technological.

Several approaches to improving the present EMI situation were discussed, but it seemed clear that no participant felt that there was a well-defined solution. Three approaches are the following:

a) Education. Improve understanding of the EMI problem among designers, manufacturers, regulators, and users.

b) Provide a better definition of the EM environment.

c) Develop a more comprehensive framework for the assessment of EMI to avoid the penalties of suboptimization when specifications are drawn for individual units and components.

4. PROBLEM/SOLUTION DISCUSSIONS

Several participants expressed a strong need for a comprehensive definition of the electromagnetic environment for very general situations. The environment to be experienced by automotive electronics was the example receiving the most attention. While environmental data has significance in a broad range of applications, discussions in this working group concentrated on the problems of compatible designs for electronic and communications equipment. As with other topics, the term "environment" was not clearly defined. While many users would prefer a comprehensive definition of signals to be encountered in various locations, a list of signal sources and selected characteristics would be a big help. At the moment, very little data of this kind are available to the community at large.

Designing to worst case possibilities was raised as an alternative to environmental definitions. Some concern was expressed that such an approach imposes undue constraints on the design, cost, or use of susceptible systems.

There was a strong consensus regarding the need for a program with more focus and cohesion. The topic was discussed without a full understanding of what the "program" is now or should be. In general, elements of the program were thought to include research, standards, instrumentation and measurement procedures, measurements, definition of cause and effect relationships, environment definition, and related legislative and regulatory activity. While a strong role for industry was acknowledged, the principal concern expressed was directed to the many government participants at Federal, State, and local levels.

Concern was expressed about the stultifying effects of premature regulation, although a need for guidelines and voluntary standards, education, and basic information (generally to be supplied or encouraged by government) was widely acknowledged.

Meaningful measurements are important to the solution of the EMI problem. However, lack of a definitive statement of the overall problem precluded a very clear response. There was general accord that measurements, measurement procedures and related standards, and instrumentation were necessary to define

a) susceptibility (of electrical, electronic, and communications devices),
b) emissions, and
c) the electromagnetic environment.

In addition, the enforcement function produces similar requirements. Some key points follow:

a) The scope of the problem is extremely large--too large to permit exhaustive measurements of all items of interest. More appropriate is a rational combination of analysis and measurement.

b) Measurement objectives should include the definition of statistical distributions. This is particularly true where factors have large variations, as is the case with many EMI variables.

c) A clear understanding of the purpose for which measurements are to be made is important (and has frequently been missing in the past) prior to the start of a measurement program.

d) In general, the technology required to develop needed instrumentation is available, but it has not been reduced to commercially available devices.

e) The traditional reliance on measurement of some characteristic relative to an arbitrary standard is to be avoided in the future wherever possible. Such an approach provides very limited understanding of underlying causes and inhibits extrapolation to more general situations.

f) New and improved measurement guidelines (as opposed to formal standards) are considered helpful and needed.

As noted elsewhere, there was a broadly felt need for improved guidelines and voluntary standards, but there was also a concomitant aversion to regulation and mandatory standards. Concerns concentrated on guidelines for the measurement of the EM environment and of the susceptibility of electronic equipment. The measurement question appeared as a semantic convenience. At the conclusion of the sessions, the emphasis appeared to be on the definition of selected EMI characteristics, whether through measurement, analysis, or a combination of the two. The practical approach to "measurement" topics involves the judicious combination of measurements and analysis--an approach as demanding of guidelines and standards as either of the others.

5. PRACTICAL SOLUTIONS TO IDENTIFIED PROBLEMS

Identified problems were not heavily technology dependent and the practicality of various solutions (or approaches to solutions) was very uncertain. Solutions considered included increased educational efforts and improved organization and coordination among government agencies. The educational need applies both within the EMI community and the public at large. A general air of pessimism characterized the group's feelings toward the prospects of improved government interagency coordination.

Solutions to the problem of improved environment definition included both prediction and measurement, neither of which was defined specifically enough to assess the practicality of developing such results. The Canadian proposal in their EMI Advisory Bulletin was offered as one possible approach.

6. BASIS FOR ACTION

Within this group there appeared to be very little agreement as to a basis for future action beyond the identification of a partial list of needs. Foremost of these needs was an improvement in the institutional arrangements for dealing with EMI. A more cohesive and readily understood program was strongly urged by most participants. Other needs, addressed elsewhere in this summary, include definition of environment, development of confident exposure criteria, better education of active participants as well as the general public, and some consistency in regulations, standards, and guidelines.

The consensus was that technology does not represent a significant barrier to the problem solutions, although there is a continuing need to improve on measurement methods and instrumentation.

7. PRIORITIES FOR PROBLEM SOLVING

At the end of the second session, the group drew up a set of four resolutions as a means of focussing the concerns of the group and of identifying priorities. The document prepared is reproduced here:

Draft Resolutions from the Communications Working Group

BE IT RESOLVED THAT:

1. The government shall provide industry with EMI profiles to facilitate design, engineering, and marketing of consumer and industrial products.

2. The government shall determine "safe" levels of electromagnetic exposure for people. Further, the government will not adopt mandatory personnel exposure levels until maximum safe levels have been established.

3. Government and industry shall promote consumer education with respect to EMI.

4. Standards and regulations shall be consistent and uniform on a national and international basis.

TRANSPORTATION WORKING GROUP SUMMARY

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1. PROBLEM AREAS

During this workshop there was considerable discussion about the content of the electromagnetic environment, including how the environment should be defined. Generally, attendees determined that there was a definite need to define the electromagnetic environment, but characterizing the environment was another matter. After considerable discussion, it seemed that a definition of the environment should not be made on a basis of a time/level average because designers of equipment need to know the instantaneous peak values of the electromagnetic environment to insure proper product compatibility within the environment. This type of definition would require almost continuous measurement and vector analysis of the E or H fields. Also, there is a definite need to provide appropriate design goals by technical societies and voluntary standard groups. Currently there are confusing and conflicting standards such as the ANSI Standard for design specifying a one volt per meter field strength requirement to meet compatibility requirements, whereas the Canadian government has set other levels.

Overall, the need to define the environment seems paramount.

Attendees also expressed a definite need to develop electromagnetic test procedures that manufacturers need to insure product compatibility. Specifically, most manufacturers are working on products that will be introduced in three or four calendar years. The electromagnetic environment may change in that timeframe and representative, accurate test procedures for measuring electromagnetic environments that the products will be exposed to should be available now. Additionally, most products will be in the field several years after introduction and the expected electromagnetic environment, throughout the operational lifetime of the product, must be known to insure compatibility.

2. CRITIQUE OF THIS WORKSHOP

The working group sessions would have been more useful if more Federal regulatory agencies had attended and participated. The National Highway Traffic Safety Administration has indicated an intent to regulate motor vehicles for electromagnetic emissions/compatibility in the future. Also the United States Environmental Protection Agency has been making measurements on electromagnetic levels in cities throughout the United States.

To permit users and manufacturers of equipment that might be regulated at a future date to understand the regulatory philosophy, a dialogue with regulators is needed. Unfortunately, the regulators were not in attendance at the working group sessions, although they were requested to attend. In addition, the National Telecommunications and Information Administration (NTIA) was requested to participate because the Federal government allocates the electromagnetic spectrum and transmitter power. This agency should have information on how to map the electromagnetic environment. Once again, NTIA was conspicuous by its absence.

In a connected note, it was apparent from conversations at the workshop that the Federal Communications Commission personnel in attendance were not aware of the fact that the National Highway Traffic Safety Administration might be regulating products for electromagnetic radiation/compatibility.

3. FUTURE EMI WORKSHOPS

On the subject of future workshops, this working group did not provide a definite answer if another workshop is needed. An expression of concern was that without discussion of all the appropriate parties who are involved in transportation, electromagnetic test procedures, and future possible regulations, the definition of a specific problem could not be reached. However, the feeling that the electromagnetic environment needs to be defined was strong and pervasive.

Although there was no definite feeling within the group if another workshop should be held, several opinions were endorsed by the group. These are:

a) The proceedings from this workshop must be published to provide a continuum of information on electromagnetic radiation and future activities in this area.

b) There was a definite indication that a need to include all transportation sources should be included in any future workshops because problems common to surface transportation may not be applicable to aircraft, watercraft, or rail transportation. A definite need exists to have all of these functions involved in any future workshop.

c) Another suggestion that received very strong support from the group was that any future workshops revolve around concerns rather than working groups divided by product classification. Concerns such as susceptibility, radiated emissions, regulations, etc., would provide all parties attending a workshop to enter into an overview and interaction with other parties who would be affected by the same concerns. An obvious conclusion of the transportation sessions was that the equipment impacted by motor vehicle radiation, namely land mobile communication equipment, was not represented in the transportation session, but rather was included in the communications session. Therefore, the views and considerations of the communications industry could not be incorporated into the transportation session.

d) If future workshops were structured around concerns, a more appropriate use of available time would be to solicit questions to determine the concerns of the group prior to the workshop. In this manner, pressing questions could be concentrated on. Obviously this would take some extra work, but the end results should be worthwhile.

4. SUMMARY

In summary, there is a definite need to understand and define the electromagnetic environment to permit manufacturers of products to operate within the electromagnetic environment. If the design targets are known, products can be made to live within that electromagnetic environment.

CONSUMER PRODUCTS WORKING GROUP SUMMARY

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The Consumer Products Working Group addressed the EMI problem areas by means of a panel, with each panelist briefly commenting on the problems as perceived from his or her viewpoint. Following those comments the floor was opened for interaction between the panel and attendees.

A major part of the Consumer Products sessions was devoted to the radio-frequency aspect of EMI with the focus on TVI involving CB radio emissions and television susceptibility.

Some background is helpful relative to the change in the interference "profile" between the late 1940's and the recent past. Then, before any impact from television, the number of RFI complaints (generally involving audio rectification) was fairly small (of the order of 7,000 to 8,000). The situation changed dramatically though in the late 1960's and early 1970's. The change was due in large measure to two things--the growing use of home entertainment products in the public's daily life, and a tremendous surge in CB radio sales.

Currently there are about 120 million TV receivers in use in the United States plus another 400 million radios and millions of other electronic audio products. The surge in CB sales quickly converted to a consumer product that which had been considered by many to be an industrial type product for trucker and other business use. By the end of 1977 the number of CB licenses had grown dramatically to about 16 million as had the number of RFI complaints--about 80,000 according to the FCC.

To come to grips with the problem and identify problem areas, the FCC:

a) Increased the CB transmitter harmonic suppression requirement from 49 to 60 dB.

b) Invited comments on a further increase in harmonic suppression to 100 dB.

c) Established a Personal Use Radio Advisory Committee (PURAC) to provide information on RFI and other aspects of CB use.

d) Undertook, through its Field Operations Bureau, an in-depth analysis of some 72 randomly selected interference complaints.

e) Initiated rulemaking proceedings to ban the use of linear amplifiers designed for use in the 24-35 MHz band and to bring amateur radio equipment under its type-acceptance program.

What have these actions and studies yielded in terms of problem identification and priorities? There are several problem areas that have been identified.

a) The most significant problem involves the illegal use of linear amplifiers which boost the allowable 4 watts to output power many-fold. Linears can cause two kinds of problems--overload of the front end of the television receiver across a substantial portion of the band (despite high-pass filtering at the television receiver) and harmonic interference (most prevalent on channels 2 and 5 which include the 2nd and 3rd harmonics of the 27 MHz CB transmitter). Harmonic signals falling within the passbands of television stations operating in the area cannot be filtered or "stripped out" without at the same time stripping out the desired television signals.

b) A lesser (but still significant) problem involves the adequacy of the present 60 dB harmonic suppression requirement which is applicable to the signal appearing at the antenna terminals of the CB transmitter.

c) A related problem is CB chassis radiation of harmonically related signals. This has not been adequately addressed and the problem cannot be handled by installing a low-pass filter.

With respect to solutions, there again are several:

a) The ban on the sale of linear amplifiers should address complaints involving future sales. As to amplifiers sold before the effective date of the ban, this can be handled in two ways with the FCC taking the lead. One is an educational campaign, with the catalyst being CB clubs and organizations, to communicate to the uninformed the illegality of using linears. As to those users who persist, there is FCC enforcement which necessarily, because of personnel and budget constraints, must be on a "rifle shot" basis with enforcement publicized to deter others.

b) On the harmonic suppression requirment, CBer's and television manufacturers do not agree on the amount that should be required. Proposals range from the current 60 dB to 100 dB with the most likely compromise somewhere between 70 and 90 dB. Many believe the proper amount of suppression should be nearer 90 dB, but the FCC has not taken any action for some time on the open rulemaking proceeding.

c) Basically the same criteria (applicable to antenna harmonic radiation) should be extended to chassis radiation. This necessarily would have to be taken care of in product design and not later. For the 2nd and 3rd harmonics the chassis equivalent of 90 dB would be 63 v/m at three meters.

d) With these steps being taken, together with efforts of television manufacturers to reduce receiver susceptibility, it is believed further regulatory action (e.g., the Goldwater, Vanik, and Benjamin bills) is unnecessary. Television manufacturers continually are seeking to reduce susceptibility and are employing new types of instrumentation toward that end (e.g., the TEM cell) even though no techniques are presently available to cover the entire spectrum.

As to the possible long-range solutions to the problem, there are technological constraints as well as constraints on suitable test standards and methodology. As present solutions are implemented, the EMI problem should diminish with time, but it is doubtful if it will in the near term retreat to pre-1970 levels. This appears to be recognized by the FCC which was considering a new CB service in the 220 or 900 MHz bands. The FCC is reported to favor the 900 MHz band and it remains to be seen what the implications are as to availability of technology and equipment cost. It also remains to be seen whether the present Class D service at 27 MHz would be continued or phased out.

Other problem areas were discussed in the Consumer Products sessions. These included:

a) The lack of adequate test standards and instrumentation to make good EMI measurements. This applies not only to present products and systems where various standards and measurement methods have limitations, but also to future systems likely to exist in the 1980's. One current problem area touched on in several sessions during the overall Workshop involves the interference/susceptibility interaction between the fairly new home computers and other electronic products found in the home. Another problem discussed is the impact EMI is likely to have on home major appliances using microprocessors. And there was discussion of EMI problems to be addressed in new systems (e.g., carrier current systems) where home wiring would be the vehicle for control of appliances.

   Many believe that an organization such as the National Bureau of Standards is best equipped to lead the way on new measuring methods and instrumentation. This task, for the most part, was considered to be not within the resources or capabilities of individual companies.

b) How one would characterize the signal being measured. Average? Peak? Average Log? No consensus was reached on this topic.

c) The lack of an "interference profile" for any extensive geographical area. (This was discussed in several Workshop sessions). Acquiring this information could be costly, and the fast pace of technology and other changed conditions could change the profile. Even so, one view was expressed that a profile might be useful for other purposes, as for example to respond to critics who contend "EMI pollution" has reached the point where it would adversely affect health and safety.

d) A considerable amount of time was spent on the subject of educating the consumer on EMI. This discussion addressed a number of facets: The extent of awareness (if any) the consumer had as to EMI; the lack of choices existing for consumers when purchasing electronic products (should various characteristics of consumer products be emphasized, highlighted, graded, labeled?); the ability of consumers to "digest" and evaluate the relative significance of these characteristics; and more typically, what information now exists which would aid a consumer in resolving an EMI problem "in being".

With respect to RFI in television and audio products, specific discussion was directed to a booklet published by the FCC entitled "Radio-TV Interference Problems" and to two Interference Handbooks published by the Consumer Electronics Group of the Electronic Industries Association for use by the service technician (not the consumer). One was directed to resolution of television interference problems and the other to resolution of interference problems in audio equipment. The FCC booklet is available to consumers as well as service technicians, and contains a number of possible solutions which would require implementation inside the television receiver. Some discussion, therefore, centered on the extent to which a consumer might be injured in attempting to pursue one of these remedies.

INDUSTRIAL WORKING GROUP SUMMARY

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1. INTRODUCTION

Three workshop sessions on industrial EMI were organized by the author. A panel format was used which included considerable audience participation. The following is a summary of highlights from these sessions.

2. PROBLEM ASSESSMENT

The first task undertaken was to define "industrial" for the purposes of the workshop. It was agreed that this field would include process control (including machine tool control and assembly lines); information processing (including computers and peripheral devices); RF heating and diathermy; welding; construction and mining; electrical power generation, transmission and distribution; and the industrial tools which use electrical power.

The initial discussions involved defining the problem by several examples. One example given by Shulman (Foxboro Co.) involved a portable radio transmitter (handie talkie) which caused an entire refinery to shut down, costing hundreds of thousands of dollars per day. The industrial area is characterized by many large users of rather sophisticated equipment and the cost impact of EMI problems can be very large. Visek (Sperry Univac) noted that the evolution of the computer has brought about several other categories of difficulties. For example, several years ago computers were designed to operate in carefully controlled environments (e.g., air conditioned screened rooms). Today the trend is towards more distributed processing and small stand-alone microprocessor-based systems. These information processing systems are exposed to a considerably larger range of environments, most of which are not under the control of (or even known to) the component or systems designer. Keiser (Consulting Engineer) noted (via a letter to the session organizer) that many computing machines are susceptible to powerline transients that last more than 0.1 second and cause the supply voltage to vary by more than 10 percent. Such transients are caused by lightning and load changes. Uninterruptable power supplies provide relief, but they tend to be expensive. Motor generator sets are useful for outages less than 1 second. Chartier (Bonneville) noted (via a message to the session organizer) that corona noise from high-voltage (>100 kV) power lines has caused some problems to AM broadcasting. Corona noise can be reduced by line design, and the economic trade-off is significant. While the corona loss is only about 5 percent of the conduction current loss, the rising cost of energy may eventually make it economic to have quieter lines. Lower voltage (<100 kV) lines can produce noise from arcing gaps (a problem to some TV and radio receivers); however, these gap sources on both higher and lower voltage lines can be fixed by maintenance. Gauper (General Electric) noted the interaction between devices and EMI; and, as an example, he cited ground-fault-circuit interruptors which are susceptible to interference to the extent that they can close down a construction or mining site. Schlicke (Interference Control Co.) noted the technical problems caused by the lack of a common ground point in many systems, long and unfiltered power cables, and filter specification problems. Garlington (Sprague Electric Co.) noted that filters are designed to work into specific impedances but they are frequently used with a variety of different source and load impedance (which may not even be known). This can result in a filter not providing the required isolation between a source of conducted interference and the victim system. Shulman noted that filter users don't know how to test filter effectiveness in real-world systems or environments and that standards don't reflect real world conditions.

After a heated discussion on filters, the panel chose another approach in an effort to define the issues and related categories of problems, such as a) technical, b) legal/political, c) educational, d) economic, and e) standards development and coordination. The discussion of these subjects is summarized below:

a) Technical Aspects

The panel and audience had predominantly technical backgrounds, so the initial discussions focused on the technical matters. One point made by many of the attendees is that the electromagnetic environment is not well documented in a form useful to system designers and analysts. Also, the environment seems to be constantly changing, and this implies the need for a statistical description. Perhaps generic example environmental categories could be defined which can be modeled or simulated for test purposes and used as part of design guidelines or standards.

The filter discussion illustrated the need for better dialogue between manufacturers and users, and also for more descriptive data sheets to facilitate that dialogue. There is also the problem of how to apply a systems approach within a system and between systems. When a digital engineer, using circuits that switch at 70 MHz, has no knowledge of rf design practices (or his need for them), there can be an interference problem which only becomes apparent when integrating a system. Also, when a source of EMI belongs to one system (e.g., a power generation plant) that causes a problem to another system (e.g., the communications control system in a large refinery), there are the problems of separation of the planning as well as the ownerships of the source and the victim. Showers (Univ. of Penn.) noted that, over the years, there has been extensive cooperation between power companies and telephone companies in solving the inductive interference problem in those cases where power lines and telephone lines run along the same right-of-way.

b) Legal/Political Considerations

This leads to the legal problem of responsibility for resolution of EMI problems. Who pays for the fix? The manufacturer of the source, the manufacturer of the victim system, or the user with the problem? Perhaps the environmental data existed which could have helped the system designer avoid the EMI, but company proprietary (or in certain rare cases, anti-trust) considerations precluded its being shared by the industry involved. Another legal issue involves the need, and also the threat, of regulation. The attendees agreed with Herrick (Texas A&M Univ.) that regulation is a weak attempt at a solution to EMI problems; it can never "solve" them. The group consensus was that voluntary standards should be tried, and regulation should be avoided if at all possible.

c) Educational Needs

Numerous education problems were mentioned. How does a young engineer get information or answers to EMI problems? How do you educate users enough to be able to talk to manufacturers or their representatives? A distinction was made between the relatively sophisticated users and the technically unsophisticated user. How do EMI engineers educate their own management to the importance of considering (and budgeting for) sound EMI design? The main motivators of management seem to be the threat of what the competition is doing, the threat of an unhappy customer, the threat of government regulation and economic considerations.

d) Economic Impact

In the economic area, there are problems resulting from the lack of adequate information to make cost-risk and cost-benefit trade-offs. There are many dimensions of risk, including the risk of litigation. The quality of measurements needed for a given standard is frequently unknown, and this uncertainty presents a problem with strong economic impact. Also, conflicting EMI standards exist and pose a different type of economic problem. For example, such standards can be used as non-tariff barriers to trade.

e) Standards Development and Coordination

The development of meaningful standards is a problem in its own right; likewise, the coordination problem. Many groups and committees are active in EMI/EMC work at the industrial, national, and international levels. Who should coordinate these efforts? What degree of coordination is practical?

In summary, the problems are of a diverse nature with economic, technical, political, legal, and educational aspects. The problems in the industrial area are very serious, especially from an economic standpoint. EMI can cause the loss of hundreds of thousands of dollars from a single occurence of the degradation of performance to a control process. Standards can cause an impact on our balance of payments due to their use as non-tariff barriers to trade. These standards and the measurements that underlie their enforcement should be tackled first, in conjunction with a better definition of the electromagnetic environment and design guidelines for how to use the information. Work is needed on both emissions and on susceptibility (or immunity), and the trade-offs should be made from a systems point of view so that sensible economic decisions can be made.

3. SOLUTION ASSESSMENT

The solution assessment session was conducted jointly with the Consumer Products Group organized by W. T. Collins. This summary will address the industrial aspects of the discussion.

Industry prefers voluntary standards to regulation, but there is a valid question regarding criteria for limits and for measurement procedures and measurement quality. To facilitate the proper technical and economic trade-offs, there is a need to relate voluntary emission and susceptibility standards.

Copies of the new Scientific Apparatus Makers Association (SAMA) Standard PMC 33.1-1978, "Electromagnetic Susceptibility of Process Control Instrumentation," were provided to the attendees by Shulman. He mentioned that pressures from customers rather than from the Congress or FCC had caused the standard to be prepared. Twenty (20) percent of the customers provide eighty (80) percent of the process-control market, and these large customers have real clout. The small individual consumer has relatively much less clout, and hence he must complain to the FCC.

The effectiveness of voluntary standards was discussed. One view was that they are effective if they forestall regulation, and it was noted that they would not be very effective if they were too expensive to check compliance because of unduly complex measurement requirements. It was noted that each industry has mostly responsible members who plan to stay in business for a long time. This group needs educational materials, and would use them. A fear was expressed that a few fly-by-night firms might trigger regulation that would add cost and not be needed by the larger segment of responsible industry.

The following current FCC dockets which apply to the industrial area were discussed:

Docket 20780 (NPRM)* (Part 15)	Restricted Radiation Devices and Low Power Communication Devices
Docket 20990 (NPRM) (Part 15)	Remote Control and Security Devices
Docket 20746 (NPRM, MOO, FRO) (Part 15)	Technical Specifications for Receivers
Docket 20718 (NPRM) (Part 18)	Industrial, Scientific, and Medical Equipment
Docket 21371 (NPRM) (Part 2)	Measurement Facilities
Docket 78-369 (NOI)	Susceptibility (in preparation 3 Nov. 78)

It was suggested that the government could help by providing an environmental definition or description which could be useful to many industries, and so no one industry would have to bear the cost burden of acquiring this information. The company proprietary problems regarding sharing data on the environment would also be overcome by this approach. Certain insurance-related problems could be mitigated.

Regarding consumer (user) education, susceptibility limit tables versus frequency might be useful. Then an educated consumer could determine how much protection he was paying for and make a better risk assessment relative to the environment of his planned use. It was noted that this would only work for relatively knowledgeable consumers. Special attention was devoted to the Notice of Inquiry (NOI) on susceptibility that will be printed before the end of the year if the FCC follows the staff recommendation.** Jones (FCC) emphasized that the NOI will seek to answer the question of whether or not the FCC should be in the susceptibility business, not how should they regulate susceptibility. She indicated that copies would be provided to the workshop attendees, and she expressed the FCC's hope for a good response to the NOI during the proposed 6-month comment period.

Various FCC publications were discussed as part of a broader discussion of education. Browne (EIA) commented on some shortfalls of these publications. One solution seemed to be to have the information available

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* NPRM = Notice of Proposed Rule Making
MOO = Memorandum of Opinion and Order
FRO = First Report and Order
NOI = Notice of Inquiry

** This became Docket 78-369 several weeks after the Workshop.

written at various levels (e.g., 6th grade education, high school, technician, engineer, etc.). Showers noted that undergraduate curricula were already too full to include much on EMC; however, there was a need for graduate classes. The universities need to know what industry expects from their graduates.

The general problem of who should carry the responsibility for the solutions and what roles should be played by government, industry, and educators was noted to be very complex; it was not resolved.

4. WHAT'S NEEDED FOR PROGRESS

The final working group session addressed the question of what is needed for progress. Discussions are summarized below.

It was the consensus of the group that better measurements were needed for progress, along with a better understanding of how to use the results of the measurements. A presentation was made by Vincent (Systems Control, Inc.) who showed results of environmental electromagnetic measurements made with a 3-dimensional display of peak-detected level versus frequency and time. He showed that vinyl plastic welders are frequently used at high power levels outside their assigned industrial-scientific-medical (ISM) bands. These devices (and similar ones) caused interference to communications systems, and this was perceived as an FCC enforcement problem. It was noted that they were operated out of a band in some cases because they were more efficient when operated there, and this was perceived as an equipment design problem in part. Vincent mentioned that on one occasion he made 2000 observations of ISM equipments per hour at 18 MHz and 1500 per hour at 21 MHz. (Both frequencies are outside the ISM frequency allocations.) The changing nature of the environment (discussed in earlier sessions) was graphically illustrated on a time scale of several seconds. Especially noted was that the narrowband instrumentation in common use was not well matched to the problem of documenting such a dynamic environment.

Middlekamp (FCC) summarized some of the goals and findings of FCC Docket 21371 on measurement facilities. He indicated the desirability of test ranges which could provide repeatable results at the FCC laboratory and at manufacturers' plants without undue cost. A 3-meter separation was suggested for VHF and UHF to save space where land was very expensive. The importance of mutual coupling effects for such spacings was emphasized. He mentioned that FCC reports on this work will be published.

Crawford (NBS) pointed out that to make progress in assuring EMC we must first know what the EM environment is (including time and location variabilities). We must then be able to simulate it accurately and repeatably for susceptibility testing purposes; and be able to meaningfully evaluate the effects of the environment on victim systems. Also, the definition of what constitutes a system, or victim, must be sharpened and agreed upon by both users and producers.

A discussion of where to obtain information on EMI/EMC was initiated, and several categories were listed:

Publications:

- Books
- IEEE EMC-S Transactions
- IEEE EMC-S Newsletter (including abstracts)
- IEEE noise guides (e.g., IEEE Std. 518-1978)
- SAE-AE-4 publications (SAE J551, SAE J1113A)
- EIA (C-46) design guides
- ANSI standards (e.g., C.63.2, C63.4, and C63.12)
- CISPR publications (available through ANSI)
- URSI "Review of Radio Science," published every 3 years
- ITEM, published by R&B Enterprises

Seminars (e.g., Don White Consultants, etc.)

Classes at Universities
Bernie Keiser's at George Washington U.; others at Texas A&M, Georgia Tech, U. of Colorado, U. of Pennsylvania

The need for a complete list of these resources and their availability was emphasized by Thomas (Thomas Engineering). It was generally agreed that when most engineers had a problem they called someone they thought knew more about the area than they did.

Finally, the question of what is the state-of-the-art of EMI measurements was briefly addressed. EMI measurements were divided into two broad categories: Conducted and radiated. Vincent's presentation was indicative of the state-of-the-art for conducted and radiated emanations measurements when using conventional transducers with repetitive-sweep spectrum analyzers, peak detectors, and a 3-dimensional display. This technique has an estimated absolute accuracy of ± 6 dB. Crawford suggested that the most accurate (state-of-the-art) techniques for susceptibility (immunity) testing are: a) The generation of planar far fields in anechoic chambers at frequencies above 200 MHz, determined by the size of the chamber and characteristics and placement of the absorber; and b) the use of TEM cells at frequencies below 200 MHz. The upper frequency of the TEM cell is determined by the size of the equipment to be tested and hence the size of the TEM cell used. These two techniques have estimated absolute accuracies of ± 1 to ± 3 dB, depending on the frequency and size of equipment tested.

MEDICAL WORKING GROUP SUMMARY

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1. INTRODUCTION

At first glance, it appears a little strange to have a bioeffects or medical session at an electromagnetic interference (EMI) or electromagnetic pollution workshop. A major part of this "strangeness" stems from the fact that, in its common usage, the term "bioeffects" refers to the health hazards, either real or postulated, resulting from biological system exposure to electromagnetic environments. There are, of course, entire conferences and symposia devoted to this complex subject. Attendees at these conferences and symposia are generally quite a different group of people from what one finds at an EMI workshop.

But if we look deeper, we see that our basic concern is the compatibility of systems with their operational electromagnetic environment. This was certainly the case in the medical sessions at this workshop. Within the EMI community, the systems of interest have traditionally been those used in military electronic applications--radar, communications, avionics, navigation, etc. More recently, there has been some involvement with the electromagnetic susceptibility of certain medical and consumer electronic devices. This involvement has resulted in measurements being made to define the susceptibility characteristics of a large number of cardiac pacemakers and a small number of televisions, radios, etc. Also, at least one electromagnetic performance standard for medical electronic devices has been generated.

Outside the EMI community, where compatibility of systems with their electromagnetic environment has been a concern, the systems have generally been biological in nature. It has been the compatibility of these systems with their electromagnetic environment that has come to be termed "bioeffects." Although the systems and investigators differ, the basic concern with the ability of systems to function reliably and without degradation in their operational electromagnetic environment is still the primary subject of interest.

So, from this perspective, a bioeffects or medical session at this EMI Workshop was considered to be very appropriate. In this working group, the effects of electromagnetic environments on the performance of both medical electronic systems and biological systems were considered; however, the fact that the two systems are electromagnetically quite different was recognized from the outset and questions, comments, presentations, etc., were tailored to the appropriate system.

2. SESSION APPROACH

The session format was one in which invited presentations were made at the beginning of each session period. These presentations were followed by discussion periods during which specific questions were addressed. The invited presentations were as follows:

Session I, Thursday morning
Session Introduction and Overview
J. Toler, Georgia Tech

Activities of the IEEE Committee on Man and Radiation
D. Justesen, Kansas City VA Hospital

Considerations in the Development of Medical Device Standards
L. Hamilton, Health Industries Manufacturer's Association

Session II, Thursday afternoon
Activities of the American National Standards Institute
S. Rosenthal, New York Polytechnical Institute

Evolution of EMI Standards for Medical Electronic Devices
B. Flink, Medtronic, Inc.

Session III, Friday morning
Electromagnetic Susceptibility of Medical Electronic Devices
B. Jenkins, Georgia Tech

Beneficial Applications of Electromagnetic Waves
F. Cain, Georgia Tech

Typical questions that followed these presentations were:

Are regulatory and/or legislative actions, i.e., standards, necessary to assure that electromagnetically-safe medical electronic systems are offered to the public?

What EMI standards now exist for medical electronic systems?

What EMI standards now exist for bioeffects?

Is compliance with these standards compulsory or voluntary?

Should compliance with these applicable standards be compulsory or voluntary?

What organizations generated the applicable standards for medical electronic systems?

What organizations generated the applicable bioeffects standards?

Do these organizations have the technical expertise necessary to generate valid EMI standards?

Who should be responsible for generating EMI standards for medical electronic systems?

Who should be responsible for generating EMI standards for bioeffects?

How should these standards be updated?

What changes are needed in the existing EMI standards for medical electronic systems?

What changes are needed in the existing EMI standards for bioeffects?

Which of these changes is the most critical?

What research needs to be undertaken in order to develop improved requirements for existing standards?

Who should bear the cost of this research?

How do U.S. EMI standards for medical electronic systems and bioeffects compare with counterpart standards in other countries?

3. SESSION CONCLUSIONS

Primarily because of the technical and employment diversity of the session attendees, it was difficult, if not impossible, to unanimously agree on any question of major importance. In general, the divided opinions involved persons associated with the design/manufacture of medical electronic systems and the operation of electromagnetic sources disagreeing with other session attendees; therefore, all conclusions were drawn from consensus opinions that appeared to reflect feelings of the majority. These opinions are summarized as follows:

a) There should be regulatory and/or legislative actions, i.e., standards, to assure that (1) electromagnetically-safe medical electronic systems are offered to the public, and (2) ambient electromagnetic environments in public areas are not capable of causing harmful biological effects.

b) In the area of medical electronic systems, thoroughly-defined and well-documented instances of life-threatening EMI problems are almost non-existent. This situation exists in spite of the fact that the U.S. Army's Environmental Hygiene Agency has a procedure by which such EMI problems are to be documented and reported. Few of the session attendees--other than those from the Environmental Hygiene Agency--were aware that a reporting procedure for EMI problems with medical electronic systems existed. Instead of life-threatening EMI problems that are thoroughly-defined and well-documented, there are myriad reports which are verbally circulated. These reports are often emotional in nature and have tremendous possibilities for inaccuracy and exaggeration.

c) In the area of biological systems, thoroughly-defined and well-documented instances of athermal, life-threatening EMI problems in man are essentially non-existent. However, this is an area in which EMI problems may manifest themselves in subtle and difficult-to-detect ways; therefore, most session attendees did not feel qualified to present strong opinions as to whether athermal, life-threatening EMI problems exist in man. The fact that EMI effects may exist in biological systems without being hazardous was duly noted. It was also noted that research has revealed certain hazardous effects in experimental animal models; however, there was uncertainty as to whether these effects would be extrapolated to the man model.

d) Existing EMI standards for medical electronic systems are limited to the pacemaker standard developed by the Association for the Advancement of Medical Instrumentation (AAMI). The medical device EMI standard recently developed by the Food and Drug Administration is available for "guidance," but is not imposed on a mandatory compliance basis. The AAMI standard was developed via a consensus procedure that included inputs from both engineering and medical professionals. Compliance with the requirements of this standard is voluntary and essentially all pacemaker manufacturers comply with the standards.

e) Existing EMI standards for biological systems are limited to the document titled "Safety Level of Electromagnetic Radiation with Respect to Personnel." This standard was developed by the American National Standards Institute (ANSI). Like the AAMI pacemaker standard, the development of this standard was via a consensus procedure. Compliance is voluntary and a five-year schedule for review, update, and/or withdrawal is used by ANSI. The rationale for the 10 milliwatts per square centimeter level of safe exposure for personnel was discussed at length. Similarly, the possible rationale for the much lower exposure levels advocated by Eastern European countries was also discussed. It was noted that ANSI does not fund research but uses experts having knowledge of current research to develop their standards.

f) It was generally felt that EMI standards for both biological and medical electronic systems should be developed out of a consensus opinion approach in which experts from engineering, biology, and medicine fields would have the opportunity to provide inputs. Difficulties with this approach were noted, especially in terms of securing the time and travel funding necessary for individuals to adequately contribute their expertise. To the extent possible, this approach to standards development should be patterned after the successful efforts of AAMI in their generation of the pacemaker EMI standard.

g) It was also generally felt that compliance with the standards should be voluntary. Such compliance would result in a more cooperative attitude toward compliance and should reduce situations of dogmatic insistance on compliance in cases where requirements in the standards are nonapplicable. Although compliance with the present bioeffects EMI standards is voluntary, noncompliance with its requirements would be widely viewed as unacceptable.

h) There should be some well-publicized mechanism established by which EMI problems with medical electronic systems can be compiled and maintained. The lack of specific information on these problems makes it almost impossible to determine the need for an EMI standard for medical electronic systems.

i) To the maximum extent possible, EMI standards generated for either medical electronic systems or biological systems should be tailored to specific problem areas. General standards applicable to broad frequency ranges and essentially all performance parameters were considered unjustifiable. All standards should be accompanied by a detailed rationale report that documents why the standard is necessary and the technical basis from which its requirements are derived. The extent to which unwarranted standards burden manufacturers and limit their ability to compete in international markets was noted.

j) The critical need for more research in the area of EMI in biological systems was repeatedly discussed. There seems to be no overall coordination of research efforts in this area, with the result being (1) each funding agency continues efforts without appreciable regard for what other agencies have or are doing, (2) the funding available for research is small and fragmented, and (3) research methods of approach are often sloppy to the point that results are of questionable value.

k) There is a critical need to educate both manufacturers and users of electronic systems regarding EMI principles. Manufacturers need to understand interference sources and suppression techniques so more emphasis can be placed on a priori elimination of EMI by design rather than a posteriori reduction of EMI by testing.

PLENARY SESSION IV SUMMARY
"THE LAST, LAST WORD"

M. Gerald Arthur
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Following the summary presentations by session developers, reported in the preceding pages, the workshop chairman opened the final plenary session to free, unstructured discussion in which the attendees were encouraged to ask questions and make comments. The following material is a report of those discussions as extracted from hand-written notes.*

1. FCC NOTICE OF INQUIRY

Krauss (FCC) announced to the assembly that a copy of the FCC notice of inquiry (NOI) on radio frequency interference to electronic equipment will be mailed to each person registered at the workshop. (Editor's note: This was released November 21, 1978 as General Docket No. 78-369.) Appended to it will be a copy of the Canadian document "Electromagnetic Compatibility Advisory Bulletin--Immunity of Electrical/Electronic Equipment Intended to Operate in the Canadian Radio Environment (0.014-10,000 MHz)" issued by the Telecommunication Regulatory Service on September 1, 1977. The FCC NOI deals with interference, compatibility, and susceptibility in broad terms, but does not deal with bioeffects (this is to be the subject of a separate NOI). Information about this or any other FCC activity may be obtained from the FCC Consumer Assistance Office, telephone (202) 632-7000, Washington, D.C.

2. EMI ENVIRONMENTAL DATA

Showers (U. of Penn.) opened a discussion on the issue of EMI environmental data acquisition for general use by challenging the claim that "more" data are needed, citing the large amount of data already gathered by EPA on radiation levels near broadcast transmitters. Before more or new data are obtained, the purpose to which it will be put must be defined.

Hagn (SRI) supported this position by citing another example where a large quantity of data was accumulated, but its owners found it difficult to know how to use it to predict the degradation of a given known system. It is important to analyze the system to determine what information is needed before setting out to take data. So many variables come into play that non-specific data may be useless. The linkage between the environment and the victim system must be established.

Showers mentioned that, in this respect, the power line people have been an exception. They know what their system is and what information is needed. But this is seldom true in other cases.

On the other hand, Collins (RCA) pointed out that for some applications a reference point is needed from which to move forward; for instance, when the public health and safety are involved. The automotive industry has been

* Notes were taken, in part, by John F. Mayo-Wells, NBS, Gaithersburg, Md.

one group that believes environmental characterization to be very important in the designing of safety features on motor vehicles.

Thomas (Thomas Engineering) urged that a list of specific EMI/EMC information sources be compiled, identifying each document, item, etc., providing information on its contents, and where and how it may be obtained. This recommendation received general approval.

However, Hamilton (HIMA) stated that even if we had a complete and total description of the environment, he questions whether we would actually know how to use it. We have much to learn about the effects of the radiation environment on systems (for example, low-level radiation bioeffects), and it is not clear at this time what information we need. A proposal to conduct an environmental survey should be recognized as potentially growing into a multi-million dollar measurement program, and therefore we should be clear as to what we expect to achieve.

Altogether, these discussions, along with other scattered comments from the floor, pulled together and restated the discussions held earlier in the individual group sessions of the workshop. The pros and cons of conducting a survey of the EMI environment were quite extensively aired. However, the workshop attendees did not formulate a recommendation for action.

3. CONSUMER REACTION

Miller (NBS) cited the need for getting consumer reaction or involvement in FCC rule making. But it is difficult to know when such information truly represents a cross-section of consumers because only a vocal minority may speak up. How can this be done?

Collins (RCA) agreed that this is a problem, especially since only a minority normally respond, and they may not actually speak for the group they claim to represent. The problem relates to that of disseminating meaningful consumer information. This can be done through organizations (e.g., CB clubs), the press, manufacturers' pack-in information sheets with products, manufacturers' personal responses to consumer inquiries, and through the meetings that the FCC holds as part of the rule-making process.

4. "HIGH-LEVEL" VS. "LOW-LEVEL" RADIATION

One of the problems discussed was the (presumed) distinction between "high-level" and "low-level" radiation. This occurs especially in discussions of bioeffects. Thus, one attendee asked, "How low is 'low-level' radiation?"

This was quickly identified as a semantic problem. Hagn (SRI) pointed out that the meaning of "low-level" varies according to the system in question. Justesen (VA) said that 10 mW/cm^2 would be considered a moderate level in the U.S.A and a very high level in the U.S.S.R. Levels below 100 $\mu W/cm^2$ would now qualify as "low-level."

Gauper (GE) deprecated the use of such terminology entirely. We are a multi-disciplinary group, coming from a wide variety of electrical engineering areas. We should talk numbers instead of relative terms. Then we would understand each other.

5. PUBLIC RELATIONS

Toler (Georgia Tech) discussed the problems that derive from the bad connotation that the word "radiation" has in the minds of the public. They have been conditioned by the press, TV, books, etc., to view radiation as an invisible, odorless threat to their health and safety. Hagn (SRI) supported this thought, pointing out that the role of radiation in science fiction literature and children's comic books (e.g., "death rays," etc.) has conditioned people who do not have a technical or scientific background to misunderstand the true nature of radiation. This problem had been discussed in the Medical Working Group session, and an unsuccessful effort was made to find an alternative term that would not have the emotional impact of "radiation." We can perhaps only acknowledge that the problem exists, and go from there.

Miller (NBS) raised another problem faced by decision-makers who need to document radiation effects, particularly bioeffects. He asked how we can make it easy for people to report such effects without in some way putting themselves under an onus for doing so. By analogy, this is the problem with UFO documentation. Toler replied that perhaps we cannot make it generally easy. In certain cases, a reporting mechanism has been set up, as for example, recipients of implanted medical devices. In other cases, some people who experience bioeffects, or who anticipate such effects, are making their concern known through lawsuits. The greatest benefit of these procedures to the decision-maker is that they identify the need for EMI controls.

6. SUSCEPTIBILITY, EMISSION, AND REGULATION

One attendee observed that much emphasis had been placed on EM susceptibility during the workshop, whereas the greater concern in other countries has been with the total amount of radiation that can be safely emitted. Another attendee agreed, pointing to the New York City proposal to limit the radiation level from all sources combined to 50 W/cm^2. But enforcement of such an ordinance would be difficult, if not impossible. Krauss (FCC) pointed out that this is a municipal matter having to do with the safety and health of the city's citizens, and the FCC would not have any enforcement responsibility there. The FCC's jurisdiction is primarily related to EM compatibility. New York City's concerns are far different from this, and it may well be that a federal agency other than the FCC might become involved (if at all).

Miller (NBS) asked Krauss if it were not true that the FCC would respond to any known threat to health that fell under its statutory authority. Krauss replied that in specific instances where there is a clear and present danger to health or safety, the FCC will respond through specific enforcement activities, or through cease and desist orders, or through court injunctions. In broad, general cases, it is not clear that the FCC would respond by means of rule-making procedures. Even though the FCC has statutory authority to correct a known and documented situation that per regulations was at a hazardous level, it is not clear that the FCC would necessarily do anything about it. Economic factors could affect how the problem might be resolved.

CHAIRMAN'S SUMMARY AND CONCLUSIONS

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National Bureau of Standards
Boulder, Colorado

The preceding papers by the overview speakers and the session summaries give a good account of what transpired during the workshop. In addition, the following set of brief statements captures some of the concerns of the attendees that are worth pulling out from the large number of talks and discussions.

- EMI problems are in their infancy by comparison to what they will be by the late 1980's (Chris Kendall - private consultant).

- EMI generated by emitters in ISM bands is ignored by FCC.

- Would we be better off to move more AM, FM, and TV to UHF bands and reduce the power, or reduce the amount of licensed radiation by reducing power levels or limiting the number of licenses? Must we have all the radiation permitted?

- Adapting Mil Standards 461 and 462 to civilian or consumer electronics needs is not realistic or meaningful.

- Many changes in technology are taking place because of the use of electronics.

- Compatibility of electromagnetics and electronics has traditionally been addressed toward communication system needs. Electronics used for control systems cannot be restricted to the same design constraints (e.g., control systems have exposed receptors, feedback systems, several analog and/or digital connecting data transmission lines, etc.). (Paraphrase from Dr. H. Schlicke - private consultant.)

- Biological receptors exist that are sensitive to weak electric and magnetic fields (e.g., navigation by fish, birds, and animals).

- Natural fields regulate biological clocks of mammals (including man). We should, therefore, expect biological EMI to desynchronize such biological rhythms with their attendant effects. (Paraphrase from Dr. D. Justensen - neuropsychologist with V.A.)

- "Radiation effects" and "radiation hazards" are not the same thing.

- There are beneficial uses of radiated fields, and we must be careful not to "throw the baby out with the wash."

- EMI problems will grow in number and complexity because trends in evolution of U.S. economy are spectrum intensive.

- The EM environment must be measured to define present and future conditions.

- Education of engineers is lacking in EMI, so latest approaches to solving these problems are not used.

- Education of public to EMI problems would permit a more general awareness of the problem and allow us to assess the extent of the problem.

- Conventional EM environmental measurements are inadequate. Instantaneous peak values are important; statistical data must be gathered; vector analysis of E and H fields is important.

- CB chassis radiation of harmonically related signals is not addressed by FCC.

- Further regulation will not solve the EMI problems.

- Cost impact of EMI effects in industry with their sophisticated equipment is very high (e.g., hundreds of thousands of dollars per day).

- Power line transients lasting longer than 0.1 sec. with more than ± 10 percent voltage change significantly affect computer-controlled manufacturing processes.

- We don't know how to test filter effectiveness for real world environments, and we don't know how our standards relate to such environments.

- You must make a trade-off between test procedure complexity and the measurement information you get. Are we to double the number of tests by measuring both electric and magnetic effects to get the whole information, which may not be needed?

- Ground fault interruptors are susceptible to EMI.

- Coordination of EMI efforts is needed.

- Everyone should carry the cost of implementing EMI solutions.

- Parts of systems fabricated and tested separately do not imply the total system behavior can be predicted. We must have a system approach to these problems with more understanding of the EMI phenomena. EMI phenomena are often non-linear in frequency.

- The only reason the voluntary standards program works is that people are afraid they are going to be regulated. (Paraphrase from R. M. Showers - U. of Penn.)

- Conflicting EMI standards exist that are causing economic hardships and are barriers to trade.

The attendees also raised concern about legal and political matters. As an example: In a situation where an EM source is interfering with electronics equipment used for protection or control and owned by a different party, who should be responsible and pay for the fix? In general, where does the responsibility of users, owners, and manufacturers rest? Similarly, the question can be raised: If we accept the thesis that regulation, at best, is a weak attempt at an EMI solution and that regulation does not solve the problem, then how can coordination be achieved in solving EMI problems with consumer products or in any other arena? The complexity of the electromagnetic interference problem pictured by the attendees is vast and the system approach toward solutions seems to be the only viable attack that can work successfully. However, while this approach could be practical in industrial, medical, and automotive applications, it could be very difficult to apply in consumer electronic settings.

In retrospect, it was evident certain assumptions were tacitly agreed to because of traditional outlooks that were present. For example, communicators, whether representing the receiving or transmitting sides, concern themselves with mutual interference and they traditionally see themselves as having an a priori right to the airwaves; consequently, it is difficult for this type of person to recognize the need to shift communications to non-radiating methods of communication to reduce the numbers of sources contributing to EM pollution in congested areas. This concern surfaced when one attendee raised the question why more attention was not given to the amount of radiation that can be safely emitted. The FCC is chartered with planning for EM compatibility and so has no jurisdiction in assessing when an area or locality has enough radiation from a safety perspective and, therefore, no further radiators should be permitted. Should the charter of the FCC be changed in this respect? Should the rewrite of the Communications Act plan for a "sunset" provision on all licensed radiators? If state and local governments limit combined radiation levels, as was proposed by New York City, envision the complications this will create legally, technically, and in measurement verification.

The single, most accordant theme that emerged from the workshop was that EM environment measurements were needed and a Federal agency should be chartered with this responsibility.

The EMI Workshop was not successful in attracting a significant contingent of managers or decision makers. Apparently our publicity and mailings did not reach the right audience. In this sense, it was not a complete success. Nevertheless, the interaction from the more than 200 attendees was generally quite favorable. The individual sessions had varying degrees of success in achieving the workshop atmosphere where concerted attendee interaction was achieved. The industrial session achieved a greater degree of interaction than most.

It is not clear at this time that a third EMI workshop will be sponsored by NBS. Questions of emphasis, usefulness, format, and timing are yet to be resolved.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report is a summary of the overview talks and session discussions at the 1978 Electromagnetic Interference Workshop, held at the National Bureau of Standards, Gaithersburg, Maryland, on November 2 and 3, 1978. These discussions addressed the following questions: What are the significant Electromagnetic Interference (EMI) problems? How serious are they? Which should be tackled first? What solutions are practical? Who is responsible for solutions? What new standards or changes in present voluntary standards are needed? What is needed for progress? Impacted areas featured at the workshop included communications, transportation, consumer products, industrial, and medical. Workshop speakers and attendees represented a broad segment of decision-makers in both industry and government.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* **Electromagnetic bioeffects; electromagnetic compatibility; electromagnetic immunity; electromagnetic interference; electromagnetic radiation; electromagnetic susceptibility; electronic smog; home entertainment electronics; industrial electronics; medical electronics; microwave electronics; non-ionizing radiation; radiation hazards; radio regulations; radio standards; RFI; spectrum management; standardization organizations; telecommunications; TVI; vehicular electronics.**

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