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Electromagnetic Compatibility: Results of a Limited Survey

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ABBREVIATIONS AND ACRONYMS

ABS	anti-lock brake systems
AIA	Aerospace Industries Association
ANSI	American National Standards Institute
ATP	Advanced Technology Program
BER	bit error rate
CAR	collision avoidance radar
CBEMA	Computer and Business Equipment Manufacturers Association
CDMA	code division multiple access
CEN	European Committee for Standardization
CENELEC	European Committee for Electrical Standardization
ci	current injection
cim	current injection method
CISPR	International Special Committee on Radio Interference
CRADA	cooperative research and development agreement
cw	continuous wave
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
EC	European Community
EEC	European Economic Community
EFD	Electromagnetic Fields Division
EIA	Electronics Industry Association
ELF	extra-low frequency
EM	electromagnetic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMP	electromagnetic pulse
ESD	electric static discharge
ETSI	European Telecommunications Standards Institute
EUT	equipment under test
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDA	Food and Drug Administration
GAMA	General Aviation Manufacturers Association
GTEM	gigahertz transverse electromagnetic
HIRF	high intensity radiated field
IC	integrated circuit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ism	industrial, scientific, and medical
ITE	Information Technology Equipment

ITS	Institute for Telecommunications Sciences
IVHS	intelligent vehicular highway system
JAWA	Joint Air Worthiness Administration
LISN	line impedance stabilization network
MAP	Measurement Assurance Program
MIL-STD	military standard
MRA	mutual recognition agreement
NASA	National Aeronautics and Space Administration
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NLAS	National Laboratory Accreditation System
NTIA	National Telecommunications and Information Administration
NVCASE	National Voluntary Conformity Assessment Systems Evaluation
NVLAP	National Voluntary Laboratory Accreditation Program
OATS	open area test site
OEN	Office of European Norm
OSAH	Occupational Safety and Health Administration
PC	personal computer
PCB	printed circuit board
PCS	personal communication service
rf	radio frequency
Q	quality factor
SAE	Society of Automotive Engineers
SAR	specific absorption rate
SCUSA	Standards Council USA
TDMA	time division multiple access
TEM	transverse electromagnetic
USCAR	U.S. Cooperative Auto Research
VDT	video display terminal
VLF	very low frequency
VSWR	voltage standing wave ratio

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The purpose of this report is to give up-to-date information on the measurement-related needs and problems associated with electromagnetic compatibility (EMC) that are identified by U.S. industry. To achieve this goal, we interviewed representatives of 28 major U.S. industries, 5 industrial associations, 1 university, and 7 government agencies concerned with electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues related to product performance and compliance, equipment use and manufacture, safety, and health. Although this report does not give specific recommendations for an expanded EMC technology program in the Electromagnetic Fields Division at NIST, it contains a wealth of information that should be considered in the Division's planning exercises. The anticipated result is a NIST program in EMI/EMC measurement technology that will provide optimum support to U.S. industry.

Key words: compatibility; electromagnetic field; emission; immunity; interference

1. INTRODUCTION

Electromagnetic compatibility (EMC) refers to the ability of electronic and electromagnetic systems to operate and perform their intended functions without any adverse effects on other systems or the environment. That is, the systems are capable of existing "compatibly" in a common physical and electromagnetic environment. As used here, EMC covers all types of interference and extends to biological hazards associated with electromagnetic fields. Electromagnetic compatibility is of increasing concern to industry, government agencies, and the general public since it has impacts in four important areas – economics and competitiveness, national security, health, and safety. As the number and use of electronic systems increase, these problems become more severe. Hence, appropriate steps must be taken to ensure that products have sufficient immunity to electromagnetic fields and do not emit fields that can interfere with other systems.

In order to control emissions, provide adequate immunity, and thereby achieve electromagnetic compatibility, performance standards which cover many (but not all) products manufactured in the U.S. have been developed. Measurements and tests are required to determine compliance with these standards. One of the main purposes of the National Institute of Standards and Technology

(NIST) is to provide industry and other government agencies with the measurement tools they need to do their jobs well. The Electromagnetic Fields Division (EFD) of NIST (located in Boulder, Colorado) develops physical standards and measurement techniques for electromagnetic quantities. This Division develops standards and measurement techniques relevant to EMC metrology and provides appropriate EMC calibration services to industry and government agencies. By this means NIST helps U.S. industry remain competitive in national and international markets by complying with EMC standards and regulations. Government agencies are also provided with the measurement support they need to carry out their assigned missions.

In order to better provide the nation with EMC metrology support, we believed it imperative to obtain reliable, first-hand, up-to-date information on the measurement needs and problems associated with EMC. Therefore, with the encouragement and approval of all levels of NIST management, the EFD undertook a survey to identify the important EMC issues confronting U.S. industry and government today. The data obtained from this survey will enable NIST to more accurately define (or redefine) its role and to plan a forward-looking EMI/EMC program responsive to the specific industrial needs and requirements identified. The anticipated result is a NIST program in EMI/EMC measurement technology that will support U.S. industry.

2. EXECUTIVE SUMMARY

The survey was conducted by Motohisa Kanda, Leader of the Fields and Interference Metrology Group, and Ramon Baird, formerly Chief of the Electromagnetic Fields Division, now retired. Our objective was to interview representatives of major U.S. industries concerned with EMI/EMC issues related to product performance and compliance, equipment use and manufacture, safety, and health. We also visited representatives of prominent EMC test houses, government regulatory agencies, industrial associations, and standards organizations to obtain their views. We visited 23 private companies, 5 industrial associations, 1 university professor prominent in EMC, and 8 government agencies, for a total of 37 different organizations. The areas covered included aerospace and aircraft, computers and peripherals, motor vehicles, medical equipment, consumer electronics, and telecommunications.

The visits were arranged in advance by telephone. In addition, letters were sent to each person one to two weeks before the visit so that they would have time to prepare. These letters explained the purpose of our visit and outlined the issues and problem areas that we wanted to discuss. In particular, we asked them to consider the following questions:

1. What are the most serious EMI/EMC problems confronting you today?

2. What are the most critical regulations and standards? Which measurement requirements are most difficult to meet?

3. What specific measurement problems do you have? What accuracy and range limitations exist?

4. What new or evolving technologies do you foresee? What new or improved measurement techniques and standards will be required to support these technologies?

5. What is the impact of better measurements on performance, safety, and economics? Do you have any supportive examples?

6. How can NIST assist you in overcoming technical problems? In meeting the requirements of national and international EMI/EMC standards?

7. In general, what type of NIST technical support would be of greatest value to your organization?

We found that these questions did indeed address issues of importance to the entire EMC technical community. All of the people interviewed are experienced and knowledgeable in EMC, and many are prominent in relevant professional societies and committees. Consequently, the information obtained from the survey represents a good cross section of American industry and government and reflects the views and needs of the EMC community.

The visits and interviews were conducted during June through August 1993. Subsequently, the comments and responses were classified and arranged according to topics. The remainder of this report consists of summaries of this information, organized under headings corresponding to the seven questions listed above. In this discussion we have tried to retain much of the flavor of the original comments. Some redundancy inevitably occurs due to overlapping issues and different people making essentially the same comment in different contexts.

The survey identified many important technical tasks appropriate for NIST which are listed below. The number in parentheses indicates the number of organizations which cite the technical tasks, and the alphanumeric label indicates the identification of the individual organization listed in Table I.

A. Aerospace and aircraft industries

Immunity testing at high intensity radiated fields (HIRF)
(16 = A4, A5, A7, A15, A17, A18, A19, A20, A21, A22, A23, B1, B4, D3, D5, D8)

Correlation of current injection tests to radiated field testing
(10 = A5, A10, A14, A15, A18, A19, A21, A22, B4, C1)

Immunity testing for electromagnetic pulse (EMP) (radar, lightning, etc.)
(8 = A3, A5, A9, A10, A12, A18, A19, A22)

Environmental EM surveys and predictions near airports and roadways
(7 = A4, A5, A7, A11, B1, B4, D3)

Correlation of sub-system or module tests to whole system qualification
(6 = A3, A5, A6, A13, A18, D3)
Test procedures and emissions limits for carry-on personal electronics
(5 = A2, A5, B3, B5, D3)
Techniques for measuring shielding effectiveness of gaskets and bonding materials
(5 = A7, A15, A18, A22, C1)
Shielding effectiveness measurements of composite airframes
(2 = A5, D3)

B. Computer and peripherals industries

New integrated circuit (IC) and printed circuit board (PCB) emission/immunity test methods
(6 = A6, A7, A10, A11, A15, A19)
Alternatives to open area test site (OATS) testing
(6 = A2, A10, A13, A14, A15, A21)
Evaluation of absorber-lined shielded room measurements
(5 = A4, A7, A11, A19, A22)
Criteria for intercomparison and evaluation of facilities
(4 = A2, A13, A14, B4)
New test methods for broadband signals
(1 = C1)

C. Motor vehicle industries

Radiated immunity and emissions testing for large systems
(9 = A3, A5, A10, A11, A13, A15, A18, C1, D3)
Reverberating chamber study
(6 = A4, A6, A7, A12, A22, C1)
Immunity testing for collision avoidance radar (CAR)
(2 = A10, D4)
EMC test procedures for effects on external systems of high currents and magnetic fields of electric vehicles
(2 = A10, A11)
Techniques for measuring shielding effectiveness of nonmetallic bodies
(1 = A19)

D. Medical equipment industries

Test procedures and limits for radiated emissions/immunity
(7 = A13, A14, A19, D2, D4, D5, D8)
VDT safety test procedures and emissions and limits
(3 = B3, D5, D8)
Characterization of EM environments in medical facilities
(1 = A12)
Standards and tests for systems sharing industrial, scientific, and medical (ISM) bands
(1 = D7)

E. Consumer electronics industries

New EM field probe developments
(13 = A2, A4, A5, A7, A11, A14, A15, A22, C1, D1, D2, D5, D8)
Characterization of anechoic materials; rf absorbers and ferrite tiles
(3 = A12, A13, A19)
Test methods for immunity to electrostatic discharge (ESD)
(3 = A15, A19, A21)
Swept frequency calibration methods for broadband antennas
(2 = A12, D2)
Semi-anechoic chamber performance and correlation to open area test sites (OATS)
(2 = A21 D2)
TV receiver/VCR immunity testing procedures and emissions limits
(1 = D4)
Evaluation of performance of gigahertz transverse electromagnetic (GTEM) cells
(1 = A12)

F. Telecommunication industries

Probe calibration/transfer standards
(21 = A1, A2, A5, A7, A9, A10, A11, A12, A13, A14, A15, A16, A19, A20, A21, A22, C1, D1, D5, D6, D8)
Environmental EM surveys
(9 = A1, A6, A11, A12, A20, C1, D1, D5, D8)
Cellular phone personal communication service (PCS) interference to hearing aids, health hazards, etc.
(8 = A2, A10, A19 B5, D1, D4, D5 D8)

Emission/immunity test methods for higher microwave frequencies
(7 = A2, A6, A9, A11, A15, B3, D4)
EMI test methods for spread spectrum and digital communication
(3 = A14, A21, D7)
Standards and test methods for communication systems sharing ISM bands
(3 = B3, B5, D4)

The survey also revealed more general, but serious, EMI/EMC related issues confronting U.S. industries.

A. The survey confirmed that EMC issues pervade modern industry, and they will increasingly affect the public if the necessary performance standards and metrology are not developed and applied. The very fact that EMC issues are so widespread contributes to the problem. No single industry or group wants to take responsibility for solving the problems, so existing efforts are diffused throughout many industry organizations and segments. This is an important argument for greater government oversight in EMC standards and metrology.
(15 = A1, A3, A4, A7, A12, A13, A19, A21, A23, B1, B3, B4, D4, D6, D7)

B. One thing became very clear during the survey. Both industry and the regulatory agencies think NIST should become more involved with national and international standards-making bodies and should take the lead in establishing a national laboratory accreditation program in EMC. This may not be the traditional role of the EFD, but it is what industry wants and needs. At the very least, the EFD should assign someone to participate in CISPR (International Special Committee on Radio Interference) Sub-Committee G which is concerned with EMC measurements and standards. This NIST representative would be in a position to influence committee decisions and to know what is going on internationally. He or she could use this "inside" information to provide direction to the Division's technical research efforts.
(25 = A1, A2, A3, A5, A6, A9, A10, A11, A12, A13, A14, A15, A19, A20, A21, A22, A23, B2, B3, B5, C1, D2, D4, D6, D7)

C. There is strong sentiment for some kind of National Laboratory Accreditation Program, administered by NIST of the Department of Commerce (DOC), for EMC test labs. Exactly how NIST can best promote an accreditation program is not clear, since its efforts are currently hampered by lack of funds and perhaps, by lack of legal authority to establish such a program. This type of program transcends the EFD and would have to involve the NIST Office of Standards Services and perhaps the DOC. In any event, the EFD must be involved since its technical expertise and contributions are essential for a successful program.
(15 = A1, A2, A3, A13, A15, A19, A20, A21, A23, B2, C1, D2, D4, D6, D7)

D. EMC metrology is considered by some to be a rather mundane technology. This is far from the truth. The technical problems are often quite intractable and solutions do not come easily. The measurements and tests cannot always be performed in a controlled laboratory environment, and extraordinary care is required to obtain accurate measurements. Consequently, a lot of poor measurements are made. These problems are compounded by the fact that most industries are very cost conscious and are looking for the simplest, most cost-effective methods for EMC testing available. Many small companies cannot afford elaborate tests and may curtail testing if the costs are too high. Hence, whatever NIST could do to provide repeatable measurements at lower cost would be extremely valuable.

(14 = A4, A7, A10, A12, A19, A20, A23, B1, B4, C1, D2, D4, D6, D8)

E. Industry is more concerned with repeatability than accuracy. Accuracy has an exponential cost curve associated with it, but high accuracy is not normally required. Current NIST standards are more than adequate to support EMC metrology if they are applied properly. The entire industrial measurement chain will have to tightened to achieve an EMC testing repeatability of 3 dB. It is probably in this area that NIST could have the greatest impact.

(14 = A1, A2, A3, A5, A10, A12, A13, A14, A16, A20, A21, B3, C1, D6)

The survey identified many important technical tasks appropriate for NIST. Because NIST cannot do all of them with existing funds, we should select only those areas of greatest interest and need for inclusion in an initiative. Additional committee activities may detract from the primary function of developing standards and measurement methods, work which is equally important in achieving the goal of better measurements throughout the EMC community. Therefore, we should choose external activities with care so that a balance is maintained between purely technical projects and committee-related activities. It seems entirely appropriate for NIST to seek additional funds for participation in international committees, and therefore this should be a prominent item in any EMC initiative or request for funds.

3. SUMMARY OF RESPONSES TO SURVEY

3.1 The Most Serious EMC Problems

3.1.1 Lack of Unified International Standards, Regulations, and Testing Methods

The lack of a single, unified set of EMC standards and regulations, accepted internationally, was perhaps the most cited problem area. This attitude is largely due to recent European Community (EC) legislation requiring virtually all electrical and electronic products sold in Europe to meet EC emissions and immunity standards. However, the problem is not restricted to Europe. The lack of international standards combined with a multitude of national standards produces de facto trade barriers for exporters of products. This is certainly the case for telecommunications products, since almost every foreign country has a different set of regulations for products that attach to phone lines. Economically, the single most important issue regarding regulations and standards today for Information Technology Equipment (ITE) is the lack of uniform standards worldwide. We were told that this is very important.

Regional standards, such as those of the EC, represent a potential threat to the United States when the U.S. cannot get information on the draft standards in a timely manner. This allows European manufacturers easier access to the standards and faster access to the market by starting their product development earlier. A related problem is that the U.S. does not have standards in some areas. This hurts American manufacturers because their products cannot compete in world markets. Further, the EC immunity standard is the only one in existence. We must meet their standard but they do not have to meet any U.S. standards; this gives them an unfair trade advantage. Moreover, the Federal Communications Commission (FCC) accepts EC test data but the EC does not accept our test data. Our respondents' reaction was: "Why is this? It is not fair to U.S. industry!"

Another aspect of this problem is the lack of unified testing methods which results in costly test facilities to address different but related needs. For example, one EMC standard requires shielded enclosures for military tests, open area sites for FCC tests, and anechoic rooms for EC tests. A single set of universal standards is needed. At present, products must meet FCC, MIL-STD (Military Standards), EC, and IEC (International Electrotechnical Commission) requirements, depending on the location and type of customer. Why can we not be consistent and all use the same standard? Our system of voluntary standards further confuses the issue, since the various standards organizations, Institute of Electrical and Electronic Engineers (IEEE), American National Standards Institute (ANSI), Society of Automotive Engineers (SAE), etc. all have their own standards. National, unified standards would save considerable money by eliminating redundant testing and test equipment. If NIST will help promote unified standards, it will be doing the country a great service, we were told.

The bottom line is that manufacturers would like to be able to test their products once to a single set of standards for marketing worldwide. The European standards are, by and large, transpositions of CISPR (International Special Committee on Radio Interference) and IEC standards. Some are new, under development, or in process of being amended at the international level, particularly those concerned with immunity. These standards should be adopted by the United States so that one standard applies internationally. Industry would like to see the U.S. exert greater influence in CISPR and IEC to promote the development and adoption of international standards.

3.1.2 Lack of International Acceptance of U.S. Test Data and the Need for a National Laboratory Accreditation System (NLAS)

Regional standards pose another problem to the United States. Regional authorities can require that the testing of products to their standards must be done by "qualified laboratories" and limit the qualified laboratories to those located within the region. The EC is already doing this in the area of telecommunications where only "notified" European laboratories can approve telecommunications equipment. Manufacturers and U.S. laboratories would, naturally, like to have the Europeans (and others, where relevant) recognize the EMC test results and product certifications performed in this country.

The Europeans seem to place a greater emphasis on testing and certification than do we in the United States. The policy set forth by the EC could lead to control of their market place by testing and certification. This could result, at worst, in trade barriers and, at best, in economic and logistic hardship for U.S. manufacturers trying to penetrate the EC market. Such policies of either total or partial nonacceptance of U.S. test data will have a devastating effect on independent testing laboratories in this country.

One argument made by the EC is that "they are not quite sure how to accredit U.S. laboratories." The basis for such statements is that we do not have a national system for accrediting laboratories. They, of course, mean a government-approved system, since that is the way most other countries operate. The people we interviewed were nearly unanimous in their belief that some kind of National Laboratory Accreditation System (NLAS) is badly needed for EMC, and most felt that NIST should take the lead in establishing and managing such a program. Without exception, they felt that NIST involvement would lend credibility to the program and that the tests done by these "accredited" laboratories would be recognized and accepted by foreign governments. They felt quite strongly that NIST should be involved in evaluating the independent test laboratories that evaluate company performance. NIST sanction of test procedures and laboratories would help sell whatever program we adopt to the EC and internationally.

The U.S. needs a national program for certifying labs for EMC testing, and the required test methods should be down to earth and practical. Many believe that the existing National Voluntary Laboratory Accreditation Program (NVLAP) may be a starting point but NVLAP needs to get better and expand to cover the industry. (A few companies said they were paying money into NVLAP but did not believe they were getting anything out of it.) NVLAP could be much more effective and it should work with FCC to solve problems of national importance. NVLAP should also be coupled more strongly with the Electromagnetic Fields Division's technical expertise. Companies would feel better if the EFD were involved in the testing and accreditation process. The present system does not provide rigorous measurements. This is one reason for poor international acceptance of U.S. tests. The EFD should provide greater technical support to NVLAP. Official NIST technical backing would help sell certification to the EC and would enhance our credibility and international competitiveness.

The automotive industry is a notable exception in terms of meeting international standards. This is because most EC standards are also SAE (Society of Automotive Engineers) standards, since U.S. engineers were on the international committees. U.S. auto makers also provided to CISPR inputs which were incorporated into EC documents. Automobile manufacturers routinely test for compliance with internal EMC standards that are far more demanding than the EC standards.

However, certification, which comes through an observer from an EC standards body, still poses problems. Several new vehicular EMC testing facilities are being constructed to meet EC standards requirements.

3.1.3 Need for More Government Leadership and Involvement

United States standards activities are divided among many organizations; this presents difficulties in dealing with other countries. One source stated that the EC is "beating us over the head" with its unified approach with respect to standards. Industry believes government support for standards setting can be most clearly justified in the international arena and that the federal government should establish some kind of charter with standards organizations to represent the U.S. internationally. "The U.S. must become a leader in international standards." The perception is that the Federal government is not responding to the needs of a competitive U.S. industrial base; this failure of government to do its job hurts our manufacturers in EC competitiveness. There are some things the private sector cannot do that require government involvement, and industry is looking for someone to take the lead in coordinating these efforts.

The United States government must become involved in the crucial issue of Mutual Recognition Agreements (MRA) between countries on the mutual acceptance of test laboratory results. These agreements must be signed by official representatives of the respective governments. Such agreements would allow U.S. manufacturers to design, build, and test their products for EMC standards compliance completely within the United States and market them any place in the world.

NIST has proposed a new fee-supported scheme called the NVCASE (National Voluntary Conformity Assessment System Evaluation) program for regulated products. It would establish an EMC Mutual Recognition Agreement between the U.S. and the EC, and NIST would provide a list of accredited test houses. Companies would come to NIST and request accreditation under this NVCASE program. They could be accredited by NIST, NVLAP, or other accredited laboratories that meet the criteria. If adopted, this program would certainly help solve the problem. Some industry people do not think that the regulatory agencies will take the lead in resolving these issues and would welcome a NIST leadership role.

There seemed to be a consensus for more NIST involvement in both standards setting and technical roles. The DOC should take the lead and negotiate standards and methods that are acceptable everywhere. NIST could help in interacting with the EC to achieve realizable standards and tests. Important EMC technical issues need addressing but political issues are standing in the way of getting anything done. One lead agency is needed, and the EC seems to be playing on our confusion. The U.S. has no national standards or accredited technical testing methods. NIST could provide extremely valuable coordination and leadership in this area. The Department of Commerce, utilizing NIST, should assure the quality of designated testing laboratories and certification centers. Additionally NIST could help by getting more involved with international technical advisory groups and committees, especially CISPR-G which covers measurements and standards. It should also perform research and development in support of U.S. standards. In general, there needs to be greater concern in the U.S. for better measurements and NIST should help bring this about.

Several people said that the EFD should work more closely with the NIST Office of Standards Services and should provide more technical support to the FCC. The FCC could benefit from NIST technical competence.

3.1.4 Lack of Repeatability in EMC Measurements

The most frequently mentioned measurement problem was the lack of repeatability in emission and immunity measurements. This problem exists throughout the industry due to a lack of standardization and applies to techniques, equipment, sites, standards, and companies. Large variances occur from setup to setup and site to site, and most dramatically from facility to facility. Sizeable discrepancies also occur among EMC test house measurements. Because this lack of repeatability costs a lot of money, industry would like help from NIST to correct the situation.

There is no error management or error budget strategy included in the standards and regulations. A rigorous error analysis of each measurement process should be done, and NIST is the logical organization to do it. The analysis should consider specific aspects of a test setup such as antenna, cable, and site attenuation. For example, the 4 dB limit on site attenuation is too loose. There need to be a better definition of the ground plane itself and a study of the differences between ground level and roof-top sites. An analysis of these and other related issues would benefit the entire industry.

Some companies have found measurement repeatability to be a serious problem among their own test sites. We were asked if it is possible to normalize measurements to NIST or to one of their own sites. Could NIST study this problem and determine if it is a feasible approach? For instance, a study could address the metal portions of antenna masts and turntables to determine their effect on test site performance and repeatability.

Repeatability is more important to the industry than accuracy. Measurement results must repeat from one time to another and from one laboratory to another. Now, however, discrepancies can be 8 to 10 dB or more. Measurements within 3 dB are adequate for most EMC purposes.

3.1.5 Increasing Interference among Industrial, Commercial, and Telecommunications Equipment and Systems

A growing problem is the interference of industrial and commercial equipment with communications systems. Many new services are planned for the 2400 MHz to 2500 MHz ISM (industrial, scientific, and medical) band, causing concern about interference from microwave ovens which operate at 2400 MHz. Included are personal communication services and mobile communication systems involving satellites. Another 200 MHz band somewhere between 1 and 6 GHz is being sought for mobile (satellite) services. Both in- and out-of-band interference are caused by leakage from microwave ovens. Harmonics are a problem since the radiated field levels from some ovens increase with frequency. Can these communications systems coexist with microwave ovens and other commercial equipment? The required test procedures are inadequate and not well defined. NIST could help by developing standards and test procedures. With this problem in mind, the FCC reports a need for practical, economical measurements of emission levels and immunity above 1 GHz. One important issue is whether microwave-oven emissions should be reduced to accommodate communications systems in the ISM band.

The FCC reports an increase in the number of complaints of interference in homes, especially telephones. The number of complaints of TV interference is down slightly, but this may be due to more cable systems, which are more nearly immune to radiated fields. There are no EMC or immunity standards covering such commercial units.

Other significant interference problems confronting the electronics and telecommunications industries are:

- Direct pickup of interference by TV receivers connected to cable TV. What immunity do TV receivers require?

- Interference from personal electronics devices carried aboard aircraft. This is a definite safety issue. There have been a lot of incidents but few have been verified as due to EMC.

- Home radio interference. Better education may be the answer to this problem.

- Interference with hearing aids by cellular radio signals. This needs resolving.

- Video display terminal (VDT) safety measures. What are safe field limits and what can be done to control these fields?

All of these issues require measurement and standards support to resolve.

3.2 The Most Critical Standards and Regulations

3.2.1 General Immunity and Emission Standards

The main standards of concern to the commercial electronics industry are the EC Radiated Immunity Standards (immunity to radiated emissions). These standards are driving the industry, and compliance does not always come easily. Tables II and III are lists of EC standards, together with the CISPR and IEC standards upon which they are based. The U.S. has some equivalent standards and there are some industrial standards for specific industries (for example, SAE standards for the automotive industry), but not all areas are covered. Some of these U.S. equivalent standards are listed in Table IV. The U.S. does not have any immunity standards, which is a real concern to industry since immunity specifications are the most difficult to meet.

We need a U.S. equivalent of IEC 801, which is required of all equipment sold in Europe. The absence of radiated emissions and immunity tests is the major problem, and we need rigorous, practical methods for making these measurements.

CISPR standards and measurement methods are most important to the National Telecommunications and Information Administration (NTIA), which is currently most concerned with the microwave area (1 to 6 GHz), since NTIA must not only demonstrate that communications systems are protected from radiation from other devices (such as microwave ovens), but must also obtain standards and procedures for immunity testing of receivers (TV, radio, communications, ISM, etc.).

Emissions standards are most important to some industry segments because of FCC regulations which restrict emissions and are governed by FCC Part 15. Information technology equipment (ITE) manufacturers follow FCC Part l5, ANSI (American National Standards Institute) C63.4, EN 55022 (CISPR 22), EN 50082-1 (Generic Immunity Standard including IEC 801-3 on RF Immunity), and VCCI (Voluntary Control Council for Interference by Data Processing Equipment and Electronic Office Machines, the Japanese version of NVLAP). They would like one unified standard. Emission tests are also important for health and safety reasons but standards and regulations are inadequate. For example, exposure levels, Specific Absorption Rate (SAR), etc. for cellular phones are not defined. The Electronics Industry Association (EIA) is currently funding studies of this issue and is documenting telephone systems. The associated metrology issue is near-field measurements, an area where NIST could help.

Standards that affect human life and safety, such as those issued by the Federal Aviation Administration (FAA) and the Food and Drug Administration (FDA), which cover avionics and medical equipment, are very important. Many unresolved problems exist with respect to medical equipment and devices. There are no government standards for medical equipment, which is exempt from FCC regulations. The main problem for the medical community is meeting the EC standards for emissions and immunity, but no U.S. regulations cover them. Equipment approved in the U.S. is not acceptable in Europe without the addition of shielding. There are also IEC standards, including a new IEC immunity standard for medical devices of 3 V/m. Most U.S. manufacturers are not even aware of it. There is a need for better standards, but it is not clear how to get them. The FDA cannot broadly impose them; a need must first be demonstrated, and the process takes a long time.

To sum up, manufacturers are concerned about the differences among labs for testing in general, but most specifically for immunity testing. They now rely on generic immunity standards since product family standards are still under development in Europe. Those companies that work for the Defense Department are primarily concerned with Military Standards.

3.2.2 High Intensity Radiated Fields (HIRF) Standards

Radiated immunity measurements in fields above 200 V/m are designated as HIRF (high intensity radiated field) testing. This is a special case of radiated immunity, but difficult measurement problems and standards issues arise due to the high fields involved. HIRF standards are most important to military contractors and to the commercial aviation and aerospace industries. Because the Department of Defense (DOD) is concerned with EMP phenomena, the military, commercial aviation, and aerospace industries are all concerned with lightning simulation.

HIRF testing is probably the biggest problem for the FAA because there are no standards for external fields illuminating the aircraft. FAA funding is down and expected to remain down for 2 to 3 years, so FAA-sponsored research in this area is limited. The FAA has designated two classes of equipment that must be immune to HIRF:

1. Flight Critical Systems (such as aircraft control systems). These must be immune to all external fields. Fly-by-wire systems with no mechanical backup are susceptible to HIRF and are, therefore, very critical.

2. Essential Systems (such as navigation, altimeters, communications). These are important but don't affect flight capabilities, so a higher probability of failure can be accepted. The FAA is currently developing rules to cover these systems. The aircraft industry wants the rules to be consistent with international rules established by the Joint Air Worthiness Administration (JAWA).

The General Aviation Manufacturers Association (GAMA), the Aerospace Industries Association (AIA), and their constituents indicate that HIRF and lightning test requirements are the most difficult to meet. Compliance with the constantly changing HIRF test procedures is also a problem. No firm regulations have been established by the FAA; instead, they have established "special conditions." Specific regulations, consistent with the actual environment, are needed. Many feel that the field levels specified in the "special conditions" are too high and not realistic. Other pertinent documents are the RTCA DO160C, Boeing D6-16050-4, and Airbus ABD0007, which cover environmental conditions and test procedures for airborne equipment. Adequate HIRF standards are very important considering the potential implications for aircraft safety and national defense.

3.3 Specific Measurement Issues and Problems

3.3.1 Characterization of Electromagnetic Fields and Environments

Better methods of characterizing both test and environmental fields are needed. Known electromagnetic environments are needed for radiated immunity tests and, according to one report, such fields cannot be replicated within 12 dB. A cost-effective, reliable method of validating uniformity of test fields is required to correct this situation. A proposed FDA standard covers this, but is not practical; for example, 6 weeks were required to map one test field in accordance with this standard. Repeatability is more important than high accuracy; 3 dB is adequate for most situations. A means of characterizing emissions over a sphere is desirable.

More-accurate methods for monitoring and measuring radiated fields are needed. There is too much variation in results from different methods and sensing techniques, especially for HIRF. Accurate measurement of radiated emissions below 2 MHz is required for measuring AM emissions (on vehicles), which affect AM radio performance. To comply with the ANSI exposure guide, an rf dosimeter must be developed to measure cumulative operator exposure for a workday (1.8 MHz to 1200 MHz). Techniques for measuring H-field exposures below 100 kHz, including 60 Hz, are needed for the same reason.

Better low-level emissions measurements from 300 MHz to 2 GHz require a simple, less expensive, less bulky means of characterizing broadband signals. Existing systems miss effects because the sweep time is too long. In general, more accurate emissions measurements are needed above 1 GHz, where spectral analyzer accuracy may be only ± 7 to 10 dB. Near-field measurements are still a problem in cellular bands (800 to 1000 MHz) and should go to 2 GHz or higher. Better ELF and VLF field measurements are needed to cope with hazards issues.

NTIA said that it requires better standards and test procedures for emission and immunity tests above 1 GHz and below 30 MHz. Near-field measurements are a concern, and if NIST would evaluate the Van Veen loop it would benefit the entire EMC community. Cellular radio and personal communication systems require EMC analysis and measurement for safety and performance reasons. "How do you measure accurately the near fields of hand held devices, e.g., H-fields from cellular phones at 1 GHz?" Tutorials on this topic and the measurement of hazardous fields in general would be useful.

The FCC indicates a potentially serious interference problem below 30 MHz related to rf (electrodeless) lights. These new light bulbs will soon be on the market in response to new Department of Energy (DOE) efficiency standards for lighting. There is already one at 2.6 MHz. These devices are not covered presently by the FCC, yet millions of them will be made. How should the emissions be measured? Is the Van Veen loop adequate? NIST could provide a great service by evaluating the Van Veen loop or recommending a different method.

The FAA requires aircraft to meet severe EM environmental tests without verifying that the environment exists outside the test, and the automotive industry is concerned about fields along highways. They could waste much money if they are required to provide EMC hardening to 18 GHz if there are no significant fields above 1 GHz. Someone needs to identify the frequencies of significant sources, the number of sources at each frequency, and the peak field each source produces along public highways. Worst-case information is needed, and the measurements should be repeatable within 3 dB. These data could be used to determine the upper frequency limitation for radiated immunity testing and if the regulations are out of line. NIST could be of great help in determining just what the environment is and validating the environmental rules. Perhaps a joint project with the Institute for Telecommunication Sciences (ITS) is in order if environmental surveys are required.

3.3.2 Open Area Test Site (OATS) Measurements

The open area test site is probably the oldest and most widely used facility for many EMC tests. Despite this, problems with its use still exist. Some of them are:

- Uncertainties due to ambient signals.
- Difficulties with site qualification (the normalized site attenuation model is written into CISPR documents but there are questions on the sensitivity of this model to actual site parameters).
- Field uniformity requirements for immunity tests are difficult to meet.
- Disagreements on the proper testing distances. Some labs use whatever distance is suitable to the user.
- Some standards are difficult to meet, although the cost and time involved are the main problems.

Added to these is the difficulty in obtaining repeatable measurements when using commercially supplied support equipment which may or may not be in compliance with the standard (for example, use of printers or monitors, when testing PCs). Many times, the emissions of the support equipment either exceed the test specification or are much greater than the equipment being tested.

Valid and useful concepts and methods for OATS testing above 1 GHz need to be developed and disseminated to users. Some issues are: What are the best antennas for emission and immunity tests in this frequency range? Is site attenuation a useful concept for microwave testing? If so, what are the criteria? If not, what concept replaces it and where is the dividing line (frequency)?

3.3.3 Measurements in Shielded Enclosures

Some of the current problems/issues with respect to measurements in shielded rooms are:

- There are no standards for frequency response, VSWR, etc. A standard EMI generator would be a great help in qualifying shielded rooms.
- Disagreement exists over which test distances to use; some prefer 3 m, others prefer 1 m.

- Better ways of measuring/monitoring fields during equipment tests are needed, especially at 30 to 100 MHz. An uncertainty of less than 6 dB is desirable. Automobile companies would like to measure H-field versus frequency in cars (including those fields generated by the car). Could NIST develop a small, practical H-field probe/system for this purpose?

Absorber lined shielded rooms present other problems to solve and questions to answer. A reliable method for determining the performance of absorber-lined rooms is needed, along with a technique for determining the losses (Q) of such rooms. MIL-STD 461-D (which deals with absorber-lined rooms) may be acceptable, but the anechoic material and room performance need evaluating. Better absorbers and tiles are appearing, and better ways of evaluating their performance must be developed. This is a good task for NIST.

How good is the semi-anechoic chamber (a shielded room with strategically placed absorbing material)? How do you account for field disturbances when devices are put in the chamber? An evaluation of these facilities should be undertaken and should include rooms with ferrite tiles. Any evaluation should determine the minimum cost approach for adding absorbing material so that adequate performance is achieved while providing a reasonable working space. Broad-range, multi-use chambers like the gigahertz transverse electromagnetic (GTEM) cells are very useful, but they need to be evaluated by a neutral party. NIST should undertake both of these evaluations and publish the results for the benefit of industry. This would be a great service to the EMC technical community.

The reverberating chamber is thought to be a good broadband technique but it removes polarization data. Most laboratories still prefer testing in uniform fields. Other concerns are: not everyone has the capability; many have large investments in standard chambers; and it is not clear that the required field strengths for (HIRF) testing can be generated. In spite of these problems they have a niche and will be used. Their use could be enhanced by the development of probes that are responsive to pulsed fields. Frequency/phase stirring should be studied as an alternative to mechanical mode stirring. It may be faster and could complement mechanical stirring. We were asked if it is possible to convert absorber-lined shielded rooms to mode-stirred chambers by putting temporary metal screens in front of the absorber. NIST should investigate all of these issues and report on them.

3.3.4 Antenna and Probe Calibrations

Antennas used for EMC work are generally poorly calibrated and the antenna factors are not well known. There is considerable disagreement on how to calibrate antennas for EMC measurements. The main frequency band is 10 kHz to 1 GHz, but there are problems below and above this band. Large variations in antenna factors are observed, depending on who does the measurement and how the antennas are used. "No one knows the correct antenna factors used for site surveys," was a comment made to us. Differences of 10 to 12 dB are noted between biconical antennas and dipoles, when they should be the same. This is especially true for 3 m testing in shielded rooms. The industry needs better known antenna factors that are determined for the particular situation in which they are used.

A related issue is the accurate calibration of field strength meters. Calibrations are not consistent; typical differences are 6 dB and can go as high as 12 dB on occasion. Variations exist even among those of the same type of meter from the same company. Some companies would like to do in-plant calibrations. Is there a way to calibrate meters in company facilities? Could NIST help establish a method and set up facilities that would provide repeatable measurements? A Measurement Assurance Program (MAP) would be effective in achieving the desired repeatability and might be supported by enough companies to succeed.

At least one manufacturer of field strength meters would like a reference or transfer standard and a general, practical procedure that works for all sensors and test locations. The transfer standard would function as a standard "black box" for measuring fields. It should be capable of effecting calibrations in TEM (transverse electromagnetic) cells to 2 dB. The manufacturer believes his sensor is accurate to 1 dB, but with meter, handle, cable, etc., attached it is no better than 3 dB. Can the overall accuracy be improved through better compensation for these perturbations?

3.3.5 Testing of Large Systems

Radiated immunity testing of large systems is important but fraught with difficulty. Systems with 10 m dimensions and larger must be tested over the entire rf and microwave spectrum, but problems are more severe above 1 GHz because of insufficient dynamic range. In situ testing would be very useful if rigorous methods could be developed. They would be used primarily by large companies and the DOD because small test houses probably could not afford the necessary facilities. Large companies would still have to test their own large systems. The VLF frequency range may become important in the future because of potential hazards.

More efficient antennas with low antenna factors are needed from 1 to 40 GHz to avoid making measurements in the noise. One problem is the 10 m separation required since ambient fields must be 6 dB below the test limit. The automobile industry cannot consistently generate the 100 V/m fields required for immunity tests. They use chambers but cannot obtain field uniformity over the required volume. They need a practical, cost-effective way of illuminating an entire vehicle. Radiated emissions testing is generally acceptable, but sometimes they are forced to measure only 6 dB above the noise floor. They would like to know where to place the antennas to optimize vehicle radiated immunity tests above 1 GHz. They also need to know what type of modulation produces a realistic worst case test for different frequency bands and systems. For example, is pulse or cw best for radar? Pulse or AM for TV? RF for on/off switching? What are AM and FM most suited for? Is this an energy or frequency problem?

3.3.6 Measurements Associated with HIRF

There are no standard procedures for HIRF testing of aircraft. Some fundamental tasks that need to be done are:

- Determine what tests are required to obtain the desired information (military and commercial aircraft needs are different).

- Develop adequate measurement techniques and establish accuracies.

- Develop cost effective field strength measurement methods, probes, standards, and calibration techniques (400 MHz to 1 GHz).

Generation of the required high field levels is also a serious problem, especially above 2 GHz. Sources and equipment are very expensive, and this limits the companies that can perform these tests. For example, immunity tests to 200 V/m at 1 GHz for a 1 m separation distance costs $1.5 million for the equipment alone – this is too expensive for most companies. Alternative, less expensive methods would be welcome.

These are questions concerning what constitutes EMC and what levels of interference or immunity are required? Clearly, better definitions and standards are needed. Further, there are large differences between HIRF test results in a laboratory and real world events. More knowledge of how short duration, high energy pulses penetrate an airframe is needed. The best test may be whether the equipment works on the aircraft or not. The aircraft environment is different from the test environment and it is impossible to test in all configurations. If NIST could provide a more accurate model that would explain these relationships, a more rational test program could be established.

HIRF tests on a simple digital system have been run at several facilities showing variations in immunity of up to 14 dB. A method to correlate or calibrate these variations out of the measurements would be extremely useful. This applies to both immunity and emission measurements.

A standard automated test set and software are needed to provide consistent measurements among various test labs. The equipment is very expensive and standardization could reduce the cost. Could NIST help in any way?

HIRF tests are difficult, expensive, and time consuming. One manufacturer spent $2.5 million on full-scale testing of one aircraft. There is real concern over how to make these measurements more efficiently. If airborne systems could be qualified without full-scale testing, huge sums could be saved. Could the actual measurements required be reduced through analysis and simulation? The FAA will accept 100 V/m immunity tests of subsystems, performed with no attenuation or shielding, in lieu of HIRF exposure of an entire aircraft. There are some problems associated with this approach, but they are not as severe as with whole system tests. Standards and cost-effective methods for demonstrating compliance need to be developed for both approaches. If a reliable method of qualifying subsystems with bench tests could be developed it would save huge sums over time, and would benefit the entire aircraft industry. The frequency range is 10 kHz to 18 GHz.

The following problems apply to testing of components and subsystems in laboratories. (1) The required antenna placement and modulations are poorly defined. To cover all locations on cable and all possible modulations seems too extreme and costly for the benefit gained from a simulated environment. (2) Radiated emission measurements can vary with system layout on the test bench. It would be best if a given facility and setup could be calibrated to remove effects of test cables, load boxes, and shielded-room characteristics; for example, replace the equipment under test (EUT) with a known source and inject a calibrated power into the EUT cable and measure the response to the setup. This would be used as a relative measurement baseline. Also, does every inch of the laboratory test cable have to be exposed? If so, this drastically extends the testing time. (3) Too many antennas are needed for emission tests. Better broadband antennas would be extremely valuable, including small E-field antennas practical for use down to 10 kHz or as low as one can go.

HIRF measurements are required within aircraft; both definitions and measurements issues are involved. Fly-by-wire systems will have more problems. Each component must satisfy EMC and HIRF requirements for immunity while up to 1.5 MW is distributed around the aircraft. There may be a need for new measurement methods, instruments, and suppression techniques. NIST could provide an important service by comparing the current injection and radiated field tests used in determining airframe attenuation.

A device for measuring induced currents (including those induced by lightning) is needed. The ideal unit would be compact with fiber optic leads that could be used to evaluate currents throughout the aircraft and find areas that are affected least and most. The aircraft industry has both multiple-stroke and multiple-burst generators for lightning simulation tests along with other good test facilities. Some of these facilities are not fully utilized and NIST could use them in testing sensors, techniques, methods, etc. as part of cooperative research efforts.

The aircraft industry is conducting research on HIRF and lightning problems in order to meet regulatory requirements, provide better analytical models/tools for design, and reduce weight. (A jumbo jet may have close to 500 kg of EMC hardening.) The direct and indirect effects of lightning and HIRF are being studied by investigating the points of entry (cargo doors, windows, etc.) and field-to-cable coupling mechanisms. They have modeled HIRF coupling to wires, analyzed the statistical characteristics of previous HIRF attenuation data, and identified test method enhancements to reduce attenuation data variability. They have also modeled cables over poorly conducting (graphite) structures, and have predicted lightning effects for wiring on graphite structures. They need to verify and improve the test data on cables, and the trend toward composite structures may lead to more EMC problems.

3.3.7 Impedance Measurement Problems

The survey uncovered a few practical impedance-related problems that, if solved, would improve EMC measurements. Problems were reported with conducted immunity and output tests due to impedances other than 50 Ω. Instruments are all designed around 50 Ω but many systems/components have different impedances. Could NIST improve measurements under these conditions? There is also a problem in specifying the impedance of line impedance stabilization networks (LISN) out to 400 MHz; it is difficult to measure the impedance over the whole band. The use of LISNs in EMC testing needs to be clarified.

There does not appear to be a good standard method for evaluating the rf impedance of gaskets. Is there one? A method suitable for nonideal cases is needed.

There is a need for better bonding resistance and impedance measurements throughout the EMC frequency bands of interest. This is important to airframe manufacturers, who have a problem with bonding of joints. The problem stems from water condensation at low altitudes. The plane then goes up, gets cold, and the water freezes and weakens or breaks bonds. A method of measuring the impedance/resistance of the bond is required to see if it has changed. NIST could also evaluate the sealants used for the bonds. The impedance of the bonds affects the shielding and EMC properties of the aircraft, so it is important to know when and how the impedance changes.

3.3.8 EMC of Medical Equipment, Devices, and Instruments

The main problem for the medical equipment manufacturers is meeting the EC standards for emissions and immunity. The U.S. has no standards so medical devices made in this country are not very well designed for EMC. They are exempted from FCC regulations and no U.S. regulations cover them. There are EC standards which U.S. companies must meet to sell overseas. There is a new IEC immunity standard requiring medical devices to withstand electric fields of 3 V/m.

Hospitals are a naturally bad EM environment and many problems occur in them. The most important medical systems and devices are:

- Patient monitoring – millivolt signals are involved.
- Computerized devices with microprocessors and analog controls.
- Infusion pumps.
- Respirators and ventilators.
- Hearing aids – they tend to pick up signals from cellular phones.

Radiated immunity is the main issue with medical devices, and better testing techniques are needed. Better conducted immunity tests are also needed.

3.3.9 Some Practical Measurement Issues That Need Addressing

Most EMC laboratories are under serious time and cost constraints. Test methods must provide acceptable accuracy for acceptable cost and must be repeatable. This is the only way to retain product competitiveness and is essential to retaining product lines in the USA. Consequently, for EMC the emphasis is on practical and repeatable measurements. Existing calibration standards are sufficiently accurate but the overall measurement process needs tightening up. Therefore anything that will improve EMC measurement efficiency and repeatability is important. Some examples of practical measurement problems follow.

In any EMC test facility, we need to know the effects of cables on the system and the overall accuracy expected. How are these determined? What are the tradeoffs between equipment sensitivity and testing speed for continuous wave (cw) and swept frequency measurements? How do turntable and mast-scanning speeds relate to this problem? No overall system amplitude error budget or accuracy reporting requirements are in place. The result is poor measurements. This applies to many EMC test facilities. Near-field problems and errors in antenna factor contribute to the problem. Overload and distortion are other causes of poor results. More sensitive antennas could help when operating close to the limit. Accuracies of 4 dB are sought for antenna-site combinations but, with these errors, one could reject items that would actually pass and vice versa, so better overall accuracy is needed.

In many EMC tests the noise limit of spectrum analyzers is encountered; this is a serious problem. MIL-STD 461-D RE102 limit-to-noise ratio is a problem. It requires measurements close to the noise limit and measurements of peak signals, resulting in reduced accuracy. The required tests have not been fully checked out. Are the requirements really valid? Recent increases in ambient noise have made measurements more difficult. How do we cope with this problem?

The automotive industry wants an objective measure of AM/FM broadcast quality that correlates with all types of interference. In other words, a standard for characterizing entertainment system quality is needed. Lots of problems exist with audio-visual entertainment systems on aircraft. This is important to the industry because passengers are directly involved and aware of the problems.

The automotive industry also needs a practical "how to" guide for making radiation hazards measurements that can serve as a guide for practicing field engineers. They must meet IEEE SCC28.1 limits.

Problems with radiated immunity and emissions measurements are: Cables that deliver the rf power from the generator to the antenna are breaking down when producing 200 V/m fields. Apparently this is due to high VSWR, which causes burnout of cable shields. MIL-STD 461 calls for measurements within 2 dB for emission and immunity, a requirement which no one has been able to achieve. IEC 801-3 prescribes immunity tests of 3 V/m at 3 m distance. Some believe they should be able to test at any distance as long as the required fields are established in the test zone. There are also some who think the FCC should throw out the 3 m distance and keep 10 m. Could NIST study these issues and help resolve them? Many EMC tests call for a field uniformity of 2 to 3 dB over the test volume. This is difficult to achieve, so alternative methods would be useful.

The aircraft industry needs a standard test setup and procedures for testing cables and wiring harnesses. Consideration should be given to shielding and bonding procedures, pigtail length on components, terminations, cable configurations, grounding techniques, and bonding to the ground plane. Presently there is no uniformity among aircraft manufacturers; the tests are costly and time consuming, and the results cannot be replicated.

There are no regulations covering electric static discharge (ESD), yet problems persist. One challenge is to design circuits that withstand ESD; this is a problem as low as 7 to 10 V due to the narrow line widths of ICs (integrated circuits) and chips.

Test procedures and emissions limits are needed for carry-on electronics on aircraft. As small computers proliferate, the problem will intensify. Current regulations require immunity of aircraft systems to 20 V/m fields. More study of this problem is required. There have been many incidents, but few were verified as due to EMC. Problems due to carry-on electronics are not well documented, and few people believe they constitute a hazard.

3.4 New or Improved Measurement Methods Needed

3.4.1 Reliable, Cost Effective EMC Testing Methods

The EMC community needs faster, more cost-effective methods for practical EMC testing. The methods should reflect how systems are used in actual situations. Standardized calibration procedures for the RF equipment and components used for these tests are also needed. The use of LISNs (line impedance stabilization networks) on the power mains during radiated testing should be clarified. Predictive models and tools would be a useful adjunct to the actual measurements and should be investigated.

Often, regulations are developed before the development of sound testing methods. A good example of this today is the new spread-spectrum technology now entering the marketplace. The FCC has defined regulations but does not have defined test methods. Some organization (NIST?) needs to develop the test methods. An associated area is the use of code-division multiple-access (CDMA) and time-division multiple-access (TDMA) techniques in telecommunications; these also require the development of standards and test methods.

NIST must develop criteria for intercomparing facilities (for example, semi-anechoic chamber versus OATS and demonstrating that alternate techniques are equally good and should be accepted.

3.4.2 Standardized Immunity Tests

Standardized immunity tests embodying approved techniques that are repeatable and well understood are required. The need is greater below 100 MHz and above 1 GHz, but it exists throughout the spectrum. Better techniques are especially important for large system testing. NIST could help by developing the basic standards and cost effective methods needed for these immunity tests and disseminating "how to" information to industry. As an example of the impact NIST could have, one company told us that NIST probes now available commercially have so simplified immunity tests that it has no problems in this area.

Standards covering instruments and equipment used in the work place are desperately needed. Out-of-band response of meters and equipment is a real problem. Devices designed for 60 Hz operation can malfunction in rf fields. Errors of 20% or more are common and produce serious safety, health, and economic problems. For example, welding arcs produce broad-spectrum fields that can affect other systems. Faulty responses due to EMI in industrial instruments are poorly known and a serious problem. For example, combustible-gas-level meters may give false alarms in walkie-talkie fields, yet workers carry both. They also give safe readings when concentrations are dangerous. These comments apply to many similar instruments such as hazardous particulate material pumps used in safety monitoring systems. False readings can shut down whole industries, and costs can run into millions of dollars. Clearly, standards and reliable test methods are needed for such instruments.

Many people believe the current-injection method (CIM) has considerable promise as a less expensive alternative to whole system immunity testing. NIST should evaluate this technique and determine how it correlates with radiated immunity tests.

3.4.3 Antenna Calibrations and Reference Standards

The EMC community needs standard antennas with better-known antenna factors. Commercial antennas can give different results depending on how they are connected and used, and poorly known antenna factors are a problem. A reliable, inexpensive technique is needed for determining antenna factors to reasonable accuracy from 30 MHz to 2 GHz. As evidence of this need, one company uses the manufacturer's antenna factors and verifies them daily against a local FM station. When they sent the antennas out for calibration, they were told they were 10 dB off. Further, according to NVLAP, antennas should be calibrated annually, yet there is considerable variation between calibrations. Companies do not know whom to believe.

Most people we talked with think NIST involvement could correct this situation. Some ways NIST could help are described below.

- These are discrepancies in antenna factor definition and usage. NIST could study these issues and specify correct procedures for determining antenna factors. The validity of vertical antenna calibration factors should be analyzed. This is a tough theoretical problem and appropriate for NIST.

- NIST could validate manufacturer and test house antenna calibrations. The question is often asked, "Who calibrates the calibrators?" NIST should be involved in some formal way to help industry attain the accuracy it needs along the calibration chain. A measurement assurance program (MAP) would be ideal for this purpose and there is evidence that a MAP might succeed if one could be established for a reasonable annual fee.

- Existing NIST antenna calibrations are too expensive for most EMC test houses and they take too long. If NIST could offer less expensive antenna calibration services more companies would use them. A reasonable target price is $1500 to $2500 for dipole antennas.

- Standard field probes, standard transmitters, and standard EMI generators are all important and could help bring about improved accuracy in commercial measurements.

- Reference or transfer standards are one way to evaluate antenna factors and perform calibration checks. NIST could identify suitable antennas for use as standards; if none were available, it could develop rugged, stable artifact standards of moderate accuracy for this purpose. A general broadband antenna would be useful for site surveys. The shortened antenna should also be evaluated for such uses.

- An absolute field-strength reference-standard radiator is needed. It could be either an absolute or a transfer standard. A standardized marker generator for testing test site calibrations and intercomparing test sites would be a useful adjunct.

- Swept calibration techniques are needed for broadband antennas. NIST could study swept calibration versus single-point methods and publish the results.

3.4.4 Electromagnetic Field Probes and Instrumentation

Better near-field probes are needed throughout the FCC enforcement range (50 Hz to 26 GHz) at least. Test requirements are moving into the gigahertz range and industry would like probes that are broad band, isotropic, and sensitive, yet not easily overloaded by unwanted signals. Ideally, probes should have fiber optic leads and a sensitivity of at least 10 dB above 1 μV/m. Out-of-band response of probes may be a problem.

The auto industry would like small, practical H-field probes for measurements inside cars, and the FDA could use better H-field and E/H-field probes. It especially needs a sniffer probe for use in swept-frequency immunity measurements.

More needs to be done on EMC instrumentation for the workplace. Field probes, meters, and instruments to determine risks to humans are badly needed by industrial hygienists. Affordable, field-portable instruments are essential for monitoring work place conditions and for measuring emissions and immunity. Users also need access to cost effective means of equipment calibrations and education on proper measurement practices. This is important because significant health effects decisions will be based on these measurements.

Inexpensive, portable spectrum analyzers are needed to measure industrial environmental fields and indicate where the bulk of the energy exists. Kilovolt-per-meter electric fields and 10 A/m magnetic fields are common around industrial heat sealers, and medical imaging units have very high fields. It may be time to look at some alternative (nontraditional) ways of measuring high level fields. Also, there may be quantities that relate to bioeffects better than E and H fields; contact current and voltage are a possibility. Such topics could be profitably investigated.

3.4.5 Large (Whole) System Testing

Practical, less expensive methods for determining the EMC characteristics of complete systems are needed by many companies and industry segments. Methods for whole system testing or subsystem testing with the ability to adequately predict the whole system response would satisfy this need. Someone (NIST) needs to evaluate both approaches and see how modular testing correlates with whole system testing and with complete systems in actual use. Standardized modular test methods that would give reliable results, repeatable within 3 dB, would be extremely valuable to the automotive and other industries. In order to achieve this, better measurements of radiated emissions and immunity of modules may be required. (Refer to Section 4.3.6 for additional comments on this topic.)

3.4.6 Pulse and Transient Measurements

Pulse/transient measurements are in worse shape than cw measurements. Practical measurement procedures, including supporting calibration methods, standards, and error analyses all need developing. A quasi-peak standard detector for calibrating instrumentation (receivers, spectrum analyzers) may also be needed. There are problems in automated methods using swept frequency techniques. Present methods with long sweep times may miss events while sweeping a different part of the spectrum. Measurement of transient bursts with rise times as low as 15 μs are required.

Measurement of conducted transients is a problem for the automobile industry. These transients affect sensors and control systems, and tests are not specified adequately.

Pulse modulation produces different biological effects than cw, so SAR (specific absorption rate) is used as the hazards criterion. But SAR is not easily measured, at least directly. A related issue is how to measure modulated fields. What should be measured? What probes, antennas, and instruments are needed? The primary frequency range of interest to bioeffects people is 3 MHz to 6 GHz. Below 3 MHz, induced currents are used, and above 6 GHz, the penetration depth is too short.

3.4.7 Absorber Characterization and Shielding Effectiveness of Materials

As explained in Section 4.3.3, better methods of characterizing absorbers, including ferrites, are needed. Existing methods work best at normal incidence but information on oblique incidence is required to analyze the performance of chambers and shielded rooms. Problems tend to be worse at frequencies below about 1 GHz. What is needed is a practical procedure that can be used by manufacturers and users. Absorber materials are getting better. Improved absorbers and tiles continue to appear and better ways of evaluating their performance must be developed. This is a good task for NIST.

Measurements of shielding effectiveness would also be useful for characterizing materials used for gaskets and shielding, etc.

3.4.8 EMC of Integrated Circuits and Chips

The effects of electromagnetic fields on integrated circuits and chips is a growing problem. ICs and chips are becoming common but techniques for determining their EMC properties are not in place. Radiated immunity tests for ICs and chips are a serious need for the automotive industry. They need common test procedures for characterizing emissions, immunity, sensitivity, and other properties from 10 MHz to 1 GHz. Someone needs to investigate basic mechanisms for fields coupling in and out of the devices and determine what part of the RF energy (the E-field or induced currents) affects the devices. Also needed are methods for reducing EM radiation from microprocessors. Optical measurement techniques that are not affected by RF fields would be ideal.

3.4.9 New Technologies and Trends with Implications for EMC Metrology

Areas where the demands for EMC work are growing are telecommunications, personal computers (PCs) and peripherals, and medical electronics (discussed in Section 3.3.8). New communication systems emphasize spread spectrum, digital, and multiplex formats. These broadband systems may need new measurement techniques, instruments, detection methods, and interference models involving BER (bit error rate). The trend is toward smaller, faster, digital systems at higher frequencies with less power. There will be new EMC problems, but it is not clear what the measurement implications are. Standards will be required.

The IRIDIUM project – a scheme involving 66 satellites for worldwide personal communications (1 to 2 GHz) – has many EMC issues associated with both the satellites and ground units. "Wrist watch locators" are coming, and they will have EMC problems.

Computers are getting faster, but mechanical design and shielding techniques are not catching up. New testing procedures and models for pen-based products (such as, notepad PCs) are needed.

To meet this need, we must understand how the presence of the hand (entire body) affects the function of the computer (device). Artificial hands for radiated testing and human body models may need to be considered.

New materials (such as graphite epoxy) are being used for construction. A new commercial challenge is to minimize radiation from circuits and devices so plastic cases can be used instead of metal cases. The trend toward smaller devices, faster data rates, and less shielding create a need for circuit board design that has minimal radiation and susceptibility. This "design without shielding" is a new technology that is under investigation. Present models yield 100 dB differences. Immunity of such devices is another part of the problem.

The automobile industry is moving into using mobile antennas and collision avoidance radar (CAR). Transmitter antenna performance is an important issue for these systems. Intelligent vehicular highway systems (IVHS) will use millimeter-wave components and systems. Frequencies under consideration range from 70 GHz to 140 GHz, with the optimum frequencies still to be determined. IVHS may include blind-spot warning systems and forward-looking radars coupled to braking systems, etc. No EMC tests have been devised above 18 GHz, and only a few at X-band (8 to 12 GHz). EMC will be a major factor in intelligent highways and in new communications, navigation, and other systems in cars. In fact, EMC will be an issue in all future transportation systems. Electric vehicles pose new EMC problems due to the high currents and magnetic fields involved.

Industry is currently conducting experiments to control aircraft engines by means of fiber optic leads to sensors in the engines. This involves weak digital signals which will require new EMC measurement methods, instrumentation and analysis. Growth in use of fiber optic systems is currently slowed by lack of an automated method for making terminations. Present methods are very labor intensive.

3.5 Impacts of Better EMC Measurements

Our interviews indicated that better EMC measurements would have major impact in the five areas described below. Although economic impact is one of these areas, the other four areas also have significant economic consequences as will be evident from the context.

3.5.1 International Acceptance of Tests Performed by U.S. Laboratories

Reliable EMC measurements will lead to broader acceptance of tests performed by U.S. companies. The greater the veracity of the tests, the more credibility we have with the EC and other nations. For this to happen, we need test specifications and procedures which result in repeatable and defendable test data. Foreign governments then will be more inclined to accept our tests. This will mean value added to all products that must meet EMC requirements.

3.5.2 Better Use of the Electromagnetic Spectrum

Because of growing demands for space in the electromagnetic spectrum, dual use of some spectral regions is being considered. The mobile communications people (and others) want to use the 1 to 6 GHz band, which overlaps the ISM band. If the interference problems can be solved and interservice compatibility achieved, dual use of this part of the spectrum will have big economic impact. Fifty megahertz of spectrum is worth $40 to $80 billion if it can be used.

3.5.3 Improved Electromagnetic Environment

A lot of poor measurements are being made. Better cost-effective EMC measurements would result in less interference and a better overall environment for systems and people. More companies would comply with the standards and regulations if tests could be performed more efficiently and if they had greater confidence in the test results.

3.5.4 Improved Public Health and Safety

This section gives examples of past and present health and safety problems caused by electromagnetic fields. Some problems have been corrected, some have not. Some directly affect relatively few people, while some affect the general populace. The common element is that they all require some type of EMC measurements to solve or eliminate the problem.

Military systems have failed with disastrous consequences due to EMI; helicopters and the Exocet missile are two notable examples. Anti-lock brake systems (ABS) had problems with EMI when they first appeared, but they are fine now. These and all other sensors, computers, and control systems used in vehicles are subject to rigorous EMC testing.

In one particular aircraft, St. Elmo's fire occurred in the windscreen and obscured the pilot's vision -- a real safety problem. The problem took three to four years to track down but only one week to fix.

The aircraft industry has been unable to prove that carry-on electronic devices do not cause interference. Some incidents have occurred but they have not definitely been ascribed to EMI. Navigation devices are most susceptible. Problems in the workplace are common. There are health issues associated with the use of cellular phones. There is no common standard to control these devices. IEEE C95.1 specifies exposure limits at distances greater than 20 cm from the source yet phone users have antennas much closer than 20 cm. This issue has not been resolved.

One state university has 11,000 VDTs. The magnetic fields in front of these VDTs can be up to 10 times the levels allowed by the Swedish standard (we have no standard). People are trying to sell them shields at $400 to $500 each, which translates to $5.5 million. Good measurements are needed to verify that the shields actually work and that they represent a cost-effective solution.

Workers in a steel plant work right under huge transformers which produce H-fields of several tenths of millitesla (several gauss) fields so strong that they cause computers to malfunction. At one plant, currents of 30000 A DC had large ripples, so much of the problem was above 60 Hz.

The Omega antenna in Hawaii operates at 10 kHz and produces 300 V/m fields on a local highway. These fields caused failures in the highway contractor's equipment. A highway in Germany had to be shielded to eliminate EMI problems. Medical diagnostic equipment is very susceptible to EMI. For example, apnea monitors failed at 0.05 V/m in the FM band and there were 60 nonreported deaths associated with one manufacturer's monitors. Electric wheel chairs can move due to EMI effects on control systems – an obvious hazard to invalids. There are serious problems in hospitals. In one operating room when the electro-surgery unit was turned on it disabled all the other systems. The wife of one person we interviewed went to a clinic for some tests, and the EKG indicated she had had a heart attack. It turned out to be a false reading due to EMI. Ambulances are now being manufactured with plastic roofs. Five-watt antennas on the roof cause false readings on the medical instruments inside. These sorts of problems abound in the medical community.

3.5.5 Economic Impacts

National unified standards would save considerable money by eliminating redundant testing and test equipment. Consumer product specifications are beginning to get tight enough that manufacturers are having difficulty meeting them. A company cannot get a license for a new product without verifying its performance and compliance with regulations. If the cost of compliance with EMC regulations could be reduced, huge savings would result. Considering the size of the U.S. electronics and communications industries, potential economic losses due to a lack of national standards and laboratory accreditation program are astronomical. Medical equipment companies that must redesign for the EC have cost the U.S. millions of dollars due to delays, redesign, and lost sales.

Better measurement techniques allow designers to work with lower margins from limits and realize significant economies in design and production costs. Overdesign due to poor measurements or conflicting regulations is expensive. For example, high-end devices (from \$50k to \$500k per unit) may require an investment of \$1k to \$8k for a simple EMI gasketed cabinet to help achieve a 6 dB over-design margin. Some TV manufacturers estimate that an additional 25 cents per receiver could be saved if design margins were reduced from 6 to7 dB to 3 to 4 dB. Given their volumes of production, total savings could exceed \$1 million per year per manufacturer. Repeatable measurements have a big impact on design margins and time to market issues. The biggest impact is on time to market for new products; millions of dollars can be at stake for each company. Each new product has about 18 months market time, from inception to obsolescence. Any delays in testing can cost a company huge sums. A two week turnaround to fix a design, added to other delays, can easily cause a 10 percent loss in total sales for the product. For example, \$2 million is saved by the PC industry if the time to market is shortened by 14 days. Associated with accuracy is an exponential cost curve, which explains the lack of interest in accuracy and the emphasis on repeatability.

In the electronics and computer industries, estimates of EMC costs (testing and production) are 1 to 2 percent of total production costs. In some cases, better design could reduce the need for testing, and testing costs could be reduced by automation and simpler test procedures. Any techniques that would reduce the testing time would save manufacturers significant sums. For example, one small PC sells for $700. If the company makes 40 000 a month, it does not take long to realize large savings.

EMC testing costs for avionics systems are typically less than 5 percent of product-line costs, but that can be substantial. EMC problems are very expensive to correct after an aircraft is constructed.

HIRF testing costs are very high. In fact, companies may not use upgraded systems because of the cost of the tests, and this has a negative impact on safety and performance. One company spent $25 million to perform whole body EMC tests at Patuxent River. Another manufacturer spent approximately $2.5 million for HIRF tests on one plane. This same company estimates the EMC effort for a new aircraft will cost approximately $10 million; suppliers and subcontractors may spend an equal amount. However, this is still less than 1 percent of the total effort. One company estimates costs of HIRF testing in the billions of dollars. A general aviation company estimates $2 million for HIRF tests of first model and $100 000 for additional production units.

Any reductions in whole system testing would cut costs dramatically. A method of qualifying sub-systems with bench tests to eliminate the need for whole body tests would save billions of dollars over time and would benefit the entire aircraft industry. More cost-effective whole system tests would also be useful. These improved techniques would also be useful to the automobile industry and other manufacturers of large systems.

Automotive electronics are increasing about 5 percent per year. By the year 2000, some cars will include $2000 worth of electronics. EMC will be more critical and will require more measurements and testing. More accurate prediction of interference can reduce costs for unnecessary suppression and hardening. Economics in the automotive industry is obvious. Estimated costs to achieve EMC range from $15 to $50 per car. That may not seem like much, but when multiplied by 10 million cars per year, the total is significant. In some cases, EMC designers have actually saved the company money by becoming involved in early design stages and simplifying designs. One company saved $3 per car for a total of $20 million. Major savings result if recalls can be avoided. For example, one radio problem cost $90 per vehicle to correct on 5 percent of the vehicles, for a total expense of more than a $1 million.

The companies represented by CBEMA constitute a $250 billion industry, with $35 billion to Europe. According to the Electronic Industries Association, the total annual factory sales of consumer electronics equipment in the United States in 1992 were $37.8 billion, with an estimated retail value of $49.3 billion. Huge sums are at stake and even small savings (less than 1 percent) achieved through better EMC metrology can have an enormous impact on the economies of the affected industries.

3.6 Ways in Which NIST Can Best Support Industry and Government Agencies in Achieving Better EMC Metrology

The items in this section are the responses we received to the two questions: (1) How can NIST best assist you in overcoming technical problems and in meeting the requirements of national and international EMC standards? (2) What types of NIST technical support would be of greatest value to your organization? Some of the answers may seem surprising, but they reflect the attitudes of those industries and agencies that participated in the survey.

3.6.1 Becoming More Involved in International Standards Committees and Technical Working Groups

NIST should do all in its power to bring about national EMC standards and regulations and to develop international standards that are practicable and acceptable to the United States. More NIST technical representation on international standards committees and technical working groups will be required to achieve this goal. Committee participation is an excellent way to get NIST views heard and to influence the committees and their member organizations. CISPR functions under the IEC and there are several committees on technical issues of interest to NIST. Sub-committee G is probably the most important for EMC; it is chaired by Uwe Larsson of Sweden. Most international standards, including the EC standards, are based on CISPR documents, if so NIST expects to influence international standards development, it will have to become involved with CISPR. Nationally, ANSI C63 is the committee responsible for EMC.

Industry support to international committees (such as CISPR) is declining and government does not send representatives. The U.S. needs better representation and more government involvement. Europe has considerably more representation from government agencies than we do. Further, U.S. companies are not funding and supporting committee participation. NIST could fill the void and provide a valuable service to U.S. industry. Some people believe test houses have too much influence on these committees and that more representation is needed from manufacturers' product design and development areas. In general, these committees need the impartial inputs that NIST can provide.

3.6.2 Performing Research and Development in Support of EMC Standards and Metrology Services

Sections 4.2, 4.3, and 4.4 contain many specific examples of research and development that need to be done; many of these tasks are appropriate for NIST. The emphasis is on developing new, cost-effective measurement techniques and the probes, antennas, reference standards, etc. required to support them. In this section we list a few important items.

- The United States needs more reliable, less expensive immunity testing. NIST could review existing tests for improvement and develop new ones where called for.

- NIST could develop cost effective alternatives to the open area test site (OATS). If available, industry would push for acceptance. One approach would be to develop near-field to far-field models and predictions. This would relate near field measurements to regulatory requirements and provide reliable estimators to allow 100 percent testing of production. This would be an enormous contribution.

- Measurement automation standardizes measurements and reduces variability. NIST could assess the quality of automated measurements including software package evaluation, and study signal types versus measurement algorithms.

3.6.3 Presenting Tutorial Courses and Publishing Tutorial Papers

A general problem is a lack of training in EMC techniques. There are textbooks on many electrical and electronic subjects, but what are needed are good, technically correct tutorials on EMC calibrations and measurement methods. New EMC engineers need some means of learning terms and techniques. Tutorials should be written and presented at a practical level so a practicing engineer can understand and follow them. These should explain methods and facilities and how to use them, while indicating advantages, limitations, areas of applicability, etc.

Tutorials on the measurement of hazardous fields are important and should include measurement methodology, distances, frequencies, etc., and range of validity. The public will become more interested in this topic as people become more aware of the potential problems. The automotive industry would like a practical "how to" guide for making radiation hazards measurements that can serve as a guide for practicing field engineers.

Some suggested topics for tutorials are: (1) the effect of bandwidth on sensitivity for various types of noise, (2) the difference in responses to impulse and random noise, (3) derivation of loop antenna factors for small magnetic loops, (4) use and limitations of field strength monitoring probes, (5) how to measure the loss/attenuation of fields at short distances, (6) the relationship of magnetic units (gamma, gauss, tesla, etc.).

NIST could make more use of IEEE symposiums to disseminate developments and information. Several people said they would like better access to NIST publications on EMC topics.

3.6.4 Evaluating Measurement Methods, Facilities, and Requirements

NIST could evaluate new measurement methods, tools, and facilities with respect to their advantages, disadvantages, ranges of applicability, and expected accuracies, together with any cautionary notes that may apply. Some topics that were suggested for study are:

- Evaluation of the various test facilities (shielded rooms, anechoic chambers, open field sites, etc.) to determine what variations are acceptable and which techniques are best for different situations. In particular, several people mentioned the need for NIST to evaluate the GTEM cell and publish the results. MIL-STD 461-D, which deals with absorber lined shielded rooms, should be evaluated as part of this study.

- A study of commonly available antennas to optimize their performance. Review the 3 m versus 10 m test distances to determine the measurements for which each is best suited. Why are both needed? Should limits be tightened or relaxed in certain frequency bands?

- Evaluation of predictive software used for predicting the EMI/EMC potential of products and situations.

- NIST could function as an independent technical review body since it is nonpolitical and respected. In this role it should: (1) evaluate the technical accuracy of regulations and standards (including such things as site attenuation and antenna calibration requirements); (2) evaluate the feasibility of test methods (accuracy verification); (3) study effects of measurement procedures on data accuracy; (4) determine repeatability of data with a given procedure; (5) investigate boundary conditions and accuracies of measurements; (6) develop a better understanding of basic phenomena such as shielding effectiveness and how to characterize the environment.

3.6.5 Becoming Actively Involved in Upgrading the Quality of EMC Measurements in the United States

According to the people we interviewed, the quality of EMC measurements in the United States is generally rather poor. Greater emphasis needs to be placed on quality assurance at all levels in the measurement chain and NIST should be more involved in the process. NIST could have the most impact by providing the following kinds of support.

- NIST should supply technical assistance and coordination in the development of test specifications and procedures. This effort should be both national (FCC, FDA, FAA) and international (EC, IEC) in scope. The need for coordination may be greater than the need for technical assistance. The SCUSA (Standards Council USA) and the NVCASE (National Voluntary Conformity Assessment Systems Evaluation) proposals put forth by NIST are good starting points.

- The Electromagnetic Fields Division (EFD) could provide new measurement techniques and technology, accessible and less expensive calibrations, and reference standards. It should develop and disseminate guidelines (how often) and procedures for calibrating EMC test equipment (amplifiers, spectrum analyzers, receivers, signal generators, etc.) to improve repeatability and traceability.

- The EFD could work through NVLAP (or a similar, expanded program) to evaluate industry test facilities and testing service companies to achieve better measurement repeatability and, where required, traceability to NIST. Measurement assurance programs (MAP) are one of the best ways to achieve this goal, and several companies and government agencies expressed interest in participating in MAPs for antennas, probes, and other EMC measurements. A MAP in basic EMC metrology would be a good way to achieve credibility in the EC.

- EFD personnel could provide valuable support by teaching workshops and seminars on specific measurements required to obtain accreditation.

- NIST could establish a knowledge base for information on EMC standards, methods, and facilities. The purpose would be to identify problems, limitations, ranges of applicability, accuracies to be expected under different situations and circumstances, and to indicate when to use each method.

- NIST could assume a leadership and coordination role; no one is doing it now. U.S. companies have a difficult time getting EMI/EMC test information for different countries. DOC/NIST could provide a valuable service in this area if they were willing to act as a clearinghouse and provide this information to U.S. companies. Measurement requirements change as the regulations change. NIST should keep on top of these changes and keep industry informed. In this role NIST could also promote worldwide reciprocity on testing limits and standards.

3.6.6 Providing Technical Support to Regulatory and Other Government Agencies

NIST could assist government agencies (such as FAA, FCC, FDA, NIOSH, OSHA), in developing technically sound test methods for verifying compliance with their regulations. These organizations would also benefit from a transfer of measurement technology from NIST to assist the agencies and industry in making good measurements and in solving their problems. Specifically, NIST could help by providing testing procedures and standards, and by certifying laboratories and testing procedures.

Other important tasks for NIST are: (1) disseminate a collection of NIST EMC activities and results; (2) calibrate instruments and provide second opinions on immunity measurements; (3) promote better quality assurance throughout the EMC community through MAPs or other means.

Some government agencies have poor technical facilities and limited technical expertise. Funding and equipment are short in most agencies, and they could all benefit from closer ties with NIST and its technical competence. The only problem is that these agencies do not have the funds to pay NIST, and NIST does not have funding to do the work for them. According to one respondent, NIST has the credibility but is not marketing its capability as it should.

These agencies all have inputs to standards committees and organizations, but believe NIST should have a greater voice in such activities. NIST should take the lead in forming a Council of EMC Measurements. Representatives could meet annually to discuss issues and problem areas, what measurement techniques and instruments need developing, and how they can be developed. Such a body will be important to these agencies and might be a means of justifying and providing funding for the EMC technology program in the Electromagnetic Fields Division. One issue is that U.S. industry often views research in EMC and hazards negatively because it may result in constraints. This resistance will have to be overcome through education.

3.6.7 Developing Needed Metrology Through Cooperative Research and Development Projects

Representatives of all of the industries we visited expressed interest in participating in joint research and development efforts with the NIST Electromagnetic Fields Division. They believe more government – industry cooperation is needed and would like to work with the EFD on jointly funded projects. NIST could help in the following technical areas:

- Improving in-house quality assurance, traceability to NIST, and measurement repeatability.
- Evaluating in-house measurement methods and facilities.
- Developing new methods and supportive standards, where needed.
- Assisting in the design, construction, and evaluation of in-house test facilities.

For example, the auto industry would like help in correlating screen-room tests with open area test site measurements, and in characterizing source antennas and emitted fields. One automobile company would be willing to give money to NIST if NIST would provide and evaluate a facility, and handle the total task from the problem to a turnkey solution. The auto industry would probably fund cooperative research and development agreements (CRADA) for addressing important tasks; one possible source of funding is an organization called USCAR (U.S. Cooperative Auto Research).

One aircraft company representative was eager to achieve more government-industry cooperation and establish cooperative research efforts with NIST. He asked about joint proposals and about the Advanced Technology Program (ATP). There is a technical advisory council, sponsored by the National Aeronautics and Space Administration (NASA), which supports and advises the aircraft industry. It may be possible for NIST to work under this program, or at least have a representative on this council. This would make NIST privy to all the latest information and programs, and enable us to identify potential areas for CRADAs.

One caveat is that funding is easier if NIST can demonstrate existing expertise in pertinent technical areas. No one is likely to fund NIST to develop competence. Moreover, they are most interested in jointly funded projects so NIST would have to pay its negotiated share, whatever that may be. Many of these companies have excellent facilities that NIST could use for these cooperative projects. All in all, there appeared to be some good opportunities for cooperative work and NIST should follow through on them.

4. CONCLUSION

The survey identified many important technical tasks appropriate for NIST. Because NIST cannot do all of them with existing funds, we should select only those areas of greatest interest and need for inclusion in an initiative. Additional committee activities may detract from NIST's primary function of developing standards and measurement methods, work that is equally important in achieving the goal of better measurements throughout the EMC community. Therefore, we should choose external activities with care so that a balance is maintained between purely technical projects and committee-related activities. It seems entirely appropriate for NIST to seek additional funds for participation in international committees, and therefore this should be a prominent item in any EMC initiative or request for funds.

TABLE I

Companies and Organizations Visited During the Survey

A. Private Companies

A1	AMADOR Product Service, New Brighton, MN
A2	Apple Computer, Cupertino, CA
A3	AT&T Bell Labs, Holmdel, NJ
A4	Beech Aircraft Corp., Wichita, KS
A5	Boeing Aircraft Co., Seattle, WA
A6	Chrysler Corp., Auburn, MI
A7	Collins Radio, Cedar Rapids, IO
A8	ELDEC Corp., Linwood, WA
A9	EMACO, San Diego, CA
A10	Ford Motor Corp., Dearborn, MI
A11	General Motors Corp., Milford, MI
A12	Hamilton Engineering, Inc., Seattle, WA
A13	Hewlett-Packard Corp., Cupertino, CA
A14	Hewlett-Packard Corp., Santa Rosa, CA
A15	IBM Corp., Poughkeepsie, NY
A16	Instruments for Industry, Inc., Ronkonkoma, NY
A17	Lindgen, Los Angeles, CA
A18	McDonnell Douglas, Long Beach, CA
A19	Motorola, Inc., Scottsdale, AZ
A20	R&B Enterprises, West Conshohocken, PA
A21	Retlif Testing Laboratories, Ronkonkoma, NY
A22	Sundstrand Data Central, Redmond, WA
A23	TRW, Redondo Beach, CA

B. Industrial Associations

B1	Aerospace Industries Assoc. (AIA), Washington, DC
B2	Computer and Business Equipment Manufacturers Assoc. (CBEMA), Washington, DC
B3	Electronic Industries Assoc. (EIA), Washington, DC
B4	General Aviation Manufacturers Assoc. (GAMA), Washington, DC
B5	Telecommunications Industry Assoc., Washington, DC

C. University

C1	University of Pennsylvania, Philadelphia, PA

D. Government Agencies

D1	Environmental Protection Agency (EPA), Washington, DC
D2	Federal Drug Administration/Center for Device and Radiological Health (FDA/CDRH), Washington, DC
D3	Federal Aviation Administration (FAA), Washington, DC
D4	Federal Communications Commission (FCC), Washington, DC
D5	National Institute of Occupational Safety and Health (NIOSH), Cincinnati, OH
D6	National Institute of Standards and Technology (NIST), Gaithersburg, MD
D7	National Telecommunications and Information Administration (NTIA), Washington, DC
D8	Occupational Safety and Health Administration (OSHA), Cincinnati, OH

TABLE II

COMMISSION COMMUNICATION IN THE FRAMEWORK OF THE IMPLEMENTATION OF THE 'NEW APPROACH' DIRECTIVES

Titles and references of European harmonized standards complying with the essential requirements

'ELECTROMAGNETIC COMPATIBILITY'

Council Directive 89/336/EEC of 3 May 1989 [a]

Under OEN[b] reference No	Title of the harmonized standard	Year of ratification
CENELEC EN 50065-1	Signalling on low-voltage electrical installation in the frequency range 3 to 148,5 kHz Part 1: General requirements, frequency bands and electromagnetic disturbances	1990
EN 55011	CISPR 11 (1990) ed 2 Limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment	1989
EN 55013	CISPR 13 (1975) ed 1 + Amdt 1 (1983) Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment	1988
EN 55014	CISPR 14 (1985) ed 2 Limits and methods of measurement of radio interference characteristics of household electrical appliances, portable tools and similar electrical apparatus	1986
EN 55015	CISPR 15 (1985) ed 3 Limits and methods of measurement of radio interference characteristics of fluorescent lamps and luminaries	1986
EN 55020	Immunity from radio interference of broadcast receivers and associated equipment	1987
EN 55022	CISPR (1985) ed 1 Limits and methods of measurement of radio interference characteristics of information technology equipment	1986
EN 60555-2	IEC 555-2 (1982) ed 1 + Amdt (1985) Disturbances in supply systems caused by household appliances and similar electrical equipment Part 2: Harmonics	1986
EN 60555-3	IEC 555-3 (1982) ed 1 Disturbances in supply systems caused by household appliances and similar electrical equipment Part 3: Voltage fluctuations	1986

a OJ No L 139, 23. 5. 1989
b OEN: European standardization bodies, CEN - CENELEC, ETSI

TABLE III

COMMISSION COMMUNICATION IN THE FRAMEWORK OF THE IMPLEMENTATION OF COUNCIL DIRECTIVE No 89/336/EEC OF 3 MAY 1989, IN RELATION TO ELECTROMAGNETIC COMPATIBILITY[a]

Titles and references of harmonized standards under the Directive

OEN[a]	Reference	Title of the harmonized standard	Year of ratification
CLC	EN 50081-1	Electromagnetic compatibility generic emission standard–part 1: residential, commercial and light industry	1991
CLC	EN 50082-1	Electromagnetic compatibility generic immunity standard–part 1: residential, commercial and light industry	1991

a OEN: European standarization bodies:
CEN, rue de Stassart 36, B-1050 Brussels, tel. (322) 519 68 11, fax (322) 519 68 19;
CENELEC (CLC), rue de Stassart 35, B-1050 Brussels, tel. (322) 519 68 71, fax (322) 519 69 19;
ETSI, BP 152, F-06561Valbonne Cedex, tel. (33) 92 94 42 12, fax (33) 93 65 47 16.

TABLE IV

EMC STANDARDS COMPARISON

International Standards	European Standards	U.S. Standards
Emission		
CISPR 11-ISM Equipment	EN 55011	FCC Part 18
CISPR 13-Sound & TV Broadcast Receivers	EN 55013	FCC Part 15B
–	–	FCC Part 15C (Intentional Radiators)
CISPR 14-Appliances	EN 55014	No Equivalent
CISPR 15-Fluorescent Lamps	EN 55015	No Equivalent
CISPR 22-Information Technology Equipment	EN 55022	FCC Part 15B
IEC 555-Harmonics and Voltage Fluctuations	EN 60555	No Equivalent
Immunity		
IEC 801-2-ESD	EN 55101-2 (Draft)	ANSI C63 (Draft)
IEC 801-3-RF Fields	EN 55101-3 (Draft)	MIL-STD461/462
IEC 801-4-Electrical Fast Transient/Burst	EN 55101-4 (Draft)	ANSI/IEEE C62.41
IEC 801-5 (Draft) - Surge	EN 55101-5 (Draft)	ANSI/IEEE C62.41
IEC 801-6 (Draft) - Conducted RF Disturbances above 9 kHz	EN 55101-6 (Draft)	No Equivalent
CISPR 20 - Sound and TV Broadcast Receivers	EN 55020	No Equivalent