FIFTY YEARS OF EMC IN THE DEPARTMENT OF THE ARMY

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ABSTRACT

The dependence of the Department of the Army on the use of electrical and electronic equipment necessitated that it develop a comprehensive program to assure relatively interference free communications. This paper traces from pre-World War II the growth of the program, problems encountered and achievements attained. The current program is described and future efforts predicted.

ORIGIN OF REQUIREMENTS

The date that the first radio was installed in an Army vehicle is debatable but it is generally recognized that it occurred some time prior to World War I and it probably resembled that shown in Figure 1. It was at this time that the Department of the Army's Electromagnetic Compatibility Program was established, although it can be accepted that none of the participants were aware of either the complexity or the scope of the program that would evolve.

With the exception of a few scattered reports prepared primarily by mechanical engineers describing modifications to vehicles for interference reduction purposes, little is known of the efforts to combat this problem during the period following World War I until the early 1930's. In 1932 the Proceedings of the Institute of Radio Engineers published a paper entitled "Electrical Interference in Motor Car Receivers." The paper acknowledged that "circuits outside the car itself are beyond our control" but listed the various sources of interference in the vehicle and means of reduction. Page one of this paper is shown on Figure 2. In 1934 the Signal Corps, which had been assigned the responsibility for the design and development of Army communications and their interference free operation, issued Specification No. SCL-49 entitled "Electrical Shielding and Radio Power Supply in Vehicles." This document specified the shielding requirements for vehicles to "provide for the satisfactory operation of a radio receiver operating in the frequency band ranging from 150 kc to 80 mc" and included the requirement for a 12 volt battery charging system. The

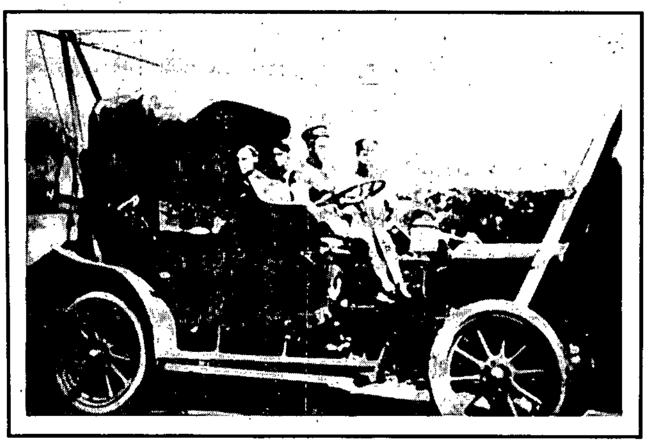
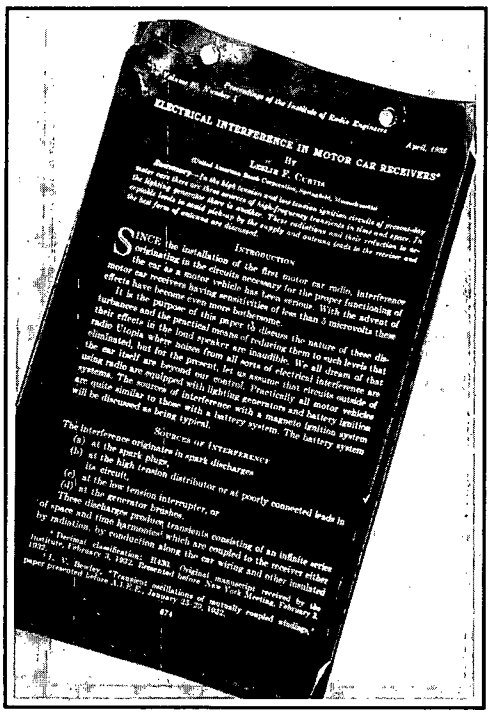


Figure 1. Early Army Communication System.



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ELECTRICAL INTERFERENCE IN MOTOR CAR RECEIVERS*

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Summary—In the high tension and low tension ignition circuits of present-day motor cars there are three sources of high-frequency transients in time and space. In the lighting generator there is another. These radiations and their reduction to acceptable levels to avoid pick-up by the supply and antenna leads to the receiver and the best form of antenna are discussed.

INTRODUCTION

SINCE the installation of the first motor car radio, interference originating in the circuits necessary for the proper functioning of the car as a motor vehicle has been serious. With the advent of motor car receivers having sensitivities of less than 5 microvolts these effects have become even more bothersome.

It is the purpose of this paper to discuss the nature of these disturbances and the practical means of reducing them to such levels that their effects in the loud speaker are inaudible. We all dream of that radio Utopia where noises from all sorts of electrical interference are eliminated, but for the present, let us assume that circuits outside of the car itself are beyond our control. Practically all motor vehicles using radio are equipped with lighting generators and battery ignition systems. The sources of interference with a magneto ignition system are quite similar to those with a battery system. The battery system will be discussed as being typical.

SOURCES OF INTERFERENCE

The interference originates in spark discharges

(a) at the spark plugs,

(b) at the high tension distributor or at poorly connected leads in its circuit,

(c) at the low tension interrupter, or

(d)[1] at the generator brushes.

These discharges produce transients consisting of an infinite series of space and time harmonics[1] which are coupled to the receiver either by radiation, by conduction along the car wiring and other insulated

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[1] L. V. Bewley, "Transient oscillations of mutually coupled windings," paper presented before A.I.E.E., January 25-29, 1932.

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Figure 2. IRE 1932 Paper on Electrical Interference.

specification required shielding of the entire ignition system plus the regulator and generator of the charging system. The only quality control specified was that "reception will be free from electrical disturbance arising from the vehicle regardless of the receiving set or antenna location with the car stationary and at various road speeds."

Perhaps the greatest impetus to the program was the results of large scale maneuvers conducted just prior to World War II. It was found that the hundreds of trucks and tanks used in this exercise radiated such high levels of interference that communications were virtually impossible. The measures taken to reduce the interference were found to be inadequate and the components used proved to be unsatisfactory under field conditions. In addition no instrumentation was available to measure the interference being emanated.

WORLD WAR II

The Signal Corps, after performing considerable work to correct the numerous problems encountered during the maneuvers, issued in January 1943, Specification No. 71-1303 entitled "Vehicular Radio Noise Suppression." This document had the following requirements:

(a) "Effective radio noise suppression of all vehicular electrical interference over the frequency range of 0.5 to 30 mcs."

(b) "Means other than complete shielding of the wiring of the vehicle shall be used. Filters, by-pass capacitors, resistor-suppressors, bonding and grounding and proper routing of wiring shall be used with only limited shielding permitted."

(c) The instrumentation specified included Signal Corps receivers BC-314 (150 to 1500 kc), BC-312 as shown in Figure 3, with a frequency range of 1.5 to 18 mcs., and BC-603 (20 to 28 mcs.). These were standard receivers and had been in use for many years.

(d) "The allowable interference as read on a rectifier-type audio output meter shall not be greater than 2 milliwatts. However the nuisance value of the interference shall be determined by listening tests conducted by Signal Corps engineers."

(e) Tests were to be conducted at a distance of five feet from the vehicle in an interference-free area whenever possible although tests in a screened room were permissible.

(f) Tests on every production vehicle, except tanks were required and the contractor was required to provide sufficient screened rooms to accommodate his daily rate of production. Visual inspection of the interference reduction applications were also required. The contractor was permitted to use a commercial receiver (Hallicrafters Type SX-28 which had the frequency range of 0.55 to 42 mcs. to perform the tests. Correlation of test results between screen room and out-of-door tests and between Signal Corps and commercial receivers was required.

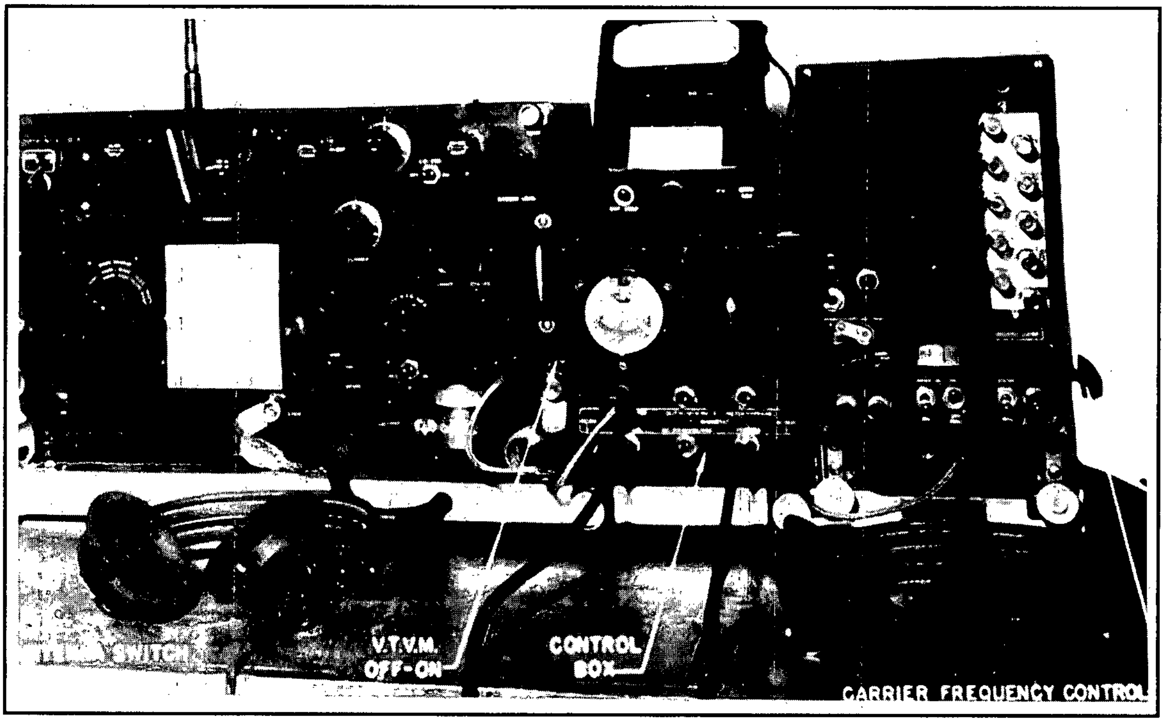

Figure 3. World War II EMC Instrumentation.

Simultaneously Specification 71-1305 which detailed requirements for filters and by-pass capacitors was issued along with Specification 71-1344 which provided "manufacturing requirements to provide radio set operation in tactical vehicles having battery ignition systems."

Although the issuance of these specifications was a definite advance the problems encountered in the implementation of Specification 71-1303 under war-time conditions were enormous. For example:

(1) Correlation between the two types of test receivers was most difficult if not impossible.
(2) Attempts to correlate screen room and out-of-door measurements were appalling.
(3) Contractors of trucks with extremely high volume production were required to have as many as fifty screen rooms, few of which were completely satisfactory. The Signal Corps had prepared and issued in 1941 a manual complete with drawings and specifications detailing their construction and test, but the government inspection teams were unable to assure their integrity because of the constant usage (24 hours/day - 7 days/week).
(4) The specified listening tests proved to be a dilemma. One engineer would consider the interference detected in the headset as of definite nuisance value while another listening to the same output would believe to the contrary.
(5) The requirement that little or no shielding be used, although an excellent economic measure, required the excessive use of bonding applications. A typical truck would require approximately forty tinned copper braid straps and three hundred fifty tooth type washers, most of which would be discarded during maintenance.
(6) Contractors anxious to meet their production schedule would wash the vehicles immediately prior to test or find that a heavy set or very slim driver would have more success in vehicle approval during the screen room tests because of the vagaries of the particular room.
(7) The quality of the components (filters, capacitors, resistor-suppressors) was questionable.
(8) Little technical information was available and newly hired engineers were given "crash courses" on the subject which further compounded the many problems.
(9) Most contractors had no previous experience with this requirement and it was most difficult to convince them of its necessity.

In an effort to cope with some of the problems the following was accomplished in a relatively short time.

(A) Experienced personnel using the knowledge gained at the contractor's facilities were utilized to thoroughly train newly hired engineers in all aspects of the problem.
(B) As a result of the more than adequate results being obtained, the use of screen rooms was discontinued. A more thorough visual inspection was conducted by specially trained inspectors and random tests of production vehicles were conducted by Signal Corps engineers in an interference free out-of-doors area. The elimination of screen room tests was a major decision as every truck factory in the U.S. had made considerable capital investment in rooms ranging in size for testing the 1/4 ton "JEEP" to huge trucks requiring rooms 60' x 30' x 20'.
(C) Work was initiated to improve the instrumentation and to prepare specifications for the suppression components. Trained inspectors were also assigned to component manufacturers to assure conformance with the requirements then specified.

With the development during the war of more sensitive electronic equipments operating in higher frequency ranges it became necessary to assure interference free operations from 0.55 to 156 mcs. for vehicles. In addition, and based on field experience, it was considered essential that all types of engine driven equipments including engine generators be required to conform to interference control specifications.

Tests conducted by the Signal Corps quickly revealed that the requirement contained in Specification 71-1303 for a "minimum of shielding" was unattainable not only for vehicles but all engine driven equipments and that complete shielding would be required if adequate attenuation to 156 mcs. was to be achieved. Consequently, Specification 71-1303 was amended and Specifications 71-3004 and 71-3214, for engine generators and miscellaneous engine driven equipments respectively, were prepared and incorporated in procurement documents. The specifications required that all sub-assemblies of the ignition and battery charging systems be shielded and that tests would be conducted at a distance of ten feet from the unit. At about the same time Specifications were prepared for components; 71-1585 for resistor suppressors, 71-1667 for by-pass suppression capacitors and 71-1688 for suppression filters.

It is interesting to note that at that time Army contractors had little or no knowledge of interference reduction techniques. Consequently Signal Corps engineers along with truck mounted laboratories which were fully equipped with suppression components, instrumentation and the necessary ancillary devices visited contractors from coast-to-coast of the U.S. Standardized applications to the unit being procured would be made on a pre-production model, tests conducted and additions made as required. A report, complete with drawings would be prepared and furnished to the contractor and government inspectors. Revisits to the contractor would be made to test production models to assure conformance with the previous tests. At the peak of hostilities more than forty mobile laboratories were in constant use. Considerable literature was prepared and distributed widely to assist contractors and inspectors in an effort to alleviate the work load which had increased dramatically. The Signal Corps was now responsible for the interference reduction program for all of the other services of the Army who procured engine driven materiel from mobile showers and bulldozers to concrete mixers and cranes. It was estimated that their efforts required close relationship with approximately one hundred government offices and seven hundred manufacturers. As the Signal Corps were not logistically responsible for these items great care was necessary to assure that no malfunctioning would occur that could be traced to the interference reduction components. This procedure continued for many years and although some improvement would be detected it was minimal. One reason was probably the lack of readily available instrumentation which gave consistent results and was relatively easy to operate and maintain. Considerable research and development in this area was in process at the Signal Corps laboratories but it was not until after the war that improved measurement equipment was available.

POST WORLD WAR II

The World War II program was conducted by approximately six hundred personnel at a laboratory located in Detroit, Michigan, in close proximity to the automotive industry. At the end of the war this laboratory was closed and a small cadre of engineers were transferred to Fort Monmouth, New Jersey, the Headquarters of the Signal Corps, to carry on the program. With the conversion to a peace time economy production of the Army materiel was practically stopped and time could be devoted to development activities. The efforts initiated during the war came to fruition with the completion of Test Set AN/URM-3. This equipment covered the frequency range of 0.15 to 40 mcs. and incorporated an impulse generator which permitted the operator to match the interference from the equipment under test to obtain more exact readings. In addition an Air Force receiver which covered the range of 38 to 1000 mcs. was modified as a measuring set and termed AN/URM-29. These sets at least eliminated some of the problems of conflicting measurement results. Another development completed was the feed-thru type capacitor which provided excellent attenuation characteristics and replaced many filter applications. Specification MIL-S-11693 was prepared to detail its requirements.

The agency responsible for vehicle development determined that waterproof electrical systems were necessary on all combat vehicles to permit fording of rivers and streams. The Signal Corps, always aware of the problems of the interference reduction applications being removed and not replaced during maintenance procedures, resolved that this would be an ideal opportunity to incorporate the suppression components as an integral part of the vehicle's electrical system thus eliminating bulky shielding and separate components. Working with the development manufacturers, it was found that the ignition coil and distributor could be incorporated into one completely shielded unit and that the resistor-suppressor could become an integral part of a shielded type spark plug. Thus complete waterproofing with integral interference reduction applications became possible. Similar success was achieved with the battery charging system and other sub-assemblies of the electrical system. Such assemblies could also be used on all types of engine driven equipments to eliminate the problems associated with maintenance while providing excellent interferences reduction characteristics. Figure 4 depicts the advances.

In 1948 Specification 71-3336 was prepared requiring that all types of rotating electrical machinery (motors and driven equipments) for the first time be included in the program. This document specified tests over the same frequency range. (0.15 to

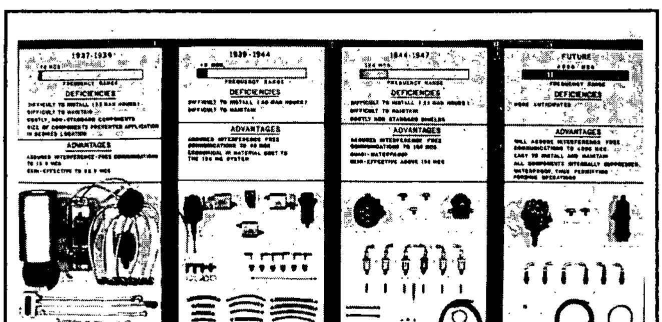

Figure 4. Evolution of Vehicular Interference Reduction Systems.

156 mcs.) with the antenna located twenty-five feet from the unit under test.

As a result of the efforts in developing waterproof interference-free electrical systems Specification MIL-S-10379 was issued in 1959. This document delineated requirements for tactical (tanks, trucks, self-propelled cannons, etc.) and administrative types (sedans, busses, etc.). It also included reference to railroad equipment. Tests were required over the range of 0.15 to 1000 mcs. Tactical vehicles were tested at two feet on all sides and tests within tanks were also specified. Administrative vehicles were required to incorporate a basic system in accordance with a drawing and no testing was required unless interference producing devices not shown on the drawing were installed. No detailed requirements for railroad equipment were included.

When the Army embarked upon a sizeable program of providing communications from locomotives to caboose and from caboose to wayside it was considered that Specification MIL-S-10379 was unsatisfactory. Consequently in 1952 MIL-S-12348 describing requirements for railway rolling stock and maintenance of way equipments was issued. Tests were required over the same range as vehicles but the antenna was located ten feet from the locomotive, ambulance car, etc.

At this time component specifications (MIL-S-12944-resistor-suppressors; MIL-C-12889-capacitors; MIL-F-15733-Filters) were prepared to reflect the advances made since the preparation of the original documents. MIL-STD-220 which described the preferred method of insertion loss measurements of filters was also issued.

As the procurement of military materiel was increasing and to provide optimum service to Army contractors, field laboratories manned by approximately twenty people were established in Milwaukee, Wisconsin and Los Angeles, California. This was necessary as the Signal Corps was still responsible to the Department of Army for the performance of all interference tests. No testing was conducted in screen rooms.

Although not generally appreciated, the Army has a great number of what is termed "watercraft." These boats include patrol boats, tug boats, floating repair shops etc., most of which are 250 feet or less. When it was determined that the communication systems aboard such craft should be up-graded Specification MIL-S-13237 was prepared. This document covered the usual frequency range but the emphasis was placed and tests conducted to assure that on-board equipment would not be adversely affected by interference.

In an effort to combine requirements whenever possible Specification MIL-I-11683 was issued in 1953 to supercede Specifications 71-3004 and 71-3214 for engine generators and engine driven equipments respectively. This document, in comprehensive drawings, described (and required prior to test) the minimum applications which would be required. The test distance was five feet over the usual frequency range.

A quantum jump in the program occurred in 1954. After many years of development highly reliable instrumentation had been completed and were being procured in quantity for use in the field. Further, equally satisfactory commercial equivalents were being manufactured and were readily available to Army contractors. The Army instrument was known as the AN/URM-85 and would cover the entire frequency range of 0.15 to 1000 mcs. As the Army was ever increasing its dependence on electronic equipments and as only minor attention had been given to their problems, Specification MIL-I-11748 entitled "Interference Reduction" for Electrical and Electronic Equipment" was issued. It ambitiously covered the range of 0.014 mc to 36 GHz (commercial receivers were specified above 1 GHz). It established three classes of equipment: Class I for all types of receivers and transmitters; Class II for equipments using RF energy for purposes other than indicated in Class I (medical diathermy, RF arc welders); Class III for unintentional generators of RF energy such as mobile machine shops, electric fork lift trucks and other tactical support equipment. Specification 71-3336 was superceded and cancelled. Further it established basic requirements for susceptibility, narrow and broad band radiated and conducted interference and harmonic generation. Now, for the first time all Department of Army potential sources of interference would be required to be investigated for possible interference.

Specification MIL-I-11748 was amended several times until the last issue dated January 1962 forecasted the future. It required that design plans and test plans be submitted for review prior to submittal of the equipment for test.

As a digression, the Navy Department in 1964 requested that a separate document be prepared for electric hand tools. Use of such tools aboard ship and treated in accordance with Army requirements, had proved satisfactory because of the shock hazard problem. Specification MIL-I-43121 was prepared which delineated two classes of equipment: the first with nominal leakage currents not exceeding 5 milliamperes, and the second with such currents not exceeding one milliampere. This was the second document to be approved for tri-service use, the first being MIL-S-10379 for vehicles.

Now, believing that adequate components and instrumentation and highly competent personnel were available and that contractors were familiar with the requirement all Department of Army interference reduction requirements were placed into a single document. Specification MIL-E-55301 simply entitled

"Electromagnetic Compatibility" was issued and incorporated requirements for all Army interference producing materiel.

EMC BECOMES OF AGE

The Departments of the Air Force and Navy had encountered problems similar to that of the Department of Army over the years and each had prepared interference control specifications applicable to their own materiel. However, when a particular item had tri-service usage a contractor was faced with conflicting requirements for the same equipment. In 1966, the Department of Defense embarked upon a highly significant program which required that the three services jointly prepare standards which would satisfy the interference reduction needs of the entire military establishment. After countless meetings and discussions, Military Standards 461, 462, 463 were prepared in 1967 and incorporated the electromagnetic compatibility requirements for all interference producing equipments. As a result of these documents eighteen basic and numerous subsidiary specifications were superceded.

Numerous handbooks and technical manuals on the subject had been prepared and widely distributed by the three services. Committees of the Institute of Electrical Electronic Engineers and the American National Standards Institute were performing considerable work in this area. The International Special Committee on Radio Interference had widened the scope of their efforts. Greater attention was being given to the requirements of the Federal Communications Commission. Commercial testing laboratories were being established. On the basis of these events it was considered appropriate that greater responsibility be assigned to the other Army agencies and their contractors. Consequently the various procurement organizations and their contractors were advised that they would be entirely responsible for the interference reduction of their equipment and that the Signal Corps would gradually discontinue testing and most other technical services. The field stations were closed.

As expected considerable difficulties were encountered with the change. Procurement personnel, required to select appropriate requirements from the new Military Standards, would establish excessive requirements, contractors would request waivers from the requirements, commercial laboratories encountered problems in the interpretation of the standards and design plans, test plans and test reports were poorly prepared. However after a relatively short period of time, experience was gained and the problems decreased to an acceptable level.

Upon issuance of the military standards the Department of Defense issued a directive delineating the responsibilities of each of the three services. The Department of Army was assigned with the mission of developing measurement techniques and instrumentation and EMC design techniques, which in turn were assigned to the Signal Corps. In addition the Army was assigned the responsibilities for test, analysis and validation which in turn were assumed by the Test and Evaluation Command who had large test facilities in Arizona and Maryland.

Currently, generally the same procedures are followed. Design, test plans and test reports are reviewed by the Signal Corps Laboratories (now known as the U.S. Army Communication Electronics Command) for equipment which they are procuring. Consultation services are provided to other Army commands upon request. Commercial laboratories have proliferated and are readily available to test any equipment and provide all other required services. The Army commands and their contractors have readily accepted their responsibilities and based on field reports, are satisfactorily accomplishing their mission.

FUTURE

It appears that the most serious problems in the immediate future are in the areas of measurement techniques and instrumentation. The increasing use by the Army of frequency hopping systems, spread spectrum and millimeter wave equipments presents many challenges to the EMC engineer. The present cost of instrumentation and ancillary items to 200 GHz or beyond requires that those responsible for establishing EMC requirements be assured that all such requirements are valid and can be traced to potential operational difficulties. The Department of Army is investigating these problems both by in-house and contractual efforts.

It must be noted that the Department of Army's utilization of electrical/electronic equipments is unique among the three services. The Air Force and the Navy are relatively certain of the exact utilization of their equipments aboard aircraft or ship. To the contrary, the Department of Army may install the same equipment in a truck, an aircraft, a shelter or it may be used by the ground forces. For this reason great care must be taken to assure that its equipment will be compatible under a wide variety of applications.

In the instance of millimeter wave equipments (MMW) an immediate need exists for measurement techniques for extraneous and harmonic outputs, two signal spurious response and intermodulation rejection. Conventional measurements using hard coupled techniques at the antenna port cannot easily be used as the antenna is generally an integral part of the equipment (Figure 5) and sampling the energy within the transmission line is extremely difficult. It would appear that a radiated field measurement could be used as the most practical approach. However, this type of measurement, when performed outdoors, can be influenced strongly by reflection from remote objects since their dimensions in terms of wavelength are much larger at MMW frequencies. Further, the directivity of antennas and narrow beam-widths require a rigorous alignment procedure and atmospheric conditions can have a significant effect on test results. In specifying a radiated field measurement technique it would be necessary to address antenna separation distance, its effects on power output and receiver sensitivity, test antenna dimensions and pointing accuracy.

The Georgia Institute of Technology, under contract with the Department of Army, studied potential requirements and measurement techniques for MMW equipments. The results of this investigation revealed that ideally radiated susceptibility and possibly emissions tests should be conducted in what was termed a "compact range." This room or building approximately 50' x 50' in size would provide atmospheric shelter so essential in MMW testing and include a range reflector and absorbing materials to provide RF shielding and would result in a satisfactory simulator of far field conditions. However, the reflector surface tolerance requirements for MMW frequencies and accurate positioning of the feed horn within one-third of a wavelength of the focal point of the range reflector are difficult because of the mechanical tolerances imposed upon the probe positioner. Despite these limitations the "compact range" is possibly the most effective technique, although its cost may limit its use. Of more serious consequence, and an area which is currently being studied, is the necessity for testing MMW equipments over the entire frequency range. It is estimated that the cost of equipment for testing the MMW spectrum from 26 GHz to 100 GHz would approximate five million dollars. It will be necessary that a very thorough review of the possible applications of equipments of this type be conducted prior to requiring such measurements.

At the present, effective methodol-

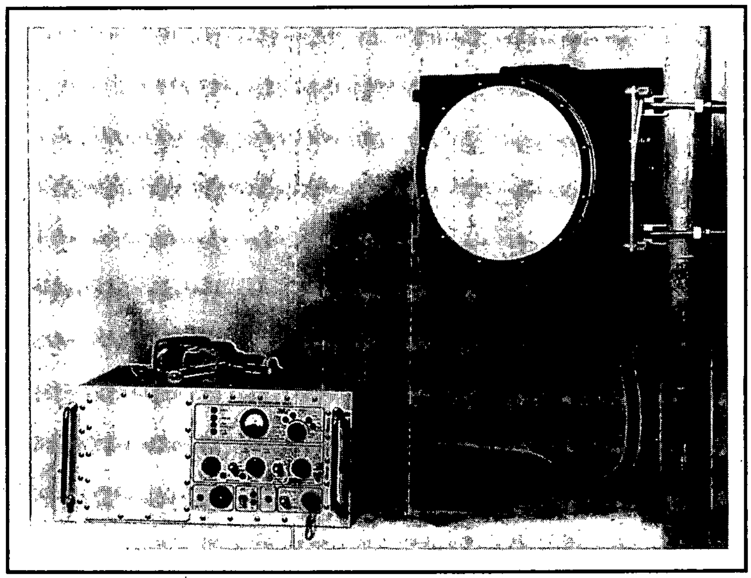

Figure 5. Typical Millimeter Wave Equipment.

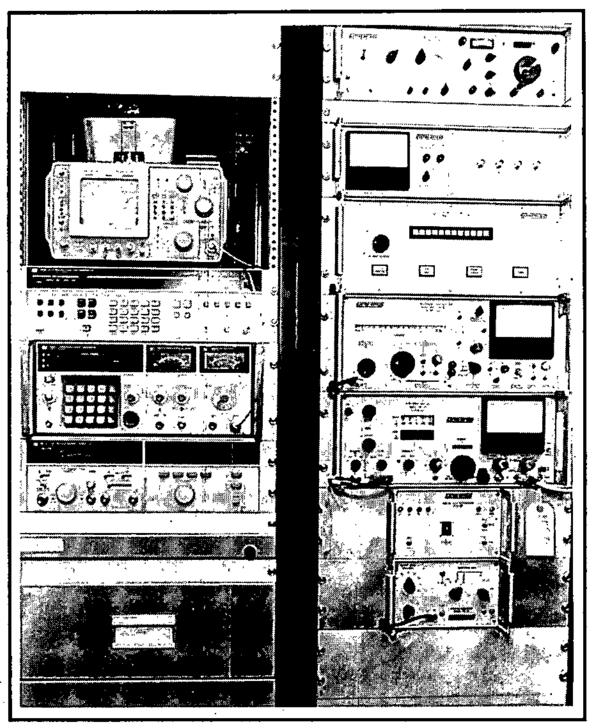

Figure 6. Current EMC Instrumentation.

ogy for measuring antenna terminal emissions of frequency hopping or spread spectrum equipments do not exist. Studies will be conducted to determine if such tests were required for systems operated in these modes. The planned studies will hopefully provide answers to questions such as: "Will such systems have any effect on similar type systems?" "What problems can be expected when these systems are co-located with conventional military transmitters?" "Are tests of this type really required?"

Computer automation of instrumentation (Figure 6) has greatly enhanced gathering, compiling and reducing data. What previously required days can now be accomplished in minutes with one exception -- radiated susceptibility testing. This test requirement is still a tedious, time consuming chore, especially when the test sample exhibits degraded performance. A method of accurately determining field strengths, assuring constant field levels across the sample and automatically monitoring a susceptible condition over the entire frequency range of interest is required.

Lastly, shielded room testing continues to present problems. Many instances have occurred where tests in one shielded chamber did not compare with tests in another. It's a long standing problem as previously mentioned since it is no longer possible to readily locate an outdoor interference-free area. Although considerable further testing is required, the "compact range" concept appears to offer the greatest potential of assuring repeatable results with little variation from facility to facility.

Future concepts now being studied by the Department of Army could have considerable impact upon future requirements for electromagnetic compatibility. One such concept is the use of non-development item equipments. U.S. contractors of electronic materiel have developed a close relationship with the Army. They have been kept informed of future requirements for many years. Through numerous development and production contracts they have gained extensive experience in equipments using their own funds. The R&D thru production cycle has been too long and costly in some instances. To correct this problem consideration is being given to the use of off-the-shelf equipment where possible. It will be necessary for the Army EMC engineers to assure that such equipments will not degrade the electromagnetic environment. Another active consideration is the procedures to rapidly introduce the Very High Speed Integrated Circuit (VHSIC) technology into developing and fielded communication, command and control systems. New EMC measurement techniques may be required for this program.

Distributed Command Control Communications is another study being pursued. This study is concerned with providing more reliable and more survivable distributed battlefield communication systems. This would require a data network which would include all available tactical communications media; satellite, UHF multi-channel, VHF net radio, and HF radio. The inter-network may be required to automatically select the best routes, provide alternate routes and control the flow of information all in a highly mobile configuration. The potential for EMC problems for a program of this scope is enormous. Modeling studies to determine the scope of such problems will be necessary if the study is approved.

CONCLUSION

This paper rather briefly describes the evolution of electromagnetic interference control in the Department of the Army. Many of the problems encountered in the early days were solved only after long hours of trial and error techniques. Those problems and their solution appear simplistic in relation to today's technology. Yet, the problems of accurate, repeatable and economical measurement techniques encountered more than forty years ago are still evident. It is to be expected that the solution of this problem will appear simplistic after another four decades has passed. ■

REFERENCES

1. Donaldson, E. E., et. al., "Millimeter Electromagnetic Measurement Techniques," Contract No. DAAK80-80-C0-569, Georgia Institute of Technology, Atlanta, GA.
2. Donaldson, E. E., et. al., "Evaluation of Radiated Emission and Susceptibility Measurement Techniques," Contract No. DAAK80-81-K-0006, Georgia Institute of Technology, Atlanta, GA.
3. FY-83 Annual Posture Report, U.S. Army Communications-Electronics Command, Fort Monmouth, NJ.
4. Leslie F. Curtis, "Electrical Interference in Motor Car Receivers," Proceedings of the Institute of Radio Engineering, Volume 20, Number 4, April 1932, pg. 674.