Electromagnetic Compatibility—A Necessity for Highway Communications

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•WITH the growth of the highway systems in the United States and the potential of an ever-expanding use of the highway system, the need to communicate between various points on the highway and between the vehicle and the highway system becomes an important requirement. An obvious answer to the problem and particularly to communications concerning vehicles must involve the use of the radio spectrum. The highway system is not the only user, or potential user, of the spectrum which is undergoing these growth pains. Many other users of the spectrum are also vieing for increased use of this natural resource. This paper attempts to show what consideration must be given to electromagnetic compatibility (EMC) in designing highway communication systems. By not considering these factors in the early design, it is conceivable that a system could be designed which could be inoperable in the real world.

NATURE OF THE PROBLEM

The ever-increasing use of the highway system implies a need for increased communications to and from vehicles both for purposes of providing information and for control of vehicular traffic. The design of a system for one of these functions may differ greatly from that of another because of the types of information involved. Potential electromagnetic compatibility problems, which can exist between these systems and also other systems that use electromagnetic energy in the environment, also greatly influence the design and operation of the system.

There are numerous factors that must be taken into account in EMC techniques. They range from design of components to design of equipment and systems to considerations of frequency allocation and frequency assignment, and also involve economics of the use of the radio spectrum, the nature of the environment in which the equipment is intended to operate, and the technical characteristics of the equipment under design and other equipment in the environment. As one can see from this list, EMC involves not only the systems under design but must also take into account characteristics of other systems and must consider a number of nontechnical factors.

EMC AND SYSTEM DESIGN

To best see the approach required to insure EMC, let us examine the path taken from the requirement for an electronic equipment through the various steps to its use in the field. By doing this, one can begin to see the picture forming that a small change in a very early stage can produce radically different results in later stages and conversely, when equipment is operated differently from what was intended, how undesirable results are often obtained.

The first step in the process is that of determining a requirement for a system or equipment. At first glance, it is difficult to see how EMC thinking can occur at this early stage. The requirement is usually for some device to perform a specific function and, in our case, by means of electromagnetic energy. Since the device uses

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electromagnetic energy, we must be cognizant of the fact that it could be a potential compatibility problem. Certainly, one must consider which band is best suited to perform this function, but he must also consider what competition exists in these bands for other uses of the spectrum. Here is where the first concept of systems work must be exercised; namely, trade-offs. We are, of course, aware of examples of trade-offs—for instance, the weight and volume vs performance—but sometimes in the early conceptual stage we forget that performance is a function of the electromagnetic environment in which the equipment is to operate. Sometimes we may be better off choosing a band which does not give the theoretically optimum performance for the intended use but does, in fact, result in better overall performance when competing in the electromagnetic environment with other equipment doing other jobs.

Tied hand in hand with this early requirement phase is the allocations process. First we should define what we mean by allocations as contrasted to assignment. There are really two types of allocation which must be considered. First, the genererally accepted definition of allocation—the allocation of frequency bands to perform particular functions—and, second, the allocation of equipments to operate in appropriate bands. The allocation job is the responsibility of frequency management personnel. When performing this function, the frequency manager must obviously consider EMC. When doing an equipment allocation, he must review the proposed use to be sure that it meets the legal requirements set up by international treaties and national rules. He must also consider whether the proposal makes sense when it is considered with the other equipment already operating in that band or when it is considered with equipment that is not yet operating in the future. Again, the trade-off concept must be exercised.

In his other allocation job, the frequency manager is responsible for providing appropriate space in the spectrum for the various services which it can provide. In exercising this function of subdividing the spectrum and allocating it to various services, he cannot neglect EMC. Providing a band to perform a particular function that is sub-harmonically related to, for instance, a service using high-powered equipment that would interfere does not really provide spectrum space at all. By contrast, frequency assignment is the process of authorizing a discrete frequency to a specific operational user.

The next step in the process involves writing the specifications for the equipment. Here, many times, the importance of the EMC portions of the specifications is forgotten because the individual concerned with writing the specification relegates this to a very low level. Many times he will grab off the shelf some already "canned" interference specifications which may or may not apply to his situation or equipment. By doing this, he is not really giving his equipment or other equipment a fair shake in the spectrum-usage game. What should really be done in this phase is a consideration of the environment in which the equipment is operated and the generation of realistic specifications that apply to this situation. Sometimes, it may be necessary to push the state-of-the-art to achieve these specifications and other times, they may be impossible to meet. In the latter case, if the specification cannot be met, at least the causes and the amount of disturbance to the spectrum will be known.

In many cases, the developmental phase of equipment is the next step of the process. Here again the development engineer should not ignore spectrum conservation principles. If he finds that a particular portion of the specification cannot be met, he should not ask for a waiver for the overall specification but should explain his particular problem and why that portion of the specification is unattainable. He should also indicate what levels can be met. With this information, it should also be possible to determine what the effect of this change will be and the importance of it to the overall spectrum.

The next step in the cycle of a spectrum-using equipment is the design phase. Here the equipment is taken from a bread board model and turned into a final prototype. Many times compromises are needed for the sake of production expediency. The design engineer should be fully aware of good EMC practices and be equally sure that the changes which he makes do not cause adverse conditons in spectrum usage. To do this, he must have an awareness of how the equipment is to be used and of the other equipment that exist with it in the field. In following the equipment through the production phase, he must continually be assured that good practices are being followed.

Now our equipment is coming off the production line in quantity; but, we must be sure that it does, in fact, meet the finally agreed upon specifications. This requires good measurement techniques and good test equipment. We, in the EMC field, have long been aware that there are problems with test equipment. Good measurements are not only important at this stage but in prior stages of the cycle.

We finally are ready to put our piece of equipment in the field. It has gone through all the previous stages of the cycle and now must be assigned an operating frequency. Here we have an important step from an EMC standpoint. It is very easy to look at a list and make quick judgment and assign a frequency, but by doing this are we really playing fair with our spectrum system? Many times, to avoid controversy, assignments are given on a noninterfering basis. Is this because we do not have the spectrum space available or because we have not taken time to assign that frequency properly with respect to the rest of the "occupiers" of the spectrum? Frequency assignment should be engineered considering as many factors of spectrum occupancy as possible and should include present and future use of the spectrum. By taking the easy route now, we may be making it infinitely more difficult to squeeze assignments into the spectrum at a future time when the secondary user's priority becomes high.

We are now ready to operate our equipment. Will it work? Certainly it will work if all of the steps have been followed and the right decisions have been made. But the user is also part of the spectrum-utilization cycle. He cannot make arbitrary changes without interrupting spectrum balance. There are many examples of this that can be cited; in some cases he may not feel the effects, although others certainly will.

Suppose we now look at some of our present problems in spectrum crowding to see how bad the situation is and will be in the future. In his report on "Frequency Management within the Executive Branch of the Government," October 9, 1966, the Director of Telecommunications Management shows many examples and reasons for the crowded condition of the spectrum. Some of the statistics projected in this report are (a) FCC licensed safety and special services radio transmitters are growing at a rate of 20.3 percent per year, (b) broadcasting revenues are growing at 12.3 percent per year, (c) world telephones are growing at a rate of 7 percent per year, (d) the sales of electronic goods are growing at a rate of 11 percent per year, (e) the gross national product is growing at a rate of 5.2 percent per year, and (f) the population is growing at a rate of 1.5 percent per year.

From this it can be seen that the uses of radio and the radio spectrum are growing at a much faster rate than our economy. This increased demand on our spectrum resources cannot help but get us into even more difficult problems unless action is taken immediately. Certainly, everyone has a part to play in spectrum utilization. I am not sure that we are fully aware of that part, and I am positive that only a very few know how their part ties in with the others that affect the overall spectrum usage picture.

By looking at the foregoing statistics, we see that EMC begins to take on an additional dimension; namely, that of economics. Economic considerations are a very important part of the quest for better spectrum utilization. The rather large view of the economics of spectrum utilization is sometimes missed. Examples of this are the impact of a service or new use of radio energy on the economy, the cost of changing allocation, and capital investment in equipment manufacture.

Sociological factors also play an important part in the spectrum utilization picture. The ability to communicate information to large masses of people can obviously change their social patterns and, conversely, the sociological needs of people influence the services that can be provided by the spectrum. Political and legal implication influence the use of the spectrum as well. International treaties, national legislation, and regulations concerning the spectrum are all important considerations.

EMC IN HIGHWAY COMMUNICATIONS

The aforementioned considerations apply to any electronic system that uses the spectrum. The purpose of the rest of this presentation is to illustrate, by example, some of the EMC factors that have to be considered in the design of highway communications systems.

Suppose one looks at the present emergency highway communication system, which uses radio, on the Washington Beltway. There are radio call boxes placed on both sides of this highway. These are periodically spaced around the Beltway. The system involves pushing one of several buttons, depending on which type of emergency is involved, and a coded signal is transmitted to a central headquarters and then the appropriate emergency vehicle is dispatched. I do not have data on the frequency of use of this system but I imagine that the time occupied in transmitting the information from the emergency call boxes is a very insignificant fraction of the total time, probably in the order of minutes per day. In order to insure that interference-free messages arrive at the central headquarters, this system must operate on a clear devoted channel. It is, therefore, using the frequency spectrum in a somewhat inefficient manner. If my assumption is correct, the time occupancy of the channel in actual transmission is quite small but the channel must be available for use at any time. The question then arises: Is availability a use?

Since the use of the radio spectrum is obtained without charge, the utilization of the radio energy to accomplish this mission has probably turned out to be the least costly means. In fact, the spectrum does have value and its use in transmission of energy and being available to transmit energy should be measured in some economic terms. The fact that no other user can occupy the channel means that the incumbent user must bear the complete cost of this channel. If one were to charge for the use of the spectrum, an economic analysis would show that a radio system from these fixed locations around the Beltway might be very costly. A system using land-lines for this function might probably turn out to be considerably less expensive. However, the above is at the moment merely speculation, since there are not means of measuring the economic value of spectrum usage. In the future, it appears that some means of establishing this value will be found. As spectrum crowding becomes severe, some value critieria will, of necessity, have to be established. When this happens, the systems that can utilize alternate means without great economic burden will be required to change their mode of operation.

This first example serves to illustrate the economic factors that must be considered in systems design. Although this is an existing system, it is quite possible that it may set the pattern for future systems, and serious examination of the above factors must be given before we crowd ourselves out of the spectrum.

Another example that would tend to illustrate the effects of man-made noise on the systems design will be given next. Consideration is being given to an inductively coupled highway communications systems between vehicles and a base station or stations. Such a system would be low-powered and in a sense be very conservative on our spectrum resources. The main undesirable feature of this type of communication is its susceptibility to the ignition noise generated by a vehicle. This ignition noise problem has been pretty well conquered in the land mobile services by the use of the resistive ignition wire or resistor spark plugs in the vehicle containing the mobile equipment. Occasionally, interference is experienced when unsuppressed vehicles are close by, but the probability of this happening for any length of time is quite small and the service is generally satisfactory.

In the situation where inductive coupling between the vehicle and communication system is used, the ignition noise problem takes on a different complexion. Since all vehicles are always close to the antenna (requirement of the system), ignition noise from all vehicles will be additive and the resulting noise might well be considerably higher than the signal. Conquering this problem will require all vehicles to be suppressed to a great degree, and the resulting cost might be too large a burden for the public to bear. This mitigating noise factor must be balanced in the design of this type of highway communications systems.

In this example, we have seen that the characteristics of the vehicle become a very important factor in the design of the communication systems. Although the use of the spectrum by such a system might generally be reduced, the noise problem would be the controlling factor. An alternate approach, which might serve as an example, might be the use of present land-mobile type equipment to perform this highway-to-vehicle communication function. Here one really gets into spectrum crowding.

The use of the land-mobile band to perform the highway communication function has several major problems from an EMC standpoint. As noted earlier, the growth of the FCC Licensed Safety and Special Services Radio Transmitters has been approximately 20.3 percent per year. This is mainly in the land-mobile services. In addition to this, the other land-mobile users are experiencing a similar growth. The number of users has been steadily increasing in the past few years. More business and industrial users find that this method of communication is a great aid in their business. In urban areas, the spectrum squeeze is particularly noticeable.

In a number of the larger cities the conditions are such that there is no additional spectrum space available within the allocations to accommodate these services. Because of shared usage of channels, some of the users have actually resorted to other means of communications. A number of other potential users have decided not to join an already crowded situation. If more spectrum space were available for land-mobile service, there would no doubt be a very great demand in urban areas. Although the urban area problem is more severe, increased use of the land-mobile type service for highway communications must compete with many, many users.

In addition to direct spectrum growth due to greater demand for service, intermodulation problems become quite severe. This then is another problem in the EMC field that would result from putting this service into the crowded portion of the spectrum.

CONCLUSIONS

In this paper I have attempted to review the EMC field and show the factors which must be considered in systems design. The examples given were meant to illustrate how the EMC problem enters into highway communications.

My purpose in presenting this paper has been to acquaint you with the necessity of including electromagnetic compatibility considerations in your efforts. This is most important and should be given your full attention when you are considering new systems in the highway communications field.