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A STUDY AND FORECAST OF THE ELECTROMAGNETIC SPECTRUM TECHNOLOGY (PART III)

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FOREWORD

This work was performed under contract No. 19859-69 for the FCC. The final report is divided into 3 parts, all under the title, "A Study and Forecast of the Electromagnetic Spectrum Technology," Part I by John H. Park, Jr., University of Minnesota, Part II by John P. German, Texas A&M Research Foundation, and this report, Part III.

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Some factors which could or should affect frequency allocations and assignments in the future are considered. These include propagation predictions, modulation, coding and information processing. In addition a forecast of the use of cables as replacements for Broadcast TV and micro-wave relay is presented.

I. INTRODUCTION

At the start of the present study of devices and techniques which might affect frequency allocations during the 1970 to 1980 period, a decision was made to restrict this portion of the study to the areas of extensive experience at the Institute for Telecommunication Sciences (ITS). These might be identified by the descriptors; propagation predictions, modulation, information compression, coding and optimizing frequency utilization. It immediately became apparent that a distinction must be made between frequency allocation, frequency assignment and frequency utilization. Because the areas of particular competence at ITS have been closely associated with frequency utilization, the scope of this study was broadened to include all three of the above classes with the primary aim still being allocations.

A short survey was made to determine what has affected allocation, assignment and utilization in the past. For allocation and assignment some gross generalizations can be made. Allocations have been made in response to: new services in frequency bands already being used (e.g. TV), new techniques for providing the same services (e.g. satellites), and new devices which allow utilization of new portions of the spectrum. Assignments contain two parts, the restrictions to be placed on the user, and the selection of the user. The selection of the user, whenever one must be chosen from several applicants, appears to be primarily a political process. The restrictions placed on the user are originally determined by technology, among other things. However, the assignment plans are not easily modified to take advantage of technological progress.

Since techniques and devices that will allow utilization of new portions of spectrum are covered in parts I and II, a search was made for potential developments which might affect the allocations in the lower portions of the spectrum. The concept of the "wired nation", made possible through the development of wideband non-radiating devices appeared promising. Consequently, a study was made to determine if such non-radiating systems would replace some of the existing radiating systems. The results of this study are contained in section 5.

The report is basically divided into two types of forecasts: sections 3 and 4 are concerned with predicting what could be done and section 5 is concerned with predicting what will be done, always with particular emphasis on obtaining more service from the portion of the spectrum between 100 MHz and 20 GHz.

Many of the techniques given here have already been mentioned in the JTAC (1968) report. All have been noted previously in other publications. Thus, their inclusion here is only to provide additional emphasis to their potential.

References are often omitted since many of these refer to a specific product or system rather than to the general concept involved.

II. EFFICIENT SPECTRUM UTILIZATION

Unfortunately, there is no measure of the efficiency of spectrum utilization, and none is likely in the future. (For an opposite view, see Spectrum Engineering JTAC (1968) where some, "measures" are proposed). Some of the difficulties encountered can be seen in the transcript of the Hearing of the House Small Business Committee of 2-20-68 where numerous references to the relative merits of reruns of

"Dobie Gillis" on TV versus "flower delivery service" use of mobile radio are found. Even more basic examples can be found; for example, compare the relative merits of the two sentences, "My wife kicked my horse" and "My horse kicked my wife", where the words in both are the same. However, comparisons can be made at various levels, even without measures of the efficiency of spectrum utilization: At the user level, teleprinter devices which can transmit over several different channels within a voice channel may be preferred to voice which transmits over the same channel. A frequency assignment plan which requires 25 kHz channel spacing is considered better by the FAA than one which requires 50 kHz channel spacing. A frequency allocation which allows sharing between satellites and common carrier point-to-point systems is considered better than the plan allocating this band only to the common carrier. Each of these has one thing in common: the provision for more service, using some definition of service, within the same frequency band, or equivalently providing the same service in a smaller frequency band.

Both allocations and assignments place restrictions on the user. These represent the boundary conditions regulating the amount of improvement the user can achieve in his utilization of the spectrum. In the following sections two types of improvements in spectrum utilization are noted, improvements which have been or could be made within the boundary conditions, and improvements made by changing the boundary conditions. These are used to indicate possible future trends.

III. PROPAGATION PREDICTIONS

In order to pry into the potential role of predictions in frequency assignments let us examine the background of TV broadcast assignment rules.

The television transmission standards presently used in the United States and in many other countries throughout the world were adopted by the Federal Communication Commission (FCC) before World War II. Color was added much later by inserting information in blank spaces in the signal without changing the basic standards. Not until immediately after the war, however, did commercial television broadcasting become a significant service to the public. Originally, thirteen channels in the VHF band were allocated. Channel one was removed partially because of the high incidence of interference from distant stations caused by sporadic ionization of the E-layer that supports propagation quite frequently in the 40-50 MHz range. Channels two through six suffer to a lesser extent from this kind of interference.

Between 1948 and 1950 rapid growth occurred in the construction of TV broadcast facilities, and it became apparent that the table of assignments was in difficulty. Interference from adjacent or co-channel stations sharing frequencies was found to be much higher than had been predicted by spherical-earth diffraction theory, a theory that worked extremely well in the standard broadcast band.

Faced with a popular and rapidly growing service and serious unknown propagation influence, the FCC froze the construction of new stations and set up an ad hoc committee to study the problem.

After several years of study, it was concluded that the atmosphere did indeed influence television propagation beyond the horizon and that atmospheric scattering, layer reflection, and ducting dominated propagation beyond the horizon at these frequencies.

A new table of assignments was adopted in 1953 wherein the geographic separations between co-channel and adjacent-channel stations were increased, and the freeze was lifted. This new assignment plan is known as a noise limited assignment plan, i.e., the grade of service is determined primarily by the signal-to-noise ratio rather than the signal-to-interference ratio.

Here we see some of the evolution of the use of predictions for assignments.

Prediction methods are divided into two classes - service predictions and interference predictions. Service predictions are directed at predicting the low values of received power which occur a small percent of the time and disrupt service, and interference predictions determine the high values of undesired power which occur a small percent of the time and can cause harmful interference. Historically, service predictions have received more attention primarily for two reasons: (1) Interference predictions are inherently more difficult, and (2) Most services began as noise limited systems, with interference treated a-posteriori on an individual occurrence basis. It should be noted that the prediction methods with few exceptions give only the level of the undesired signal, and do not predict the effect of this signal.

The methods now available have been developed from theories, data and combinations of theory and data and are extensively and successfully used for system design and installation. The one serious drawback to the use of these methods for frequency assignments or allocation appears to be the complexity of the formulas. They do not lend themselves to the simple description so desired by the rule makers. However, the general availability of large computers now makes it possible to define the rules or restrictions in terms of computer programs which give predictions, and which can be updated as improved predictions become available.

Let us examine the present status, and the future prospects of predictions. To begin with, all the pertinent propagation takes place through the troposphere and is subject to all of its perversities. Thus, even as you are frustrated when it rains continuously for two weeks at your favorite vacation spot when the weather bureau records show an average of only 1 hour of rain for this period, so is the communicator frustrated by the unforseen event which disrupts his system even though the predictions indicate otherwise. Consequently, it is necessary to make predictions in terms of statistical quantities, and here, for purposes of illustration we will use the median, the one percent and the ninety-nine percent values of transmission loss. As a convention let the one percent level correspond to the high values of received power, the value of transmission loss exceeded 99% of the time, and similarly, the ninety-nine percent level correspond to the low values of received power.

The predictions for the median level for all types of point-to-point tropospheric paths and for frequencies below approximately 10 GHz are accurate to within ±3 dB with a confidence of approximately 95% when the proper inputs are used. Usually, these inputs such as the terrain and atmospheric parameters can be measured, although an experienced communications engineer will be able to detect certain combinations which lead to unusual situations which are not adequately predicted by the theory. In almost all cases where differences between theory and measurements exist, an explanation can be found for this difference, although the probability of finding the explanation before the differences are noted is small. Consequently, only small improvements in either the accuracy of, or confidence in the prediction methods at the median level are expected in the future. It should be noted that the historical approach to predictions is to predict the median and then use the median to predict the high and low percentage values which are the only levels of interest in most situations. Consequently the need for additional improvement in predicting the median level is questionable.

For the high and low percentage levels, the situation is very different. The confidence in the predictions varies greatly with the type of path, and the confidence limits for some types are so large that the predictions are almost unusable. One of the reasons for this unfortunate situation is the lack of reliable data since very long periods of measurements are necessary to obtain good estimates at these levels. Attempts are now being made to relate these occurrences with meteorological phenomena such as sub and super refraction, layering, ducting and rain storms with the hope that the frequency of occurrence of these phenomena can be predicted and in turn be used to predict these levels. There are some isolated examples of the success of this approach which give rise to cautious optimism for the future.

Recent developments in measurement equipment and methods, and the availability of fast data processing equipment now make it possible to obtain the types of data necessary to provide the predictions at these high and low levels. However, the expense of large-scale experiments is likely to retard progress along these lines.

At frequencies above 10 GHz, data are sparse. However, systems can be designed on the basis of available data and theories if a large enough safety factor is included in the systems predictions. It should be realized however that the methods and the safety factor are both subject to revision, and their use in any assignment rules should be limited to applications which can easily be changed. That is, the preliminary predictions should not be allowed to become as dominant and inflexible in the allocations and assignment rules as they have in the past. This could be accomplished, for example, by letting the user assume all risk associated with any future change in rules. It is interesting to note that most of the work in this frequency range is again concerned with service predictions, and, in fact is primarily concentrated on determining the attenuation caused by rainfall which produces the low fields. With the increased antenna directivity at these frequencies, precise interference predictions may not be necessary.

Although most of this section has been devoted to predictions concerned with signal level, many important practical situations arise when the important information concerns the so called bandwidth of the medium. This is usually characterized in terms of the frequency independent fading in the case of beyond the horizon paths, or in terms of phase fluctuations in the case of line of sight paths. For ground to satellite paths the doppler shift could be the important characterization.

For the first case, frequency independent fading, progress has been achieved to the point where adaptive systems have been designed and operated with moderate success. However, we are again faced with an extremely complex cause-effect relationship which makes predictions meaningless except in very gross terms. The simple modeling techniques used as a basis for the design of the adaptive systems appears to be the best tool for the average situation.

Most line of sight systems do not operate with a bandwidth that is wide enough to be affected by the phase fluctuations, and most are protected from deep fades through the use of diversity. Consequently, little work has been done toward characterizing the medium bandwidth for these systems.

IV. MODULATION, CODING AND INFORMATION PROCESSING

The development of the transistor and subsequently integrated circuits (IC's) has already revolutionized the communications industry. The major impact of these developments however still lies in the future. We now see the implementation of codes with equipment that fits in one rack, or even into a small box which only a few years ago would have required a room full of equipment, we now see logic networks which cost less than a single component would have a few years ago and we now see the possibility of all digital systems.

In the past the user did not have a wide choice of systems, usually only AM, FM or SSB, particularly for mobile communications where these systems were designed for voice communications.

Consequently, decisions on which system to choose were easily made. The evolution of mobile communications in terms of voice communications has resulted in a "voice oriented" mobile communication society (analogous statements could be made about almost every other class of service). The all too human characteristics of resisting change prevents the user from evaluating his needs in terms of other types of communication. The user could ask himself, for example, if a simple paging system in the vehicle, requesting the driver to phone the office would suffice in place of the currently used voice channel.

Recently, common user systems have been proposed, and are being considered by the FCC. Here again the questions of which service is "better", or if any are "good" arise. The common user concept does appear to provide better spectrum utilization that the present systems, although its true value may be that it will force the user to critically evaluate his needs.

Again future flexibility should be inherent in the FCC guidelines for licensing such a service because of anticipated improvements in system design. Areas where progress is foreseeable are discussed below.

Part of the game that can be played with communications systems is reducing the redundancies in the information to be transmitted. As is usual in most aspects of communications many different techniques are available as shown by the following examples: companding of voice, replacing voice by teletype, coding a set of messages into a set of numbers, interleaving voice channels to take advantage of the pauses in speech, and many schemes for reducing bandwidth for TV. Systems too numerous to mention here have been built for various special purposes. A directory of such systems specifying their function and performance should be published and updated annually.

One form of message processing is popularly classified as digital modulation. This consists of sampling and quantizing some function of the signal. Two common forms of digital modulation are pulse code modulation (PCM) and delta modulation (DM). The most basic form of PCM consists of quantizing the input voltage into N equally spaced levels, while the usual DM quantizes the slope of the signal into two levels. Many modifications of both systems have been suggested with varying degrees of improvement in performance. PCM systems have received the most attention until recently, when a surge of interest in DM appeared. This interest is due to suggested modifications which have the effect of reducing the bandwidth requirements. Since both PCM and DM are "so-called" broadband systems (i.e., systems requiring much more bandwidth than AM) the prospects of reducing the bandwidth are encouraging. These systems are well suited for transmitting analog information over digital systems. All-digital systems are just now beginning their inevitable growth to prominence and the work on digital modulation schemes should be pushed ahead to keep pace with the growth of these systems.

Coding in its most common form increases the redundancy in the transmitted information in order to increase the reliability of the received information. Many systems engineers involved in the pioneer efforts to utilize coding were disillusioned by the performance of their systems. Consequently, despite the great improvement predicted by theory, implementation of codes remained dormant for a time. However some successes, for example in space probes, have greatly revived the interest in coding. Much of the impetus however should be ascribed to the development of IC's.

One embarrassing aspect of coding theory is that, for a given length code with a fixed number of check symbols, we cannot find practical procedures for designing codes which are as good as an average code with the same length and number of check symbols. For short code lengths, computer searches have yielded codes better than average, but for the longer codes this becomes impossible. Since longer codes can theoretically be constructed with less redundancy than shorter codes, it is apparent that there is room for improvement.

With the increase in communications between computers, coding will assume a more important role. For this purpose, coding is designed to essentially eliminate the probability of undetected or uncorrected errors. Despite the prominence of this role the value of coding for combating certain types of fading or interference should not be overlooked.

With coding we are again faced with a dilemma. Without standardization many systems will be incompatible and with standardization implementation of potential improvements may be impeded.

Although digital modulation was mentioned earlier in this section in connection with signal processing, from the connotation of the name it must also be considered in a discussion of modulation techniques. A direct theoretical comparison of digital modulation with analog modulation is only possible for a limited number of ideal situations, (Akima 1963), and measurements for comparison purposes are expensive. In the presence of Gaussian noise, the performance of the analog (FM, AM, SSB) systems can be calculated. However, in the presence of interference it is still necessary to conduct subjective tests. Results of such testing vary considerably for different types of systems. In some cases for example, FM appears to be better than AM, in other cases the opposite is true, and in still other experiments neither appears better. The following general results appear to hold, although additional testing needs to be done to confirm that the results are not isolated. For single voice channels with the interfering signal of the same kind (AM noise modulated interference to AM desired signal, etc.), (1) FM is better than AM when the signal to interference ratio (S/I) is high, (2) they are equal at medium S/I and (3) AM is better than FM at low S/I. The meaning of low medium or high S/I depends on whether the interference is co-channel or adjacent channel, and on the bandwidth and channel spacing. Specific tests should be consulted for numerical ranges. Most of the work with digital modulation systems has been with noise rather than interference.

For some systems the type of modulation to be used is dictated by the boundary conditions, where again the requirements for compatibility play a prominent rôle.

Multiplexing and modulation are not completely separable. For example, frequency division multiplexing will work with either FM or PCM (and others), but time division multiplexing works better with PCM than with FM. When possible, multiplexing many channels produces better performance than transmitting each channel separately with its guardband.

Summary

An attempt has been made to summarize several subjects, each of which requires several volumes of printed matter for exposition. This is done with the hope that the features useful to the frequency administrator are emphasized, and that the areas which appear most promising for increasing the efficiency of spectrum utilization are highlighted.

One common aspect of each of these topics appears from the discussions - the potential benefits of advances or breakthroughs cannot be fully realized unless the allocation and assignment regulations are revised to provide additional flexibility.

V. THE FUTURE OF NON-RADIATING SYSTEMS

A. Forecasting Method

The Delphi technique was chosen to study the future of non-radiating systems. To quote from Bernstein (1969), "It is generally assumed that the DELPHI technique is merely one method of technological forecasting. Indeed, this is true - but, since it combines the forecasting with the perceived wants or needs of the participants, it is really more than a technological forecast.

The usual forecast attempts to predict what could be - DELPHI tries to predict what will be. DELPHI could be described as an elegant method for developing a consensus; it is a polling technique employed for systematically soliciting the opinions of experts. DELPHI bears deeper investigation because it is directed toward the prediction of the future as it will develop in a situation influenced by many factors beyond the control of the company or agency making the forecast. Its methodology includes the polling of experts representing the controlling factors and from this developing a consensus which can be used in planning. Its advantage consists in the systematic treatment of data that includes the experts' intuitive assessment of related imponderables."

Bernstein (1969) gives a modification called SEER (System for Event Evaluation and Review) which has been partially adapted here. Another modification of the basic Delphi technique has also been used in this study. This consisted of a personal interview with each potential panel member to explain the Delphi technique and to explain the generality of the questions and responses. With only a slight exception, the panel members were contacted individually and did not know the identity of the other panel members.

The first questionnaire is given below.

WHAT IS THE FUTURE OF NON-RADIATING SYSTEMS AS REPLACEMENTS FOR RADIATING SYSTEMS?

A. What are the major obstacles to using cable, waveguide, or other non-radiating systems to replace existing radiating systems?

B. What steps are necessary to overcome these obstacles?

C. List those services currently using radiating systems which can be replaced by non-radiating systems, together with your estimates of

   (1) the probable date of occurrence of at least 50% replacement and

   (2) the earliest possible date of occurrence of at least 50% replacement.

The panel members were instructed to interpret the meaning of both "Non-radiating systems" and "Replacements" in the context of their experience. They were also instructed to base their replies on their own judgment and not to rely on published predictions.

Fifty-five people were contacted in connection with the first questionnaire. An attempt was made to include representatives of government (research and regulator), manufacturers, broadcasters, cable TV, common carriers, private research, universities, and the military. A panel of 25 members was selected for evaluation of the second questionnaire.

A summary of selected portions of the first questionnaire was returned to the panel with the second questionnaire. This second questionnaire (shown below in Tables I and II with the instructions on page 15) was compiled from the results of the first questionnaire and covers events more often mentioned by panel members.

A third questionnaire would be desirable, but due to time limitations is not presently feasible.

B. Summary of Responses from First Questionnaire

The majority of the responses were directed at two services, Broadcast TV and microwave relay systems. Surprisingly, the median probable date of replacement of these systems by non-radiating systems was the same, 1985. The main obstacles to the replacement of these two systems, by non-radiating systems, were: Economic (mentioned in 74% of the responses), Technological (37%), Politics and regulation (37%), Legal and right of way (32%), and Inertia (26%). None of these was considered in the replies to be an absolute obstacle.

In the major category of economic obstacles, the amortization of present investments (which might also be considered under inertia) is a major obstacle which can be overcome rather quickly if a clear need for the frequencies can be shown, and will be overcome eventually because of increased capacities of non-radiating systems, and depreciation of the radiating systems. It appears that potential customers are willing to accept additional cost for increased or improved service.

In the category of technology, it appears that the technology is generally available, but that systems development needs to advance in order to handle the very large capacities which will be available on the non-radiating systems. A major technological advance would be made if cable and/or waveguide systems were developed which did not require an undisturbed right of way, which at present presents the largest legal obstacle to the use of the non-radiating systems.

Instructions

The table which follows lists events. You are requested to check one column indicating the desirability of the event and one column indicating the feasibility of the event. Space is provided for three dates relating to the probable timing of occurrence of the event. Read x = 0.2 as "a reasonable chance", x = 0.5 as "the most likely", and x = 0.9 as "almost certain." Read all events before completing the table. Check only one item under "Desirability" and only one item under "Feasibility" in the table for each event. Give one date for each probability under the heading, Probable Timing. A place for your name is provided on the first table.

Results

The columns, "Desirability" and "Feasibility", were scored 10, 5, and 0 corresponding to the first, second, and third columns, respectively, under each heading. These scores were averaged to obtain the numbers represented by the marks in Table III. Thus the higher scores represent the more desirable or more feasible events. The marks under "Timing" in Table III are the medians of the dates given for the three probabilities x = .20, .50 and .90 from Tables I and II. The mark for the .50 probability is raised for easier reading. The numbers next to the marks give the year, with the numbers from 77-80 meaning the years 1977-1980, and numbers from 00 to 55 indicating the years 2000 to 2055.

Table I

See text for explanation

NAME ______________________________

Events	DESIRABILITY			FEASIBILITY			PROBABLE TIMING: Year by which the probability is x that the event will have occurred		
	Needed desperately	Desirable	Undesirable but possible	Highly feasible	Likely	Unlikely but possible	x = .20	x = .50	x = .90
Events Broadcast TV will be replaced by cable distributed TV in									
A. New York City									
B. Los Angeles									
C. Denver									
D. Rural areas such as Montana									
Events Microwave relays will be replaced by combinations of cables, waveguides and millimeter wave relays.									
A. In dense metropolitan areas									
B. Along the east coast									
C. Along the west coast									
D. Cross country									

Table II

See text for explanation

Events	DESIRABILITY			FEASIBILITY			PROBABLE TIMING: Year by which the probability is x that the event will have occurred		
	Needed desperately	Desirable	Undesirable but possible	Highly feasible	Likely	Unlikely but possible	x = .20	x = .50	x = .90
Events Microwave relays will be replaced by cables and waveguides									
A. In dense metropolitan areas									
B. Along the east coast									
C. Along the west coast									
D. Cross country									
Events Microwave relays will be replaced by combinations of cables, waveguides and satellites									
A. In dense metropolitan areas									
B. Along the east coast									
C. Along the west coast									
D. Cross country									

Table III

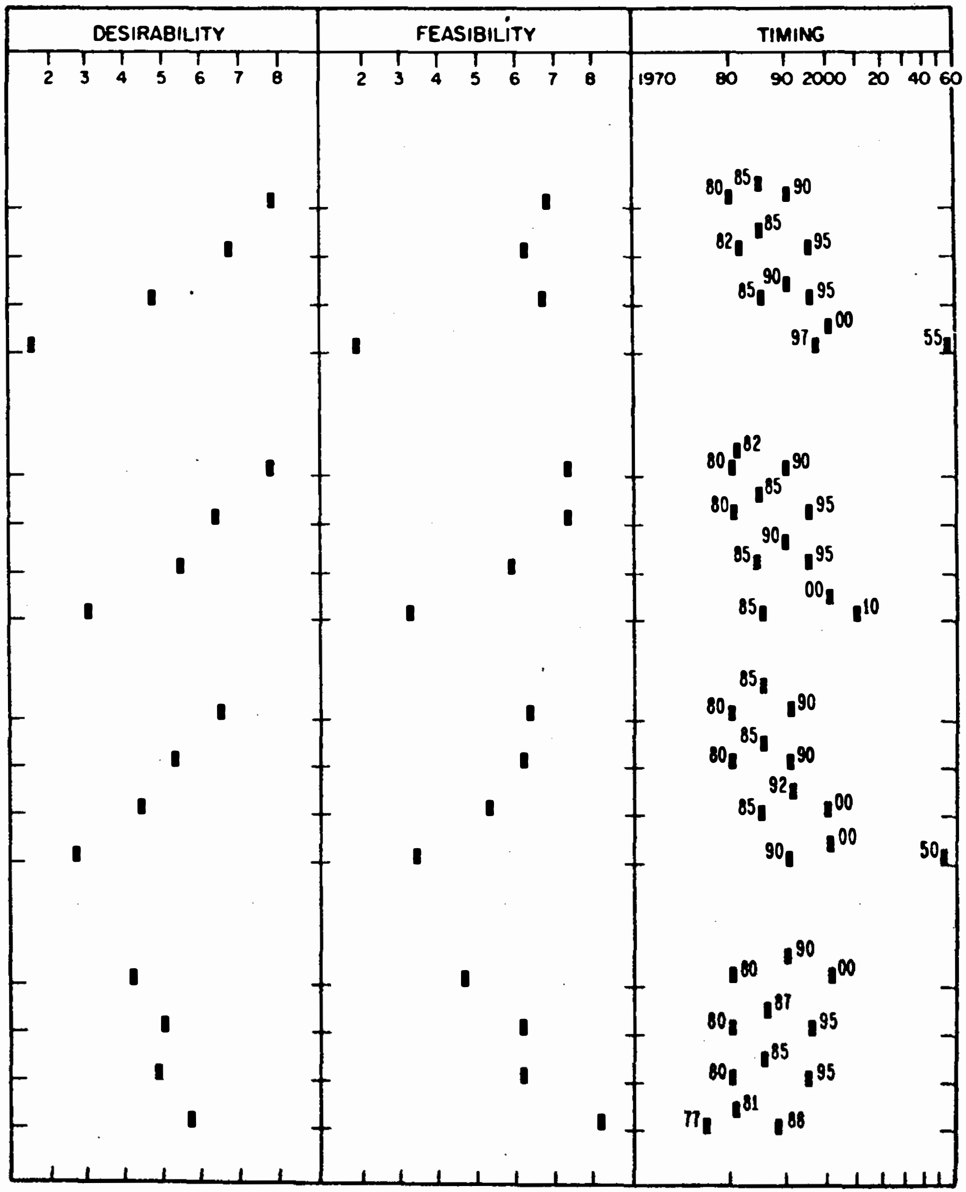
See text for explanation

Broadcast TV will be replaced by cable distributed TV in
- A. New York City
- B. Los Angeles
- C. Denver
- D. Rural areas such as Montana

Microwave relays will be replaced by combinations of cables, waveguides and millimeter wave relays.
- A. In dense metropolitan areas
- B. Along the east coast
- C. Along the west coast
- D. Cross country

Microwave relays will be replaced by cables and waveguides
- A. In dense metropolitan areas
- B. Along the east coast
- C. Along the west coast
- D. Cross country

Microwave relays will be replaced by combinations of cables waveguides and satellites
- A. In dense metropolitan areas
- B. Along the east coast
- C. Along the west coast
- D. Cross country



C. Cable Services

Cable television was developed as one of several methods for distributing television programs to areas where normal broadcast reception is limited or of a poor quality. Originally oriented in small communities and rural areas, cable systems have grown phenomenally and serve practically all communities in the U.S., in many cases offering the same material that is available off-the-air, but with guaranteed high quality reception. From the standpoint of spectrum conservation, cable TV distribution is desirable because it does not radiate signals through the atmosphere. An important aspect of television distribution systems is their potential ability to distribute signals relayed by satellite.

Beginning as a minor adjunct to the present system, cable television is on the verge of becoming a major communication medium in its own right. By June 1969, 2321 cable systems were in operation in the U.S. with more than 2000 under construction. Capital investments are in excess of $500 million and rising rapidly, while annual revenues are in the neighborhood of $300 million (Smith, 1970). In the early years, cable TV operators did not originate programs, but in time, in order to make the service more attractive, they began filling the empty channels in their customers' receivers with simple programs such as weather reports, stock market quotes, and view-a-news teletypewriters. Later a certain amount of live programming began to be seen, including newscasts. The potential is staggering, and a rush is presently on to provide commercial program packages for distribution to cable TV operators. These will include entertainment and information programs, including very soon the nationwide distribution of Public Broadcasting Act programs. It may even be feasible to provide free cable service in much the same way that free broadcasting is now provided through the sale of advertising.

In 1968, the FCC asked for comments on its proposed rule-making for cable TV and on the future of the cable in U.S. communications. Over 200 replies were submitted. In one reply, the Industrial Electronics Division, Electronic Industries Association (IED/EIA) stated that they view the services to be provided by broadband communication networks in the late 70's and early 80's of landmark proportions and look upon such systems as being of "national resource" dimensions and the development of these resources as a national goal. The wired nation as envisioned by IED/EIA would consist of two systems, the first being a more elaborate version of the present telephone system offering video phone with some capacity for a limited computer access and facsimile service. The second would be a broadband cable network (BCN), and would provide for the transmission and exchange of visual material, facsimile, printed material and data. Detailed information on other potential uses of cable can be found in the "Special Issue on Cable TV" (Proc. IEEE, July 1970).

As an indication of the potential for non-radiating systems for the common carriers, the Bell system expects that by 1980 only 10% of its bulk transmission requirements will be met by radio relay with the remaining 90% met by cable or other non-radiating alternatives. At present, where a large number of channels are required over a route coaxial cable is economically competitive with radio relays.

Another class of devices, commonly called limited radiation devices, appear to have potential for some types of mobile services. A precise definition of either non-radiating or limited radiating systems is not possible. Consequently, many people consider a laser system, or even submillimeter wave systems with very narrow beams as limited radiation systems, since most of the radiation is confined to a very narrow corridor. Utilization of G-lines, leaky wave guides and induction radio for train control and communications has proved feasible. Other suggested uses have been for traffic control along major highways, TV distribution in remote areas and vehicle locator functions.

The close interrelationships between high speed ground transportation systems and high capacity non-radiating systems have been pointed out by numerous authors. However, administrative obstacles may prevent exploitation of these relationships since the present development and regulations of the various components are handled by different government agencies.

D. Discussion of Results

The subject matter of the Delphi study was restricted to a narrow field to focus attention on the potential of non-radiating systems as substitutes or replacements for radiating systems. As a result of the interviews and the returns on the first questionnaire, the second questionnaire was both broadened (to include some non-radiating systems) and narrowed (to consider replacing only microwave relays and TV Broadcast).

Generally, the reasons given for <u>not</u> replacing broadcast TV by cable TV were (1) the regulations would not be changed to permit this, (2) the tradition of broadcasting is such that it could not be changed and (3) some remote areas would be difficult to serve. The question of cost did not appear to be a consideration, (except perhaps in (3) above) especially if other services are provided over the same cable.

Those giving reason (1) conceded the possibility that the regulations would change given enough time, in particular for the larger metropolitan areas where spectrum congestion is now a problem. Those giving reason (2) felt that no replacement was possible, regardless of demand. Almost unanimously, the panel felt that future expansion would be via cable which is reasonable in light of existing regulations.

This author interviewed a number of people who subscribed to cable TV, and also could receive broadcast TV. They responded overwhelmingly that the quality of reception was worth the monthly charge and that they would always choose cable if available. With this type of response, it is possible that, with the potential growth of cable TV, the FCC would either have to force the broadcasters to continue transmitting in order to provide outlying areas with TV or force the cable TV industry to provide this service. With proper legislation, it should be possible to maintain the traditional roles of the broadcaster and the cable TV industry. The broadcasters originate and supply the programs, and the cables act as the transmission medium. This role eventually could lead to freeing some of desirable parts of the spectrum for other uses.

The results of the study are generally internally consistent. Several returns were eliminated from the final analysis because of obvious misinterpretation of the questions.

It is apparent that the panel felt that the congested areas such as New York City and Los Angeles were the prime candidates for non-radiating systems. Whether this resulted from knowledge of the need for more frequencies and services in these areas is not known. Certainly newly developing cities have greater potential for providing the right of ways than the established cities.

It is probably reasonable to assume that some but not all of the responses giving times of occurrences past the year 2000 were intended primarily to indicate the unlikelihood of such an occurrence.

The following non-radiating systems mentioned by panel members in the returns of the first questionnaire are worthy of mention because they might provoke ideas leading to still other alternatives.

1. Inertial navigation systems to replace aircraft and ship radio navigation.

2. Acoustic propagation (as suggested for the D.C. Transit system).
3. Extrasensory perception?
4. Replacements for microwave ovens, welders, etc.
5. Limited radiation devices to replace industrial paging equipment, garage door openers etc.

VI. RECOMMENDATIONS

The following recommendations represent actions which should be taken within the 1970-1980 time frame concerned by this report. The recommendations are based on this paper, on Part I by John Park, on Part II by John German, and on the assumption that there is spectrum congestion now which will become worse in the future without drastic remedial action.

1. Fact: The FCC does not now have and probably will not have either the staff or funds to carry-out most of the recommendations of this report or of the numerous committee reports which it receives.

Recommendation: The FCC should assume the role of administrator and design and monitor the implementation of the recommendations. The actual work could be carried out and financed by the users, the equipment manufacturers and other government agencies as appropriate.

2. Fact: One of the most commonly noted requirements is for spectrum monitoring. This concerns a wide range of functions ranging from determining noise levels to determining spectrum occupancy.

Recommendation: Many of these functions could be done by the users under the guidance of the FCC. This is but one way of having the user share the expense of spectrum management. The FCC should incorporate this obligation in the allocation rules. The FCC should submit recommendations to congress for funding those monitoring functions which must be performed by government agencies.

3. Fact: There are available alternatives to spectrum utilization for some services.

Recommendation: The FCC should find means of providing incentive for the utilization of non-radiating systems.

4. Fact: The military, in its dual role of spectrum user and manager supports research and development work on new systems. The civilian government does not provide a central agency for coordinating research and development, particularly that applicable to systems used by the public.

Recommendation: The FCC should catalogue the equipment available for different types of communications systems. This would provide two benefits. It would form a data base for forecasting spectrum technology, and it would provide a basis for FCC studies comparing the efficiency of different systems.

5. Fact: Once users obtain a license, the user investment plays a dominant role in future decisions of the FCC. This prevents efficient use of technical innovations. The licenses are now issued for a fixed length of time with renewal dependent more on the negative condition, absence of misuse of the assignment, than on the positive condition, efficient use of the assignment.

Recommendation: The FCC should place more emphasis on the responsibilities of the user than on the rights of the user when renewing licenses. These responsibilities should be broadened to place emphasis on efficient spectrum utilization. This represents a change in philosophy which could be made immediately, even though the practical implementation would evolve slowly.

6. Fact: Most of the current rules and regulations were made with a view to avoiding interference between users. The concept of frequency sharing is contrary to this view.

Most users cannot give a definition of what they consider to be harmful interference, although many can give examples. The definitions also vary between users. Today, the FCC receives most of the information concerning harmful interference from complaints.

Recommendation: The FCC should compile information on the interference that the user can tolerate. This should not detract from studies designed to minimize interference which is not tolerable, but together, the two studies would form the basis for rules conducive to frequency sharing.

Qualitative information on frequency sharing and limited quantitative information is available for various services. The FCC should compile this information in order to make classifications of frequency sharing situations.

General information on frequency sharing, its potential and its problems should be prepared for the public, since many, if not most of the users of frequencies are not communications experts.

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