The Radio Spectrum--Polluted Pond or Flowing River?

LAND/MOBILE SERVICES

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ABSTRACT

A narrative account of the past, present, and future of Land/Mobile radio communications particularly as related to spectrum utilization.

INTRODUCTION

Land/Mobile radio, in its broadest connotation, was the first service to make use of the radio spectrum. And, if indeed the spectrum ever approaches saturation, mobile radio will he the last surviving service to be accommodated. The reason for this is very clear. The radio spectrum provides the only practical means of communicating with men in motion, whether they are in ships at sea, aircraft, space vehicles, automobiles, locomotives, earth-moving machinery, material handling vehicles, on motorcycles, or simply on foot. Because there is no alternative, I have always felt confident—that Land/Mobiles' need for adequate spectrum space will eventually be served.

The sequence in which radio waves have been put to work for the benefit of mankind has been characterized by two significant criteria, – mobility and urgency. Back in the year 1900 nothing was more <u>mobile</u> than a Ship at sea nor more <u>urgent</u> than a sinking ship. Therefore, Marconi sought first to provide communication with ships at sea. When we look at Land/Mobile radio as we know it today, it is easy for us to understand why police departments were the pioneer users on land. Nothing is more "mobile" than a police car nor more "urgent" than a crime in progress. In sequence of usage, the police pioneers were quickly followed by fire departments, forestry departments and electric utility companies who have comparable problems of mobility and urgency.

The history of Land/Mobile radio is one of continuous growth interspersed with periods of explosive growth, increasing congestion, and repetitive pleas to the FCC for more spectrum space. This has led to unremitting pressure on the state of the art to make more intensive use of the modest 4.7% of the spectrum allocated to these services back in 1947. In the four frequency bands available to the service, channels have been split a total of seven times at a cost of millions of dollars to users in equipment obsolescence and conversion costs. The Land/Mobile community has an-unmatched record of spectrum stewardship.

Police Radio Pioneers

Commissioner William P. Rutledge of the Detroit Police Department is credited with the initiation of police radio by his purchase and installation of a Western Electric 1A 500-watt broadcast transmitter in 1921, only four years after that city had pioneered the use of. automobiles for police work. The Detroit and other early police radio installations provided only one-way communication to the police cars and employed amplitude modulation first in the broadcast band and later in the medium frequency band, Two-way communication was initiated by the radio engineer for the Bayonne, New Jersey, Police Department,-- Vincent Doyle. The Bayonne System went on the air in March 1933 using REL AM equipment on 33.1 MHz.

Frequency Modulation Replaces AM

Mobile radio, as we know it today, really started with the advent of FM in the early 40's. On November 6, 1935, Major Edwin H. Armstrong demonstrated his system of frequency modulation to the Institute of Radio Engineers in New York City and it did not take very long for a number of engineers to perceive that FM had great possibilities for application to the mobile services because of its noise reducing properties, the capture effect, and its other superior characteristics. Specifically, an application was made to the FCC on April 26, 1938, for an experimental license to directly compare the performance of FM and AM systems on a circuit set up between Schenectady and Albany, New York. Field testing started on August 3, 1938, and demonstrations were given to members of the Navy, the Signal Corps, the FCC and IRAC, and at other various times, until September 1939. One of the objectives of the tests was to demonstrate to FCC representatives that FM could operate in the same 40 KHz channels assigned for AM at that time. It was found that a peak swing of +/– 15 kHz would confine the modulation envelope within the established channel band-width and with the same modulation index of five at voice band frequencies up to 3,000 cps, as the +75 KHz swing employed in FM broadcasting, which transmits musical frequencies up to 15 KHz. Plus and minus 15. kc swing was suggested to the FCC engineers who subsequently adopted it as standard. At the time, the Connecticut State Police were in the market for a new state-wide system and their consultant, Daniel E. Noble, was one of those who witnessed the Schenectady-Albany tests. The Connecticut system was installed during the year 1940 and became the first to use frequency modulation state-wide using equipment supplied by the Fred M. Link Company. An account of this first system was carried in the November and December, 1940, issue of Electronics.

World War II

When the United States was thrust into World War II, December 7, 1941, a number of police departments and a few public utility companies had been equipped with FM systems but further commercial use had to wait until the conclusion of the war. For the duration, only police and fire departments could obtain the necessary A1A priority to purchase equipment, Quartz crystals were in particularly short supply.

Throughout the war years, there were only three suppliers of mobile equipment,-- Motorola, Link and General Electric. Any police department in the market for a new system, could expect to receive bids from those three suppliers. In those days, the only criterion was, “How far can you talk?" Users were concerned only with receiver sensitivity and transmitter power output. Receiver selectivity was of little consequence. Spurious responses were attenuated no more than 20 dB. Transmitter spurious, too, was of little consequence. One could communicate for several miles on almost any harmonic of the crystal oscillator frequency. I recall the innumerable competitive tests which were run solely to compare communication range. Whoever could talk the farthest, got the contract
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The Radio Technical Planning Board

In January, 1944, with the end of the war in sight, the FCC established the Radio Technical Planning Board (RTPB) under the chairmanship of a truly great man of radio and television, Dr., W. R. G. Baker, organizer and manager of General Electric's Electronics Department. Dr. Baker appointed a chairman for each panel of representatives for each class of service claiming use of the radio spectrum from 25 to 890 megacycles with the objective of complete reallocation of that portion of the spectrum directly after the war. He appointed Dan Noble of Motorola chairman of the Land/Mobile group, Panel 13

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Postwar Allocation Proceedings

The result of this work was the postwar reallocation proceedings in which a number of new services were opened up to the Land/Mobile category such as Power, Petroleum, Urban Transit, Highway Maintenance, Railroads and Taxicabs. The 152-162 mc band was made available to the Land/Mobile Services for the first time. Prophetically, a Citizens Band was proposed from 460-470 mc and "provision may be made for sharing of frequencies in the television bands upon proper showing of need and that no interference will result."

Channel-Splitting

Back in 1945, I do not believe that anyone,— not one single person, foresaw the explosive growth which the mobile services would experience. Many of today's services were established since the work of the RTPB was concluded. Currently, for example, the FCC and the IRAC are working toward the establishment of an Emergency Medical Service. Land/Mobile finally emerged with a modest 4.7% of the available spectrum, but even in those earliest days there was talk of channel-splitting in the 30-40 mc band. For example, here is a quotation from a public notice issued March 21, 1947, in Docket 6651, "There is at the present time an acute shortage of channels in the 30-40 mc band. It is the Commission's belief that the use of narrower channel widths offers the only means of obtaining additional channels in this band. As a result of a conference in December, 1946, a committee is to be set up by Panel 13 of the RTPB to study the feasibility of manufacturing 20 kc channel width equipment on a commercial basis."

One of our well-known radio pioneers, Cap Priest, recognized the inevitability of split-channel operation in the already crowded 30-40 mc band, He authorized the development of equipment for initial operation on either 40 kc or 20 kc channels and which would be readily convertible in the field from one mode of operation to the other. On April 22, 1949, we ran comparative tests of the two systems at Electronics Park for the benefit of Commissioner George Sterling and FCC Engineers, Glenn Neilson and L. E. de LaFleur. These and other comparative demonstrations clearly showed that the number of channels could be doubled without degradation of service and in the best interests of spectrum conservation., We supplied an increasing number of narrow-band systems well before 20 kc channeling was implemented by the FCC.

Over the period from April 1, 1947,--the adoption of the service allocations in Docket 6651, until the finalization of Docket 17703 in August, 1971, all four Land/Mobile frequency bands were split one or more times. The 25-50 MHz band was split from 40 to 20 KHz. Under the guidance of a JTAC subcommittee, chaired by Fred Budelman of Link Radio Corporation, the 150-174 MHz band was split from 60 to 30 kc. Since that time, the channels have again been split to 15 kc, The 450-470 MHz band was the last to come into general use because of the higher inherent cost of the equipment and the more limited range. Increasing congestion in the low band and high band literally forced new users to gravitate toward the UHF band and it is now recognized as ideal for use in our densely populated metropolitan areas. Initially, assignments in the 450-470 MHz band were on a 100 KHz channeling basis but they have since been split to 50 and finally to 25 KHz channels.

In the postwar allocations the 72-76 MHz band was given to the Land/Mobile Services and some systems were installed, notably an extensive system for the Central Hudson Power Corporation in the Poughkeepsie, New York Area. However, this band was withdrawn from mobile operation because of potential interference to TV channels 4 and 5; not because of extra-band radiation from mobile transmitters, but rather because of the relatively poor selectivity of television receivers. The band is currently available to Land/Mobile for point-to-point control circuits where they are sufficiently remote from channel 4 or 5 TV stations. The original 40 kc channels have been split to the present 20 kc band width.

One might logically ask, why should the band-width differ from one frequency band to the other? The reason is that the Commission did the splitting on the basis of minimum dislocation to existing systems. The optimum channel band-width regardless of the frequency band, using FM modulation with +/– 5 kc swing is 25 KHz. The knee of the curve of the modulation spectrum occurs at approximately 12-1/2 kc from the carrier. Therefore, a 25 KHz band width is optimum for same-area, adjacent-channel operation. Where channels are spaced less than 25 KHz, we depend upon geographic spacing to minimize or avoid interference between systems. For example, the 15 kc splits in the high band, by FCC rule, require at least ten miles between base stations in the Public Safety and Industrial Services and seven mile separation in the Land Transportation Services. This is another example of the lengths to which the Land/Mobile community has gone to make the most efficient possible use of the spectrum allocated to it. Our frequency bands have now been split to the point where we no longer refer to them as “splits" but rather in such terms as "sliver band,” "splinter" frequencies, and "offsets. " The most recent splitting provides 12-1/2 kc offsets in the 450-470 MHz band for low-power services, and some band-end frequencies in the 154 and 175 mc areas having band-widths of 5 kc and 7-1/2 kc. These latter channels are used only for tone signaling rather than voice Transmission.

Cost of Channel-Splitting

What has channel-splitting cost in terms of equipment sophistication?

Frequency stability has become stringent in the extreme. The requirements have gone from 0.01% – 100 parts per million--to 0.0002%,--2 parts per million. Today's mobile units must hold operating frequency more accurately than the finest watch you can buy and they must do it in the hostile environment of widely varying temperatures and humidity, shock and vibration, dust and dirt, corrosive atmospheres and rough handling.

Receiver selectivity has gone from 60 dB at +120 ke to 100 4B at +30 kc while still accepting up to +7 kc swing at a signal input of only a quarter of a microvolt. In other words, the industry has not gained adjacent-channel selectivity at the expense of adequate band-width for good voice or data communication.

Receiver spurious responses have gone from -20 dB to -100 dB and the number of spurii have been cut in half by going from double to single-conversion superheterodyne circuitry.

Antenna Farms

The tremendous growth in these services has given rise to the proliferation of antenna farms in all of our heavily-populated metropolitan areas and at many choice locations in the hinterlands too, for that matter. It is becoming increasingly difficult to find a tall building or an accessible mountaintop which does not resemble an inverted pitchfork. In these multiple installations, the limiting item becomes intermodulation and great strides have been made in minimizing the generation of IM products in both transmitters and receivers. The use of five or more high Q circuits,--miniature cavity filters--and the relatively recent introduction of the field- effect transistor at the front end of our receivers, has provided a basic receiver inter-modulation rejection figure of 80 dB as compared to the old 60 dB spec. Even greater IM attenuation is obtained by the use of large cavity filters or quartz crystal filters at the input to base station receivers. Transmitter generated intermodulation is controlled to a remarkable degree by the use of cavity filters in their outputs as well as ferrite circulators currently available for the UHF and 150 MHz bands.

Chicago Frequency Management Center

Looking back over 34 years, I can only conclude that the Land/Mobile community has an unmatched record of cooperation with the FCC in the conservation and efficient use of the radio spectrum. Our channels have been split to the nth degree but, in addition, we have gone to the wide-spread use of tone-coded squelch, community repeaters, offset frequencies, limited transmitter power and other techniques to share the use of frequencies among a maximum number of users at levels of interference just short of intolerable. In its most recent frequency allocation plans, the FCC is departing from the “block” assignments, dating back to the postwar period, to the "pooled” concept looking toward even greater interservice sharing. The first FCC Frequency Management Center in Chicago is an experiment to determine to what degree, if any, further sharing among users is possible.

Dockets 18261 and 18262

On May 20, 1970, much-needed relief was finally granted. The Land/Mobile Services obtained additional spectrum space through Dockets 18261 and 18262. The first docket permits sharing with one or two of the seven lower UHF channels, 14 through 20, in our ten largest cities (470-512 MHz). Unfortunately there are serious limitations on antenna height, ERP, and the geographic area which may be covered by these new systems. Detroit and Cleveland cannot proceed until concurrence is given by the Canadian Government. Similarly, Los Angeles must await Mexican agreement. Nonetheless, wherever these shared frequencies can be put to practical use, it is being done. The New York City Police Department, for example, is converting its entire 55-channel system to the new UHF frequency band.

Our great hope for the future now lies in the 115 MHz of space in the 806-902 and 928- 947 MHz bands. The Commission is currently wrestling with the problem of how to subdivide the band between the common carriers and the private users and how much to hold in reserve. From an engineering standpoint one would not normally choose these sub-microwave frequencies for mobile service but the Land/Mobile community is grateful for the relief in prospect and the band will be most useful in our heavily-populated metropolitan areas where the congestion is most serious. Mobile radio congestion is directly related to population density.

In view of the fact that 115 MHz is more than double the 42 MHz previously allocated to our services, much study has gone into the most effective means of utilizing the new spectrum.

The spectrum is dimensioned by frequency, space, and time, Through channel-splitting, the Land/Mobile community has multiplied its spectrum capacity by more than four times thus maximizing the frequency dimension. Computer control of shared systems now offers a means of more intensive use of the time and space dimensions. The space dimension implies that we reuse a channel as often as possible in any given geographic area,--the cellular concept. The time dimension suggests trunking; give each user access to many channels so that he has a high probability of finding a clear channel with a minimum waiting period. In view of the brevity of dispatch communications,--some messages are as short as '"10-4"--there is virtually no time for manual switching of trunked channels such as are used, for example, on the Great Lakes where "Calling" and "Working" channels are utilized on a manual-switching basis. If we are to use the principle of trunking efficiently, the selection of the next available channel must be performed by a computer.

Cellular Systems

The multiple-user, private-dispatch system (MUPDS), proposed by the EIA Land/Mobile Section, and the Bell Broad-Band, Common Carrier System, proposed for use in the new 900 MHz band, make use of the cellular configuration with repetitive use of trunked frequencies under computer control. These systems offer the most efficient use of the radio spectrum yet contemplated. They are readily expandable to accommodate the increased traffic load which will inevitably occur. The cells can be reduced in diameter and increased in number,-- the Bell people believe that they can be reduced to as little as 1.05 miles in diameter,-- so that for the foreseeable future every user will have access to a clear channel within several seconds of his pushbutton request, even in peak traffic conditions. It is estimated that computer-controlled cellular systems can increase our spectrum utilization efficiency by a factor of 2 to 10 or more, depending upon cell size. The smaller the cells, the more efficient, but more complex and therefore more costly, the land-based system. Consider the "hand-off" problem as a vehicle travels through a number of cells while conducting a continuous two-way conversation!

Bell System estimates that its proposed 800-channel, small-cell system for Philadelphia could handle 150,000 MTS subscribers and 300,000 dispatch-type users throughout the Philadelphia metropolitan area. This represents a loading of 562 mobiles per channel. The present Bell IMTS service accommodates approximately 45 units per channel; therefore, the new system proposal represents an improved utilization of 12-1/2 Times.

RCA claims that its proposed dispersed array system, similar to that proposed by AT&T, will handle 1500 vehicles per channel in a given locality, increasing spectrum economy by a factor of 35.

Although the installed cost of the land-based portion of a MUPDS System is in the order of $1 million, cost projections show that the service will be as economic, or even more economic, than present-day private systems, particularly for the small business user who may have as few as one to three mobile units. (The national average is only 9.3 mobile units per system.) It is often difficult for the small user to justify the cost of a base station to serve only a few mobile units with the result that many potential users either deprive themselves of the service or participate in the popular community repeater systems and RCC systems. We can expect many of these small fleet operators to gravitate toward the superior service offered by computer-controlled systems in the 900 MHz band. This exodus should, in turn, clear some channels in the lower frequency bands for the extensive private systems operated by Governmental Agencies, Public Utilities, The Petroleum Industry, The Railroads, etc.

At the time of this writing, the early implementation of these multiple-user systems depends upon the resolution of political, rather than technological implications. Meanwhile, utilization of our present spectrum resource is being enhanced by the ever increasing use of digital transmission to supplement the less-efficient voice communications.

The Digital Data Supplement to Voice

A high percentage of mobile communication (40% to 60%) involves the two questions: Who are you, and What are you doing?--vehicle identification and status. The answers to these two repetitive questions can be transmitted in less than 500 milliseconds by a burst of digital information preceding or supplementing voice communications. At the dispatching center, the operator has a visual readout of all of his cars in service and their status at any given time. Obviously, this is very essential information and it is continuously updated with a minimum of human effort through digital transmissions. In addition to the ID and status systems just mentioned, many police departments are starting to provide direct access to a computer without dispatcher assistance. Complete computer inquiries are transmitted in less than two seconds of air time and the readout is displayed in a police car in a matter of seconds. Inquiries concern stolen cars and other property, missing and wanted persons, warrants, and so forth.

It is rather difficult to place a number value on the degree of improvement achieved by digital over voice transmission. In general, it may be said that 30 seconds of voice communication equals about 2 seconds of digital information throughput over a mobile radio system,--a 15 to 1 improvement. However, in the early police installations, it has been found that digital capability does not reduce the number of radio channels re quired, rather, it greatly increases the number of inquiry/responses by a factor of 100 or more. The practical effect is that the officer in the field has much easier access to computer information storage since the intervention of a third party--the dispatcher--is no longer needed.

Future Prospects

Considering all of these recent developments, what are Land/Mobile's prospects for the next 25 years? With the release of the 900 MHz band and further sharing of TV channels 14 through 20 in fifteen additional cities now under consideration by the FCC, we probably have enough spectrum to meet our foreseeable needs to the year 2000. But what about the more distant {future? Will we abandon FM for some other form of modulation? Over the years, one of the most oft-repeated questions has been, "Why don't you go to single side-band?" That question is not asked so much any more because FM has survived every comparative evaluation including those made by Motorola and General Electric engineers. It is significant, too, that Bell engineers did not select SSB or PCM for their proposed 900 MHz system. Single side-band lacks the very useful capture effect of FM, it is more susceptible to impulse noise, a very serious problem in vehicular communications, and with less than perfect linearity, a single side- band transmitter has more out-of-band radiation than an FM transmitter. This would be a serious source of interference between the clustered base stations typical of L/M systems.

Is our next generation likely to see pulse code modulation (digitized voice) employed in the mobile services? With large-scale integrated circuits increasingly economic, the world of electronics seems to be going from the analog to the digital mode.

When we consider PCM, the first characteristic which comes to mind is its wide band- width requirement. It is ideal for point-to- point transmission under the controlled conditions existent over wire lines and microwave systems operating in the spectrum where wide band-widths are most readily available. Digital signals are easier to amplify and to repeat through multiple repeater systems. Analog signals are subject to distortion whereas digital information is readily reconstructable to its original form. Unfortunately, we do not have controlled transmission conditions in mobile radio,--quite the contrary is true. Also, there is rarely more than one repeater in a mobile system.

Several years ago we considered digitized speech as a means of voice scrambling in mobile systems but were quickly confronted with the fact that the desired 20 kilo bit sampling rate would require at least two of our present 25 KHz channels. This one example indicates that a move to PCM would cost us an approximate 2 to 1 loss in spectral efficiency. Based on our present knowledge, it does not appear likely that PCM, or any other form of modulation, will replace NB FM as the optimum for Land/Mobile systems. That statement ought to challenge our younger generation to "find a better way" in the tradition of Edison and Kettering who said, "If you've always done it that way, it's probably wrong."

Land/Mobile TV Sharing

Rather than some alternate form of modulation, the key to potentially greater spectrum utilization lies in interservice sharing, Land/Mobile sharing with the lower seven UHF TV channels is now an accomplished fact. It should be extended to an increasing number of metropolitan areas to alleviate the present congestion.

Extensive laboratory and field testing has also demonstrated that we could share VHF TV channels on a non-interference basis,-- particularly the band-end TV charnels 6, 7 and 13. Land/Mobile radio is already sharing TV channels 2, 4 and 5 on an adjacent-channel basis. Much greater use could also be made of the 72-76 MHz band by Land/Mobile without harmful interference to channels 4 and 5 which are adjacent on each side. In tests of sharing with TV channel 6, the only interference encountered was with TV distribution systems using open wire transmission line which convert other TV channels to channel 6. This type of interference could be corrected by the use of coaxial, rather than open wire transmission line in the wired systems. The problems of interservice sharing are political rather than technological.

Summarizing

In summary, it can be said that no other service matches Land/Mobile's record of spectrum stewardship. The very scarcity of spectrum resources has literally forced technological developments at a faster pace than has been exhibited by other services. In a study concluded in July, 1969, the Telecommunications Committee of the National Academy of Engineering in a report to President Johnson's task force on communications policy, said, "These studies have indicated that while Land/Mobile does not appear to be achieving the maximum efficiency of spectrum usage that is theoretically possible with the present technology, on the whole, the efficiency surpasses that of other services with greater spectrum allocation."

In our metropolitan areas, channels have been shared by users to the level of intolerable interference.

The Chicago Frequency Management Center has been implemented to determine to what degree further sharing is possible, particularly through the abandonment of the block assignment plan.

We are successfully sharing the lower seven UIIF TV channels and can foresee greatly extended use of this technique on a non-interference basis.

We are on the eve of the implementation of multiple-user, computer-controlled cellular systems which will enhance our use of the available spectrum space by a factor of ten or more.

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Archivist Note: There is no date on the original document. However, the text indicates that it is most likely from the mid-1970s.