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USE OF THE FREQUENCY SPECTRUM FOR DIGITAL TRANSMISSION

THE CANADIAN TELECOMMUNICATIONS CARRIERS ASSOCIATION

USE OF THE FREQUENCY SPECTRUM FOR DIGITAL TRANSMISSION

A Report Submitted by C.T.C.A.
To The Department of Communications, Canada

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1.0 INTRODUCTION

The recently completed Telecommission studies have indicated a rapidly increasing requirement for all varieties of telecommunications services. These conclusions have been reaffirmed in the report of the Canadian Computer/Communications Task Force (with respect to data transmission) and by the ongoing planning activities of the member carriers of the C.T.C.A.

There are several available transmission media technically capable of providing this increased capacity (coaxial cable, radio relay, waveguide, satellite, and optics). It is clear that the overriding objective of providing both a flexible and economic expansion of the telecommunication network will require the provision of diverse types of transmission media.

Microwave radio relay has provided almost all of the long haul transmission capacity in Canada up to the present and it is reasonable to expect that it will continue to play an important role in the future. Moreover, the existing microwave bands are becoming increasingly hard pressed to meet the demands of increased capacity. There is thus a need for new spectrum allocations in Southern Canada.

Efficient spectrum utilization is a subject of great public importance. Because of the need for new allocations to provide new services and meet future traffic demands, the C.T.C.A. believes it is necessary that action be taken now. It is important to ensure that this natural resource be allocated in such a manner as to provide the flexibility for new services and increased capacity necessary to meet the requirements of Canadian telecommunications users.

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The increasing data traffic generated by the Canadian computer/communications industry and the economies and flexibility inherent in digital transmission techniques dictate that future use of the microwave spectrum in Canada will almost certainly exploit digital modulation* technology. Furthermore, a digital microwave system would provide an efficient backhaul facility into metro areas from earth stations carrying ~~a~~ digital traffic. To this end, the C.T.C.A. believes there is a need for new allocations in the terrestrial microwave spectrum specifically designed to meet the requirements of digital transmission.

The following recommendations represent the C.T.C.A. position on desirable frequency allocations that best meet the above objectives consistent with efficient spectrum utilization.

1.1 RECOMMENDATIONS

(1) That an allocation in the 8 GHz band be provided for medium capacity high performance terrestrial digital radio systems. It is recommended that this allocation be the two bands 7.725 - 7.975 and 8.025 - 8.275 GHz. For efficient digital operation a new channelization plan is recommended incorporating six go and six return channels on a nominal 40 MHz spacing.

(2) That an allocation in the 11 and 13 GHz bands be provided for high performance, high capacity digital radio systems. It is recommended that this allocation should be 10.7 - 11.7 and 12.2 - 13.25 GHz.

* In order to clarify and define terminology, digital modulation refers to the modulation of a carrier by a finite number of discrete states. Digital transmission refers to the transmission of discrete digital information using time division multiplex and digital modulation techniques.

A 500 MHz dual polarization channelization plan is recommended, thus providing four go and four return channels.

(3) That the 8 and 12 GHz bands be allocated for terrestrial systems employing only digital modulation so as to optimize spectrum efficiency by exploiting the superior interference immunity of these systems. Furthermore, by not imposing additional constraints inherent in a shared (analog/digital) allocation, further efficiencies envisaged by future developments in the digital technology are assured. However, it is recognized that protection should be provided for existing analog systems established in these bands.

(4) That both digital and analog systems share the existing bands below 8 GHz. However, adequate safeguards must be incorporated to ensure that future digital installations do not interfere with the growth and future use of analog systems in these bands. Furthermore, digital use of these bands should comply with presently established SRSP guidelines concerning performance, channelizing plans, service applications, etc.

The remaining sections of this report discuss the technical and economic factors pertinent to the above recommendations.

1.2 A NOTE ON THE DIGITAL HIERARCHY

Because this report is primarily concerned with digital transmission systems, it is convenient to use and hence define the terminology associated with the evolving North American digital hierarchy [1].

Digital transmission, in addition to being characterized by the discrete nature of the signals and the use of regenerative repeaters, is also characterized by the use of time division multiplexing (TDM). Multiplexing of signals in digital form allows interconnection of digital facilities with different signalling speeds. The terminology associated with this hierarchy of speeds is as follows:

TERMINOLOGY	SPEED (Mb/s)
T1	1.544
T2	6.312
T3	44.736
T4	274.176
T5	?

Specific systems operating at any of these speeds are often referred to as T1, T2, etc., type systems. Since, in this report, there is no need to identify explicitly specific digital systems, we shall use the "T" terminology to refer to either a signalling speed, or a system operating at that speed.

2.0 FUTURE REQUIREMENTS

During the last decade there has been increasing interest in the use of digital techniques in the design of transmission systems. This has occurred for several reasons:

(i) Flexibility is gained by the ability to handle different types of information using TDM (Time Division Multiplexing) techniques.

(ii) Lower equipment costs attributed to the use of integrated circuit techniques are more easily achieved in digital than in analog electronic applications.

(iii) Improvement in noise performance is obtained by the use of regeneration in digital transmission systems.

In Canada these advantages have encouraged the adoption of digital transmission systems such as T1 (1.544 Mb/s) which provides the basic short haul digital facility for metropolitan areas. For long haul, high density routes a T4 digital coaxial cable system is being developed for 1975 service. This system is capable of carrying 275 Mb/s, equivalent to 4032 voice channels, per coaxial tube, amounting to a total of 20,000 two-way voice circuits in a full cable containing 12 tubes.

Development is underway in the domestic satellite system to implement an operational digital modulation system using PCM/PSK/TDMA techniques. A February 1973 field trial will be followed with a commercial in-service date of mid 1975. Using this technique each Anik satellite will be capable of carrying up to 60 Mb/s per RF channel or a total of 600 Mb/s per satellite.

Where relatively low bit rates and higher multi-point capability and flexibility are required, satellite PSK-FDMA techniques are most suitable. This technique will be introduced commercially in Canada in early 1973. Beyond the 1975 period, the 1977 to 1980 time frame will herald the introduction of a new generation of operational satellites which will use digital techniques.

The establishment of these digital systems creates a need for the addition of terrestrial digital transmission systems to complement other systems in use or which are being contemplated for the future. The need for these systems may be discussed in terms of the need for:

(i) Low capacity (1.544 - 6.316 Mb/s).

(ii) Medium capacity (20-50 Mb/s) systems, and

(iii) High capacity (200-600 Mb/s) systems.

Because present and future low speed systems can and will be accommodated in existing spectrum allocations, we will not discuss the spectrum requirements for such systems *per se*. However, sharing considerations for low speed digital and analog systems in presently allocated bands is discussed in section 5.2.

2.1 MEDIUM CAPACITY REQUIREMENTS

2.1.1 Feeder and Medium Capacity Routes

With the establishment of a backbone high capacity long haul digital structure such as the T4 cable system, a need arises for medium capacity facilities to carry traffic on feeder or spur routes extending out from the main long haul route and as a feeder for the Anik Satellite system.

In addition, the growing use of low capacity digital facilities such as T1, for interoffice transmission creates a need for medium capacity transmission systems in the 20-50 Mb/s range to interconnect isolated groups of T1 systems and so allow an orderly growth of the digital network.

Finally, such a medium capacity facility would provide one of the building blocks necessary to meet future growth requirements.

2.1.2 Data Transmission

The report of the Canadian Computer Communications Task Force (CCCTF), "Branching Out", indicates that requirements for data communications are growing at a high rate. For instance the report indicates that the number of data terminals in use is growing at a rate of 20% per year, which from the present base of 50,000 (1970-71 figures including Telex and TWX) will mean 310,000 terminals in service by 1980. These terminals will generate a large requirement for data transmission facilities.

In order to meet this growing need the common carriers are considering several alternatives to provide digital transmission facilities for data traffic. Such facilities could include T1 and T4 digital cable systems and satellite systems using a variety of digital modulation techniques.

In addition it is possible to take advantage of existing microwave radio structures by converting portions of the system to digital operation. For example, it is possible to transmit 56 kb/s in place of an analog group of 12 voice channels. As data traffic needs grow, a T1 stream (1.544 Mb/s) can be inserted in the lowest 500 kHz of a radio channel or, by displacing 600 voice channels, a T2 stream (6.3 Mb/s) can be accommodated in the bottom 3 MHz of a baseband radio channel.

While this hybrid type of usage will suffice as digital transmission of data traffic is introduced, the growth in traffic requirements will create a need for larger cross-sections and warrant the introduction of medium capacity transmission facilities in the 20-50 Mb/s range within the next five to ten years.

2.1.3 Diversity

With the introduction of digital toll transmission facilities it is desirable to have alternate digital systems available to provide diversity in the network and protect the survivability of essential services. The use of time division multiplexing in the digital network makes it uneconomical to provide this diversity or alternate routing capability over existing frequency division multiplexed microwave radio systems for more than a small quantity of traffic. Thus, diversity for essential services carried on high capacity routes can most economically be provided by medium capacity digital facilities.

2.2 HIGH CAPACITY REQUIREMENTS

Over the longer term it is expected that telecommunications services will continue to grow as they have in the past. Currently the growth rate on long haul common carrier facilities is in the order of 15% per year. The growth rate for data alone is slightly higher and since it is becoming a greater portion of the total traffic, it can be expected to keep the overall growth rate at a high level. Extrapolating these rates into the future, facility needs of the common carriers can be expected to be approximately 15 times the aggregate of all facilities in use today by 1990. These extrapolations do not take account of the impact of new services. Video telephone and other video services may be expected to have considerable impact on transmission requirements in the 1980's.

For these reasons it is desirable to plan now for implementation of higher capacity transmission systems.

2.3 EVOLVING DIGITAL HIERARCHY

Considerable discussion has taken place within the CCITT Special Study Group D with the aim of arriving at standard digital multiplex hierarchies. The two lower level hierarchies as defined to date for use in North America are a primary multiplex operating at 1.544 Mb/s and a second order multiplex operating at 6.312 Mb/s as described in draft recommendations G.733 and G.743 respectively of Special Study Group D. Canada has submitted a proposed digital hierarchy to Special Study Group D of the CCITT for consideration in November 1972[1], concerning the third and fourth levels in the hierarchy. The recommendations are as follows:

(i) a third order multiplex operating at 44.736 Mb/s, and

(ii) a fourth order multiplex operating at 274.176 Mb/s.

It is desirable that any digital transmission facilities developed for use in Canada should conform to this hierarchial arrangement in order to ensure an orderly evolution of the digital network, recognizing that conversion may be required at overseas gateways. Hence, medium capacity systems should operate at a bit rate of 44.736 Mb/s. Similarly high capacity systems should operate at a bit rate of 274.176 Mb/s or multiples thereof.

2.4 USE OF RADIO TO MEET THESE REQUIREMENTS

Due to the unique geographical conditions existing in Canada, with isolated population centers spread out along a narrow belt, and with rugged terrain unfavourable to the placing of buried facilities, the toll network is comprised to a very large extent of radio relay systems. For these reasons, the most economical method of providing toll network digital transmission will likely be on terrestrial or satellite radio facilities.

A medium capacity terrestrial digital radio facility should be designed, if at all possible, in such a way as to facilitate an overbuild on existing microwave structures designed with nominal 30 mile spacing. This will allow use of common structures such as buildings, power plant, towers and perhaps antennas. Such a system should be designed to be compatible with the intermediate level of the multiplex hierarchy (45 Mb/s).

For high capacity systems a capacity per RF channel of 4,000 - 8,000 PCM voice channels, equivalent to 275 - 550 Mb/s is desirable to make the system economically competitive at the anticipated growth rates.

2.5 CONCLUSIONS

In view of the growing needs of the common carriers for additional spectrum to provide all types of service to the telecommunications user and the advantages inherent in the use of terrestrial digital radio to meet some of these needs, the CTCA concludes that consideration should be given to the allocation of frequency bands specifically for the application of digital transmission techniques.

3.0 SPECTRUM REQUIREMENTS FOR MEDIUM CAPACITY TERRESTRIAL DIGITAL RADIO SYSTEMS

3.1 CHARACTERISTICS OF A MEDIUM CAPACITY TERRESTRIAL DIGITAL RADIO SYSTEM

Examination of the requirements for a medium capacity digital radio system indicates that the following factors should be considered in its design.

(a) The system should be applicable to a variety of uses, such as feeder routes for high capacity digital systems, including satellite systems and for use as a data transmission facility on existing long haul radio routes.

(b) The bit rate should be compatible with the third level of the digital hierarchy (i.e., 44.736 Mb/s).

(c) Since a vast microwave radio network already exists in Canada, large savings in capital investment can be realized if a new digital radio system can make use of this existing structure in a so-called over-build mode.

(d) In order to justify the large capital expense required in establishing a new system the spectrum allocation should be such as to allow growth so that several working RF channels can be used.

(e) It would be desirable to have the potential for exclusive allocation of spectrum for use by systems employing digital modulation so that their evolution would not be unduly constrained by the high C/I requirements of analog FM systems.

3.2 AVAILABILITY AND ADVANTAGES OF AN 8 GHz ALLOCATION

In Canada the frequency band 7.725 - 7.975; 8.025 - 8.275 GHz is presently allocated[2] to use by high performance microwave systems employing frequency modulation and having capacities of up to 1800 voice channels or one television channel per RF carrier. The allocation provides for up to 8 go and 8 return channels in the total prescribed bandwidth of 500 MHz.

Up to the present little use has been made of this band by the common carriers for long haul high capacity applications. The large investment and the room available for expansion in the 4 GHz and 6 GHz bands has encouraged the common carriers to continue to use these frequencies for analog FM systems. Although there are some installations of 8 GHz systems in certain areas of Canada, in general the 8 GHz band is available for exploitation by new digital technologies. Provided that protection is given to the existing systems, it should be possible to consider exclusive allocation of the band for future systems employing digital modulation.

The 8 GHz band also has the capability of being used with nominal 30 mile hops and therefore can be used in an overbuild mode, making use of existing 4 GHz or 6 GHz microwave radio structures. This means considerable saving in capital expenditures, since use can be made of existing buildings, power plant, towers and waveguide and possibly antenna systems.

3.3 CHANNELIZATION REQUIREMENTS

The most important factors determining RF channel bandwidth for a digital radio system are bit rate and type of modulation. As mentioned previously the required bit rate for a medium capacity digital radio system, compatible with the digital multiplex hierarchy, is 45 Mb/s (nominal). This will provide up to 672 PCM voice channels or 45 Mb/s of data, or mixtures thereof, per RF carrier.

Of the known types of digital modulation, coherent phase shift keying (CPSK) is optimum in that at a given carrier-to-noise ratio it yields the minimum probability of error when compared with other modulation schemes using the same number of digital signal levels. Although, in general, required bandwidth is an inverse function of the number of phases used in CPSK (for a fixed speed) and required carrier-to-noise ratio increases directly with the number of phases, it turns out that both two and four-phase CPSK require the same carrier-to-noise ratio for the same probability of error. The use of more than four phases, of course, results in increased carrier-to-noise requirements. Thus four-phase CPSK is optimum in that it minimizes required bandwidth without requiring excess carrier-to-noise ratios for a given performance.

Thus, assuming four-phase CPSK modulation at 45 Mb/s, the required RF channel bandwidth is approximately 40 MHz. A possible frequency plan for the 8 GHz allocation then consists of 6 go and 6 return channels with a nominal 40 MHz spacing. The total capacity of the 8 GHz band using this plan would be 6 x 45 Mb/s - 270 Mb/s.

However, further studies may indicate that with the good co-channel interference properties of digital modulation, it may be feasible to use both planes of polarization, with one carrier operating on each plane, thus doubling the capacity of the band to 12 go and 12 return channels.

Although the CTCA believes that the 8 GHz band should be primarily reserved for T3 speed applications, there is the possibility that it can be used with, say a 20 MHz channelization plan for lower speed applications (20 Mb/s). This should only be considered in those cases where alternative solutions in the lower bands are not viable. However, further study is needed to determine the feasibility and coordination problems associated with such an alternative.

3.4 CONCLUSIONS

In view of the growing need for medium capacity digital radio systems in Canada and the advantages to be gained from optimizing such systems for digital modulation, the C.T.C.A. believes there is a need for allocation of spectrum for a medium capacity radio system operating at the 45 Mb/s rate. Furthermore, the C.T.C.A. concludes that the optimum allocation for this system in Canada is the 8 GHz band, 7.725 - 7.975; 8.025 - 8.275 GHz, channelized to provide 6 go and 6 return channels with a nominal 40 MHz spacing.

4.0 SPECTRUM REQUIREMENTS FOR HIGH CAPACITY TERRESTRIAL DIGITAL RADIO SYSTEMS

4.1 THE NEED FOR A 12 GHz ALLOCATION

In Canada, radio transmission facilities carry almost all of the high capacity, long haul traffic. The development of these systems during the past twenty years has been confined mainly to the 4 and 6 GHz bands. However, with the steady increase in voice channel requirements, existing allocations are becoming increasingly crowded. This is especially true around major metropolitan centers. Furthermore, the nature of the population distribution in Canada has dictated the development of a narrow communication corridor about (50-100) miles wide and 4,000 miles long. Clearly, such a corridor imposes a limit on the number of parallel microwave routes. Although it is possible to overcome this problem by expanding these corridors into sparsely populated areas, site development costs are bound to be high and operation and maintenance of these sites becomes a problem.

There is thus a need to allocate more spectrum for this use. This spectrum can only be found in the higher bands.

It has been noted in section 2 that future long haul high capacity requirements will necessitate systems capable of carrying at least 4,000 - 8,000 voice channels. The increased economies and flexibility inherent in a digital implementation of such systems has also been noted. In order to obtain such capacities in a digital mode it is not only natural, but necessary, that such systems be designed around the basic T4 speed of approximately 275 Mb/s.

If, for example, 2 GHz of spectrum can be made available, assuming that both planes of polarization can be used to carry different signals at the same frequency and that four phase coherent phase shift keying is used (at present the most economical trade-off between bandwidth and carrier-to-noise ratio) a capacity of 32,000 two-way voice channels can be obtained on a structure. This is approximately the minimum economical capacity.

Bandwidths of this order are not and cannot be made available below 10 GHz. An economical high capacity digital system thus requires an allocation above 10 GHz.

The 10.7 - 11.7 and 12.2 - 13.25 GHz bands meet the above requirements for a high capacity digital radio system and have been identified as such in various Canadian submissions to CCIR and the WARC (3, 4).

4.2 ADVANTAGES OF A 12 GHz ALLOCATION

In considering the design of a new microwave radio system even at 12 GHz, it must be realized that major improvements in microwave equipment have to be achieved before such systems become feasible. For a 12 GHz digital radio system, the constraint of short hop length (3-7 miles), and hence a large number of repeaters, dictates several requirements:

(i) size must be reduced; a large building to house equipment every three or four miles is not realistic.

(ii) power consumption must be minimized; standby diesel generators are not justifiable.

(iii) when up to a thousand repeaters are used to provide transcontinental facilities, it is clear that equipment reliability must be improved.

(iv) the cost per repeater must be extremely low.

In order to achieve all of these goals at even 12 GHz will require a major development effort. To have to do this at much higher frequencies would only make the problem more difficult. Thus the design of a new digital radio system is made easier if the frequency allocation for such systems is not too far away from the frequencies in use today. The 12 GHz band is the lowest frequency available that is able to meet the requirements of high capacity digital transmission.

Perhaps a more important consideration that makes the 12 GHz band attractive is the attenuation characteristics of rain. In the band between 10 and 20 GHz the attenuation introduced by a rainfall rate of 100 mm/hr. varies by approximately 1.4 dB per GHz per mile. An increase in frequency of only 5 GHz introduces an additional attenuation of 7 dB per mile. Compensation for this additional attenuation would require either an increase in radiated power (either by an increase in transmitter power or antenna size) or a decrease in path length. Clearly, then, there are significant advantages in operating digital radio systems in the lowest possible frequency band.

Preliminary cost estimates of radio relay systems in the 12 and 18 GHz bands indicate that systems in the higher band will cost approximately double the price of systems in the lower bands. In other countries high capacity digital radio systems are being designed for the 18 GHz band primarily because frequency allocations around 12 GHz are not available.

Finally, a digital radio system operating in the 12 GHz band is capable of greater spectral efficiency than a similar system occupying the same total bandwidth (2 GHz) and operating at 18 GHz. This efficiency arises because the band between 11.7 and 12.2 GHz is reserved in Canada primarily for satellite use and acts as a built-in guard band between the transmit and receive sections of the band. That is, no portion of the 2 GHz allocated bandwidth need be used for guard band purposes as it would be at 18 GHz.

4.3 CHANNELIZATION REQUIREMENTS

As previously discussed, an efficient digital radio system will require an allocated bandwidth of at least 2 GHz, at some frequency greater than 10 GHz. The two one gigahertz bands lying between 10.7 and 11.7 GHz and 12.2 - 13.25 GHz are presently available in Canada and are ideally suited to a digital radio application.

The two most important factors in determining RF channel bandwidth are bit rate and type of modulation. A bit rate of approximately 550 Mb/s is at present technically feasible, compatible with the evolving digital hierarchy (equal to 2 x T4 rate) and will provide a capacity of at least 8,000 voice channels per RF carrier.

As outlined in section 3.3, four-phase coherent phase shift keying is the optimum modulation scheme with respect to the trade-off between required bandwidth and carrier-to-noise ratio (or performance). Thus, assuming four-phase 550 Mb/s CPSK modulation, the required RF channel bandwidth is approximately 500 MHz. Narrower channel bandwidths would introduce an intolerable level of adjacent channel interference.

A possible frequency plan for the 12 GHz allocation thus consists of two transmit and two receive channels each of 500 MHz bandwidth. The total capacity using this plan is approximately 16,000 voice frequency channels.

Preliminary studies indicate that because of the good co-channel interference properties of digital modulation techniques, it is feasible to modulate both planes of polarization of each RF carrier with separate digital signals. This approach would then increase the capacity to 32,000 voice frequency channels, thus yielding even greater spectral efficiencies.

4.4 CONCLUSIONS

High capacity digital radio systems are a viable and economic means of meeting the projected traffic requirements of the C.T.C.A. carriers. Such systems require bandwidth allocations in the order of 2 GHz and hence must operate in the frequency band above 10 GHz.

Consistent with the requirement that any allocation for digital radio should be as low in the frequency spectrum as possible, the C.T.C.A. believes that the 10.7 - 11.7 GHz and 12.2 - 13.25 GHz bands, presently available in Canada, are ideally suited for high capacity, long haul digital radio applications. Further, a 500 MHz channel bandwidth in this allocation will maximize spectrum utilization, taking into consideration technical, economic and performance constraints.

5.0 SHARING

5.1 DIGITAL/ANALOG SHARING of terrestrial systems

Sharing criteria developed for the existing analog bands below 8 GHz are not directly applicable to digital systems operating in the 8 and 12 GHz bands. The existing analog systems were designed with very sensitive receivers and relatively high radiated power with the intention of keeping the interference power well below the inherent thermal noise of the equipment.

A characteristic feature of digital systems is their high degree of immunity to co-channel interference. Typically, a digital radio system employing coherent phase-shift keying can operate with a carrier-to-interference level of 20 dB, faded (60 dB, nonfaded) on every hop and suffer only a 1 dB degradation in carrier-to-noise ratio. By contrast, analog systems can only accept carrier-to-interference ratios as low as 60 dB (nonfaded) on a limited number of hops for satisfactory performance. Thus while digital/analog sharing of either the 8 or 12 GHz bands would pose no problem in the design of digital systems the problem of the interference sensitivity of the analog systems still remains. In effect, a shared allocation in either of these bands would mean that for the purpose of route planning and interference computations, the digital systems would have to be treated and regarded as analog systems. Hence, in a shared allocation the important interference characteristic of digital radio could not be exploited at all.

For these reasons the C.T.C.A. believes that the 8 and 12 GHz allocation outlined in previous sections should be reserved in the future for terrestrial systems employing only digital modulation. In this manner significant spectrum efficiencies can be realized. Not only is the route planning of such systems made easier but, more importantly, more systems using the same frequency allocation can be accommodated in any given geographical area.

Such an exclusive allocation must recognize the presence of existing analog installations and thus appropriate safeguards would need to be incorporated to protect these systems.

5.2 SHARING IN EXISTING BANDS BELOW 8 GHz

The existing widespread use of analog modulation techniques on microwave radio in the lower frequency bands is likely to be and should be continued. However, subject to certain constraints to be outlined below, there is no valid reason that would preclude the effective and economic use of digital modulation techniques in these same bands.

Although it has been indicated in previous sections that there will be substantial use of pure digital systems in the 8 and 12 GHz bands, there are certainly a number of low capacity, low speed digital transmission requirements that can be provided by either the satellite system or by utilizing the existing microwave communication network that presently exists in Canada.

For example, in the case of the existing microwave system, the hybrid transmission schemes mentioned in section 2.1.2 and satellite PSK-FDMA techniques appear to be means of meeting the interim requirements of the developing data networks. Also there will be requirements for low capacity digital facilities in the 6-20 Mb/s range. For example, in many parts of Canada there is the need to carry small numbers of voice signals that are already digitally encoded. Because of the added cost of providing analog/digital terminal interface equipment, it is in the public interest to directly transmit these signals digitally. In this case it would be uneconomic to resort to, for example, a fully digital 8 GHz solution. Some of the existing lower frequency bands operating in either a mixed analog/digital or fully digital mode will provide a more economic and efficient solution.

Finally, because voice (analog) and data (digital) traffic occurs between the same points, combined transmission of both analog and digital signals will often be the most economical method. This is particularly true when traffic requirements are such that separate analog and digital transmission facilities are not warranted.

In summary, the C.T.C.A. anticipates a requirement into the foreseeable future for both analog and digital microwave transmission systems carrying both types of services.

This shared use of digital and analog modulation in existing bands and channeling plans should be encouraged provided the following constraints are met:

(a) Maximum bandwidths now permitted by the DOC also apply to new digital or hybrid systems.

(b) Existing rules concerning maximum power output, frequency stability, cross polarization restrictions, etc. apply equally to both analog and digital systems.

(c) Required interference coordination rules between digital and analog systems should be such as to make the effect of a digital interfering signal on an analog system similar to that presently allowed for an analog interfering signal.

Subject to these restrictions, the C.T.C.A. believes that the public interest will best be served if the existing bands below 8 GHz are allowed to be developed for digital, analog and hybrid analog/digital systems. In this manner maximum spectral use can be achieved, taking into account the need for flexible and economic communication facilities.

5.3 SATELLITE/TERRESTRIAL SHARING

Although both the 8 and 12 GHz bands are allocated on a shared (Fixed/Fixed Satellite) basis according to WARC regulations, the superior interference immunity of digital modulation systems should pose no serious problems in frequency coordination for the terrestrial systems. However, careful coordination and planning will be necessary to ensure that interference levels into the satellite systems are maintained at tolerable levels.

The major portion of the proposed allocation for 8 GHz digital radio is, by WARC regulation, to be shared with Fixed-Satellite services. However, it is possible for digital radio systems operating in this band to adhere to the established sharing criteria so that with careful interference coordination and route planning, high performance can be attained.

Only a portion of the recommended 12 GHz band is allocated in a shared basis by WARC regulation between terrestrial and space systems (10.95 - 11.2, 11.45 - 11.7 and 12.5 - 12.75 GHz). Again, with proper coordination and planning between the carriers in Canada no severe restrictions on the performance of digital radio systems in these bands are anticipated.

5.4 CONCLUSION

In order to fully exploit the potential of the digital radio concept and achieve maximum spectrum utilization, the C.T.C.A. advocates that the proposed 8 and 12 GHz bands should be allocated in the future for terrestrial systems employing only digital modulation. However, the C.T.C.A. recognizes that appropriate safeguards must be established to protect existing systems in these bands.

Furthermore, the existing bands below 8 GHz should be fully exploited by using both digital and analog techniques subject to previously established procedures governing interference and coordination in these bands. The C.T.C.A. does not anticipate any problems in the Fixed/Fixed-Satellite shared use of the proposed 8 and 12 GHz allocations.

6.0 FUTURE USE OF THE SPECTRUM ABOVE 13 GHz

The growing need for telecommunications services will eventually require the use of frequencies in the higher microwave bands for both long haul and short haul, as well as for intra-city applications. It is likely that both for technical and economic reasons the majority of these new systems will utilize digital modulation.

The frequency band 17.7 - 19.7 GHz is presently allocated on an international basis to shared terrestrial and satellite services. Some countries are presently planning to use this band to provide high capacity digital radio systems. It can also afford growth capacity for Canada in areas where the 12 GHz allocation is unsuitable or becomes exhausted.

Consideration should also be given to the allocation of other higher frequency bands above 20 GHz for use by digital radio systems to meet the evolving needs of the telecommunications industry in providing new and different services to the public.

The C.T.C.A. will continue to study the future needs of its member companies with the intention of communicating to the Department of Communications its views on further spectrum allocations.

REFERENCES

1. Submission by Canada to Special Study Group D - CCITT "Proposed Digital Multiplex Hierarchy". November 1972.

2. Department of Communications Radio Regulations "Standard Radio System Plan 306", draft released December 15, 1968.

3. CCIR Doc. 9/8-E "High Capacity Digital Radio Submissions in the Band above 10 GHz", 19 January 1972.

4. Report of the Canadian Delegation to the ITU World Administrative Radio Conference for Space Communications and Radio Astronomy, June-July 1971, page 3.

5. CCIR Doc. 9/95-E - General Principles of Frequency Channel Arrangements for Digital Radio Relay Systems, July 18, 1972.

APPENDIX I

SPECTRUM EFFICIENCY: Digital vs Analog for Terrestrial Radio Systems

During the past few years there has been a considerable amount of discussion centered around the hypothesis that digital radio does not make efficient use of the radio frequency spectrum. The validity of this hypothesis is strongly dependent upon the assumption of what kind of traffic such a digital radio system will carry.

In general, given that voice frequency analog channels are to be provided via radio relay, a digital mode of transmission is less economical in spectrum utilization than analog transmission, at the present time. On the other hand, given that the microwave radio spectrum is to be used for data transmission, a digital mode of transmission is approximately one order of magnitude more efficient in its use of spectrum than comparable analog techniques.

For example, consider the spectral requirements for analog voice transmission. Typical FDM/FM radio structures provide a capacity of 1800 analog voice frequency channels using a 30 MHz bandwidth. This corresponds to a spectral occupancy of approximately 17 kHz per voice channel. On the other hand, typical digital radio structures using present technology (four-phase CPSK) require at most 1.0 hertz of spectrum per bit of transmission speed. Using present-day pulse code modulation techniques, each analog voice channel requires a bit rate of 64 kbits/second. This then corresponds to a spectral occupancy of 64 kHz per digitally derived voice channel.

Preliminary work indicates that both the 8 and 12 GHz digital radio systems are capable of supporting a dual polarization operation on each RF carrier. Such a technique reduces the spectral occupancy to 32 kHz per analog voice channel. Thus for analog voice transmission, digital radio has a spectral efficiency equal to approximately 50% that of conventional FDM/FM techniques.

Now consider the spectral requirements for data transmission. Present data modem techniques are capable of achieving speeds of 4800 bits per second for data transmission over the conventional analog voice channel. If these voice channels are provided via FDM/FM microwave radio then the spectral occupancy is approximately 4 Hz per bit of transmission speed. Using digital radio techniques, as has already been noted, the spectral requirements are approximately 1.0 hertz per bit or 0.5 hertz per bit using dual polarization. Thus for data transmission digital modulation is almost one order of magnitude more efficient in its use of the spectrum than the conventional analog, data modem, FDM/FM technique. The following table summarizes this comparison:

	FDM/FM Modulation	Digital Modulation
Voice	17 kHz/channel	32 kHz/channel
Data	4 Hz/bit	0.5 Hz/bit

The superior interference immunity of digital modulation allows a higher density of systems in any geographical area, thus effectively increasing the spectral efficiency of digital systems regardless of whether they carry data or voice signals.

Finally, it should be kept in mind that the present state of the art of digital modulation techniques is at a stage equivalent to that of analog radio twenty years ago. Just as there have been many improvements in analog FDM/FM radio*, it is reasonable to expect that similar improvements will occur with digital radio. In addition, further developments in analog to digital encoding for voice signals are likely to reduce the required bit rate for digitally derived voice channels. Thus, as the digital technology improves, there is every reason to expect further efficiencies can be obtained so that digital modulation will be in every respect more efficient of spectral usage than equivalent analog systems.

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* The capacity of 4 GHz structures, for example, has increased from 480 channels per RF carrier with six go and six return in the 3.7 - 4.2 GHz band to 1320 channels per RF carrier and 12 go and 12 return in the same allocation.