CHANNEL ALLOCATION OPTIONS

Robert S. Powers
Office of Telecommunications
U. S. Department of Commerce
Washington, D.C. 20230

Abstract

This paper is based on an interim report of the Frequency Allocation Subcommittee, of the Coordinating Committee for Cable Communication Systems, Institute of Electrical and Electronic Engineers.

The Subcommittee is to produce a background report on the general problems of frequency allocation and assignments in cable. The report should be useful to government regulatory and policy bodies, system planners and owners, and manufacturers of cable equipment, converters, and receivers. The present paper describes the nature and importance of the frequency planning problem, the general goals of the Subcommittee, the types of cable systems being considered, the criteria being used to evaluate characteristics of the various frequency assignment schemes, and the general allocation plan being used by the Subcommittee for purposes of discussion. An important side problem being addressed by the Subcommittee is that of potential interference between over-the-air radio systems and cable systems using the same frequencies.

Problem Definition

The Federal Communications Commission now requires that cable systems in major markets provide at least twenty television channels and some two-way services. Many system operators intend to provide even more television channels than the required twenty, in addition to other possible non-television "downstream" and "upstream" services. A major question facing the cable industry is how to deliver to the subscriber these additional services, over and above the twelve television channels assigned by the FCC for over-the-air transmission.

There are several basic ways to deliver these additional services by wire:

1. VHF coaxial cables: Coaxial cables operating in the range from a few megahertz to 300 or 400 MHz carry television signals, non-television one-way services, and "upstream" services, possibly all on the same cable. The spectrum available on such cables could be utilized to the maximum extent by delivering additional television and other services on frequencies not assigned for over-the-air television broadcasting. Alternatively, two or more cables could be used to deliver television signals on the "normal" channels used for television broadcasting*; non-television services could use either additional cables or non-television frequencies.

2. UHF transmission: Downstream television service in addition to the twelve FCC channels is supplied on those frequencies allocated by the FCC for UHF television broadcasting. Non-television services use other frequencies.

3. High frequency (HF) cables: Paired-wire or coaxial cables, capable of carrying only one or two television channels each, connect the subscriber to a local distribution center. Programming is selected by the subscriber by means of a switch at the local distribution center.

A little thought will convince one that the most critical point in the whole system, no matter which type of cable is used, is the interface between any subscriber-owned equipment and equipment owned by the cable operator. There are indeed technical

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* Hereinafter referred to as the "FCC channels."

problems associated with frequency arrangements within the cable system itself, but these can be solved independent of the 90 million existing TV receivers and the expected future subscriber terminals. Also, there is less need for industry-wide standardization of those "internal" solutions. But at the subscriber interface the cable operator must deliver a signal which can be received with good quality, and assure that no signals from the receiver interfere with the cable system itself or with the reception of other subscribers. And this must be done in such a way that the subscriber can move from one cable system to any other in the Nation without having to make a new investment in terminal equipment.

Considering now only the VHF cables, there are at present two basic ways to supply more than twelve channels to existing receivers. Either multiple cables are used, with a switch to choose which cable is connected to the receiver, or a converter of some kind is used to translate cable signals to one of the FCC channels.

In the latter case, the most serious constraint arises when the cable system is to provide some subscribers with signals on only the FCC channels and is to provide other subscribers with extra services on additional channels. This situation can arise either because the extra services are "optional at extra cost" or because the system is in transition between 12-channel operation and operation with 20 or more channels. Clearly, if all subscribers are using converters, the system operator will use whatever frequency plan is appropriate to the converters. If no subscribers are using converters, the frequency plan is automatically fixed by the TV receiver. In the "mixed" case, the need for serving existing receivers may be a severe limitation on the usefulness of otherwise acceptable frequency plans.

Presently used converters may be block converters located within the cable system, but usually are "set-top" converters installed on the subscriber's premises. The cost of a set-top converter may vary between $20 and $50, no small fraction of the total cost of delivering service. This cost could be strongly reduced if the capability for tuning extra channels were incorporated into receivers especially designed for cable reception. Herein lies a compelling argument for standardization of frequency usage on VHF cable systems.

If the frequencies upon which TV channels are delivered by cable systems were to be standardized, the feasibility of marketing television receivers capable of receiving all the cable channels would be enhanced. The cable operator would find it less expensive to extend service to new subscribers and to expand the number of channels in his system. The subscriber with a "cable TV" receiver who moved from one community to another would be assured that his receiver would interface completely with the new system.

To be most effective, a channelling plan which would provide such extra channel capability should be used universally. A universal plan might be followed voluntarily by receiver manufacturers and cable operators, as in the case of the present universal IF standard, or it might be instituted by Federal action.

The National Cable Television Association (NCTA) has asked the Federal Communications Commission to adopt standards to promote the marketing of television receivers designed to interface with cable systems. At this time, the Commission has not given indication of its probable response.

To summarize, it would be of great value to the public, to the cable industry, and to manufacturers of cable equipment and home receivers if critical standards for the cable-receiver interface could be developed and implemented. Such standards would permit maximum flexibility for choice by subscribers and for innovation by cable operators and receiver manufacturers, while assuring compatibility at the interface between subscriber equipment and cable systems.

Frequency Allocation Subcommittee - Formation and Goals

The Coordinating Committee for Cable Communication Systems of the Institute for Electrical and Electronic Engineers, chaired by Archer Taylor, recognized that the literature does not contain a convenient body of technical information upon which to base any such standardization at the interface. Therefore, the Coordinating Committee formed a Frequency Allocation Subcommittee, and gave it the task of preparing a technical report on the various possible frequency plans which could be used on cable systems. The output of the Subcommittee's work will not itself be a standard for frequency allocations and assignments*; that

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* For purposes of this report, a "frequency allocation" is considered to be the specification of which large blocks of available spectrum will be used for what general purposes, such as"NTSC television signals" or "upstream services." A "frequency assignment" is considered to be the specification of precisely how the large blocks designated by the "allocation" will be divided into individual channels.

task will be left for other bodies. But the report will be available to serve as source material for the construction of such standards. The report should be useful to government regulatory and policy bodies, system planners and operators, manufacturers of cable equipment, converters and receivers.

The author of this paper chairs the Frequency Allocation Subcommittee at the present time. The Subcommittee consists of some 22 members, whose professional affiliations include cable system operators, cable system equipment manufacturers, television receiver manufacturers, converter manufacturers, not-for-profit corporations, and government.

This paper is based on an interim report of the Frequency Allocation Subcommittee to the parent Coordinating Committee, and as such does not represent the work of the author alone. However, this paper is not itself the work of the Subcommittee, so its author must take the blame for any errors or misrepresentations of the Subcommittee's thinking.

It was recognized very quickly that the sum total of all problems of frequency usage in all of the possible types of cable systems was enough to overwhelm the small Subcommittee. Thus, the Subcommittee defined a subset of problems, which it believes can be sensibly addressed at the present time and which the Subcommittee is competent to attack.

The tasks to be addressed at this time are as follows:

1. Identify the frequency allocation and assignment problem involved in adding downstream channels to the FCC channels and the FM radio band on VHF cable distribution systems, assuming that the cable system is to ultimately feed television receivers capable of receiving only the FCC channels.

2. Describe techniques for analyzing these problems and evaluating the various possible solutions. The techniques are to be applicable to channels of 6 MHz bandwidth, as well as to channels of wider and narrower bandwidths which will be used for services other than NTSC television.

3. Make specific recommendations for one or more sets of frequency assignments within one or more sets of frequency allocations.

Note that in its initial report, the Subcommittee will not discus in detail any two-way services, although it is well recognized that two-way capability exists now on some systems and will be widespread in the future. It is assumed that two-way services will either be carried on cables other than those carrying downstream television or will occupy distinct blocks of the cable spectrum, and that there will be no mutual interference between upstream and downstream services. Thus, downstream television service can be considered by itself.

The Subcommittee has also limited its initial considerations to delivery of standard NTSC television signals and the existing FM radio band. Thus, with the exception of the FM band, channels of width greater or less than 6 MHz are not being explicitly addressed. The rationale for this restriction is two-fold: (1) It is assumed that most of the downstream cable spectrum will be used for NTSC television signals; and (2) useful channels of bandwidth other than 6 MHz can often be made up of exact multiples or sub-multiples of 6 MHz. In any case, analytical techniques described by the Subcommittee should be applicable to channels of bandwidth other than 6 MHz.

Finally, the Subcommittee is concentrating most of its initial efforts on the problems of VHF coaxial cable systems, rather than on UHF and HF systems. The remainder of this paper is entirely directed to VHF systems. This emphasis is not meant to reflect in any way on the advantages or disadvantages of the HF and UHF systems. The VHF systems were chosen for the initial effort because: (1) most existing CATV systems in this country are VHF systems, and (2) the technical problems of frequency utilization (as contrasted with transmission and other technical problems) seemed most severe in the case of the VHF systems*.

Factors Affecting Cable Frequency Allocations

The first consideration in selecting a frequency plan is the number of channels which can be delivered with high quality. The delivery capability of a system which, in other respects has adequate bandwidth, generally is limited by signal degradation

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* A paper summarizing the considerations vis-a-vis the use of UHF for the final distribution of subscriber services is being drafted for the Subcommittee by one of its members, but will not be discussed here. That draft may represent the starting point for another phase of Subcommittee activity.

caused by the following:

(1) Impairments due to distortion products generated within the cable network. (Example: Intermodulation products.)

(2) Interference to a subscriber's reception due to signals picked up by the system. (Example: Midband land mobile signals picked up by the cable equipment.)

(3) Interference to a subscriber's reception due to signals injected into the system by other subscribers' receivers. (Example: Receiver local oscillator signals.)

(4) Interference to a subscriber's reception by external signals picked up by the subscribers' own receiver. (Example: Strong ambient fields from local co-channel television stations.)

The Subcommittee is examining both the theoretical maximum number of channels available with each frequency plan and the degree of interference likely to occur in each system. The severity of impairment is largely a matter of equipment design, operating adjustments, and proximity to local high powered interfering transmitters. The number of opportunities for picture impairment can be minimized by choice of the proper channel assignment plan.

A second major consideration in some cases is the performance of the system in the "mixed" operating mode mentioned above: in the mixed mode some subscribers have converters, and other subscribers connect receivers directly to the cable system. The Subcommittee is using two primary indicators for evaluating frequency plans under this consideration: (1) The number of channels a subscriber can receive without a converter, and (2) implications of the frequency plan for the design of a special receiver for both cable and over-the-air reception. The possibilities of varactor tuning, automatic channel identification, and other advances should be considered in the conceptual design of such receivers.

The performance of present-day (unshielded) receivers operating in strong signal areas must also be considered, at least for the next 5 to 10 years. The number of channels which would be unusable because of local pick-up is being used to evaluate this aspect of proposed frequency plans.

The final major technical consideration being examined by the Subcommittee is the tuning of the receiver or the receiver-converter combination to the desired channel. The type of converter and the number and type of controls which must be used to tune channels is noted. The overall ease of tuning is the important factor to the subscriber. At the present time, the Subcommitte can only make subjective judgments of this important factor. Some type of consumer testing may be needed to fully evaluate the ease of tuning, although it is clear that a special cable receiver could have simpler tuning controls than any receiver-converter combination.

Of course, the total system cost, which will eventually rest on the subscriber in any case, is a vital factor. These costs include costs of first implementation, costs inherent in future expansion requirements, maintenance costs for equipment and plant, and possibly the cost to the public of new subscriber-owned receivers. The Subcommittee will draw general cost implications, but may not be able to make detailed determinations.

Assumptions

In planning for future usage of cable networks, certain assumptions must be made regarding the circumstances under which they must operate. Assumptions which are believed applicable to nearly all situations are set forth below*:

(1) The primary function of the cable system is to deliver off-air and locally originated television programs to subscribers located downstream from some common collection or control point (such as a head end.)

(2) Frequency space and amplitude range within the system is available for other services of unspecified type, which may or may not flow upstream from subscribers, but which must afford protection to downstream TV.

(3) The number of channels which the cable must carry simultaneously must be 20 or more.

(4) Subscribers should at all times receive pictures with minimum distortion and interference and, in no case, of poorer than "passable" quality (by TASO definition).

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* In certain circumstances, some of the basic assumptions may be erroneous. For example, it is yet too early to expect that all subscriber receivers are capable of satisfactory operation in very strong ambient co-channel fields. Such variances must be recognized and allowed for in planning individual cable systems, at least for the next 5 to 10 years.

(5) The ultimate destination of the television signals will be the subscriber-owned television receiver which is presumed to have a capability as follows:

(a) Only channels in the VHF range will be used for receiving signals from the cable system.

(b) All sets will accommodate simultaneous use of adjacent channels on the cable.

(c) All sets will operate satisfactorily in an ambient co-channel field of up to 500 mV/m.

(d) All color sets have phase characteristics suitable for high quality color television.

(e) All sets use the standard 45.75 MHz IF.

(6) Where converters are used, those converters are assumed to have characteristics which obviate co-channel (local pick-up), adjacent channel and image channel problems, and do not transmit interfering signals back into the cable*.

Alternate Frequency Plans

The major technical problems of frequency planning are associated with the detailed channel assignments rather than with the general nature of the broad allocation plan. Thus, the Subcommittee has simply adopted for its own reference a single one of the many possible allocation plans. This plan is represented by Table 1. Changes in this allocation plan could, of course, require adjustments in the detailed channel assignments. But the evaluation criteria and technical problems being identified by the Subcommittee would remain valid.

* For example, a double conversion scheme with a first IF higher than 300 MHz is one possible way to meet this assumption.

Each of the basic channel assignment plans considered in some detail by the Subcommittee is described briefly below. There are large numbers of possible variations, of course, but the plans below illustrate the basic approaches that have come to the attention of the Subcommittee.

Plan A.

Consists of the 12 FCC channels, to which 9 midband channels have been added. These continuously fill the frequency band between 120 and 174 MHz, and are transmitted in upright fashion (sound carrier above the video carrier.)

Total TV channels: 21
Maximum number available without converter: 12
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter:
N(low) + N(hi)*
Method of tuning: Tune converter

Considered attractive for existing systems, since existing active and passive hardware will cover the midband range. Addition of the midband channels to the system causes substantial build-up of second and third order distortion products on all channels, and invites interference on channels 7 - 13 from local oscillator signals injected into the system from receivers not isolated by a converter.

Plan A-1.

12 FCC channels to which 9 midband and 9 superband channels have been added. These, plus the FCC channels 7 - 13, continuously fill the frequency band between 120 and 270 MHz, and are transmitted in upright fashion.

Total TV channels: 30
Maximum number available without converter: 12
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter:
N(low) + N(hi)
Method of tuning: Tune converter

* N(low) is the number of strong local signals in the low VHF band. N(hi) is the number in the high band.

A frequently recommended next step after filling the midband channels. Extending the frequency range of amplifiers and passive devices in the cable network substantially above 216 MHz may prove difficult. Attenuation increases, securing the additional gain needed at wider bandwidths may be difficult, and the number of second and third order distortion products caused by the additional loading increases substantially.

Plan A-2.

12 FCC channels to which 8 midband and 8 superband channels have been added. These are arranged to reduce the incidence of beats from receiver local oscillators and to reduce image interference possibilities. Transmitted upright.

Total TV channels: 28
Maximum number available without converter: 12
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter:
N(low) + N(hi)
Method of tuning: Tune converter

A variation of Plan A-1 in which some of the midband and superband channels have been staggered to reduce the effects of interfering distortion components and local oscillator signals. Although certain of the more destructive distortion components are moved to frequencies where their effects will be less discernible, the number of possible distortion products seems to increase.

Plan A-3.

20 Channels arranged in the octave 120 - 240 MHz. Transmitted upright.

Total TV channels: 20
Maximum number available without converter: 7
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter:
N(hi)
Method of tuning: Tune converter

Because of using a single octave, second order products fall below the lowest channel and above the highest, easing system design.

Plan B.

12 FCC channels to which 7 midband and 7 superband channels have been added. The latter two groups are transmitted in inverted fashion, permitting block conversion with the converter local oscillate frequency above the group of converted channels.

Total TV channels: 26
Maximum number available without converter: 12
Channels lost due to local pick-up, using converter:
N(low) + 3 N(hi)
Channels lost due to local pick-up, not using converter:
N(low) + N(hi)
Method of tuning: Converter switch plus tuning of receiver

By proper selection of the local oscillator frequencies in the block converter, the midband and superband channels can be positioned so that local oscillator signals injected into the system by subscriber-owned receivers will fall at channel edges, substantially reducing their effect on the picture.

Plan C.

24 channels spaced with visual carriers 9.5 MHz apart, starting at 52.25 MHz. Transmitted upright.

Total TV channels: 24
Maximum number available without converter: none
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter: n.a.
Method of tuning: Tune converter

Second order components are made to fall in the guardband between channels. However, third order products fall on or close to visual carrier frequencies where interference is most critical.

Plan D.

30 channels, with all video carriers being placed at integral multiples of 6 MHz and phase-stabilized with reference to a common frequency source. Transmitted upright.

Total TV channels: 30
Maximum number available without converter: none
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter: n.a.
Method of tuning: Tune converter

All second and third order distortion products of the carriers fall precisely on the frequencies of other carriers, where they manifest themselves as fixed-phase contributions to the carrier of the desired signal. Unless the synchronizing rate of all signals in the systems is also phase-stable, much of the benefit promised by this plan may not be achieved.

Plan E.

34 contiguous channels, between 66 MHz and 270 MHz. Transmitted inverted. Presumes use of a single oscillator in the converter, with converter output at FCC channel 2 or 3.

Total TV channels: 34
Maximum number available without converter: none
Channels lost due to local pick-up, using converter: none
Channels lost due to local pick-up, not using converter: n.a.
Method of tuning: Tune converter

Since only a single conversion is required, converter design is simplified, and cost may be reduced. Converter oscillator frequencies fall on channel edges, minimizing stability problems and reducing interference possibilities. Second order difference products also fall on channel edges, but sum products produce a 1.25 MHz beat with the visual carrier. Third order products fall directly on visual carrier frequencies. Visual carriers from image channels may produce 3.5 MHz beats. Since the lowest downstream channel starts at 66 MHz, the design of filters for separating the lower frequency upstream signals is eased, permitting either the use of lower-cost filters or a greater utilization of the upstream spectrum.

Plan F.

Two separate VHF cables, each carrying 12 FCC channels. Transmitted upright. An A/B switch at the receiver is used to select the cable to be connected to the receiver.

Total TV channels: 24
Maximum available without converter: n.a.
Channels lost due to local pick-up, using converter: n.a.
Channels lost due to local pick-up, not using converter:
2N(low) + 2N(hi)
Method of tuning: A/B switch plus receiver tuning

All second order products fall outside of any downstream channel. The number of cross-modulation products is reduced by an order of magnitude compared to carrying the same total number of channels on a single cable.

The Potential for Cable/Over-the-Air Interference

It has been suggested that under certain conditions of faulty operation there could be interference to over-the-air services caused by signals "leaking" from cable systems. Such interference would not occur under normal conditions; there would have to be some break in the cable system and/or some radiating element improperly connected to the cable in order for any significant power to be radiated. Prohibiting the use within cables of frequencies assigned to services in the over-the-air spectrum could be a very costly burden for the cable industry to bear. It would not then be possible to utilize fully the capability of the VHF coaxial cables, which are expected to be widely used in the industry.

The Subcommittee felt that no responsible study of full utilization of VHF cables could ignore the possibility of such interference, even though some first estimates make the chance of harmful interference seem remote. Therefore, the Subcommittee requested and is receiving the assistance of appropriate Federal agencies in defining and investigating this potential.

The Federal Aviation Administration, Department of Transportation, has thoughtfully outlined the conditions under which it questions whether interference could occur. The Office of Telecommunications, Department of Commerce, has assumed the lead role in a technical study of whether any such interference is likely or even possible. This study will include theoretical analysis, laboratory investigations, and possibly field trials. The Office of Telecommunications Policy, Executive Office of the President, is also participating in the study, because of its responsibility for frequency management for Federal government radio users. The OTP is actively encouraging the investigation, participating in planning and discussions, and has assured the Subcommittee of its deep interest in reaching a sound conclusion as to whether interference could possibly occur, and if so how it might be prevented.

Acknowledgements

The working papers of the Subcommittee, on which this report is based, are the work of many individuals. But, special credit is due to Sydney R. Lines, who has drafted a working paper which summarizes the Subcommittee work to date. Lines' summary is the basis for this discussion, and will be the basis for a later full report to the parent Committee in IEEE.

Table I

Subcommittee Working Allocation Plan for VHF Cables

Frequency band (MHz)	Allocation	Possible Uses
Below 54	EXPERIMENTAL	Television Subscriber response signals Telemetry Facsimile Control of monitoring signals
54 - 72	TELEVISION	Cable television, classes I and II
72 - 76	EXPERIMENTAL	Pilot signals Control signals
76 - 88	TELEVISION	Cable television, classes I and II
88 - 108	AURAL BROADCAST	FM Broadcast signals AM Broadcast signals, re-modulated to FM Local origination, FM
108 - 120	EXPERIMENTAL	Subscriber interrogation signals Control signals Pilot signals
120 - 174	TELEVISION	Cable television, classes I and II
174 - 216	TELEVISION	Cable television, classes I and II
216 - 270	TELEVISION	Cable television, classes I and II
270 - 300	EXPERIMENTAL	Cable television, classes I, II and III Facsimile
300 - 400	EXPERIMENTAL	Cable television, class IV Telemetry Subscriber response signals Monitoring signals
Above 400	Not Allocated	