# THE IMPACT OF THE NEW FCC FREQUENCY RULES ON CATV HEADEND SYSTEM DESIGN AND OPERATION

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The report and order of October 26, 1984, amended part 76 to add cable carrier frequency requirements for operation in the aeronautical radio bands. While these new rules provide for universal compatibility with aircraft radio operations and eliminate the need for channel by channel approval, they also present new technical problems for the headend equipment manufacturer and the headend system operator. The newly specified carrier frequencies are offset from the standard assignments but the greatest source of difficulty will be the increased frequency accuracy requirements. In some cases, the rules cannot be met with conventional circuit technology or system design methods.

An assessment of the effect of these rules is presented. The impact on headend product design and specifications is reviewed. Changes in headend system design concepts, operating conditions, channelization strategies and maintenance requirements are discussed. The special case of HRC system operation and the new requirements for reference frequency generators is explained. Finally, consideration is given to the implications for existing headend systems and to possible effects on broadband system and subscriber terminal operation.

## INTRODUCTION

For some time, the Federal Communications Commission has sought a permanent solution to the problem of controlling the use, by CATV systems, of frequencies within the bands allocated for aeronautical communications and navigation uses. The first report and order of July 27, 1977, was an interim solution based on minimum offset or separation from emergency frequencies and locally used aircraft communications and navigations frequencies.

In the FCC's second report and order of December 17, 1984 a fundamentally different approach to the aeronautical interference problem was adopted. This new approach, based on the concept of precision frequency offset, places every potentially offending carrier at a frequency that is halfway between two FAA navigation or communication frequencies. If this frequency interlacing is done with enough precision, then there will be sufficient separation between any aeronautical frequency and the potentially interfering cable frequency to cause the interference heterodyne beat to be inconsequential. By placing this requirement on all cable carriers that fall within aeronautical bands, the minimum separation is assured regardless of the specific aircraft or cable frequencies in use. This otherwise 'clean' concept is somewhat soiled by the fact that different frequency spacings are used in the aeronautical communications bands (25 KHz) and navigation bands (5Ø KHz). This in turn requires CATV carriers falling into these bands to be offset differently. The overall advantage of these new rules, then, is that the methodology is completely universal, that the need for individual frequency use clearances is eliminated, and that enforcement is simplified.

## REVIEW OF THE FREQUENCY RULES

The original rule was adopted to control the accuracy of adjacent carrier spacings. It continues to apply to the frequency of picture carriers for CATV channels which do not fall into aeronautical bands. The requirement is specified in section 76.6Ø5 of the FCC rules: "The frequency of the visual carrier shall be maintained 1.25 MHz +/- 25 KHz above the lower boundary of the cable television channel . . . ". This +/- 25 KHz accuracy has been used as the basic frequency accuracy requirement for CATV headend modulators and processors.

### The Original Aircraft Band Rules

The first rules for the useage of aeronautical frequency bands were established by the first report and order of July 1977. These rules are based on minimum frequency separation from emergency frequencies and from aeronautical frequencies in use within 6Ø nautical miles of any part of the CATV system. Specifically, part 76.610 required system carriers to be offset by at least 100 KHz from the emergency frequency 121.5 MHz and active frequencies in the aircraft communications bands at 118-136 MHz, 225-328.6 MHz and 335.4-400 MHz. A 50 KHz minimum offset was required from emergency frequencies 156.8 MHz and 243 MHz and active aircraft navigation frequencies in the 108-118 MHz and 328.6-335.4 MHz bands. It was the responsibility of the system operator to determine which frequencies were in operation within 111 kilometers of the system and to obtain a clearance to use each such FAA band carriers. Later changes in local aeronautical frequency usage had to be accommodated by the operator in the same way.

## The New Rules for Aeronautical Band Frequency Useage

The current rules, specified by part 76.612, were adopted in late 1984. 76.612 applies to all CATV carriers at a level at or above 38.75 dBmV at any point within the distribution system that fall within the aeronautical bands 108-136 MHz and 225-400 MHz. These bands correspond to CATV channels 14-16, 24-53, 98 and 99, using EIA IS-6 numbering. The magnitude of the required frequency offset depends upon whether the carrier in question falls within an aeronautical communications or navigation band.

Standard aircraft communications frequencies are assigned every 25 KHz while air navigation channels occur every 50 KHz. Therefore, CATV carriers falling into communications bands (channels 14-16, 24-41, 43-53) must be offset by 12.5 KHz while CATV carriers falling into navigations bands (channels 98, 99, 42) must be offset by 25 KHz. In both cases, the maximum error permitted for the offset frequencies is +/- 5 KHz.

Harmonically related carrier operation is covered by a separate provision which requires that the fundamental frequency from which all picture carrier frequencies are derived must be 6.000300 MHz with an accuracy of +/- 1 Hz.

The progression of rules and their effects on system operation is summarized in Table 1.

## SYSTEM OPERATION WITH HARMONICALLY RELATED CARRIERS

HRC systems and other coherent carrier systems will meet the new specifications if locked to a reference frequency generator which itself meets the new frequency and stability requirements. By far the most technically difficult of these is the requirement for the HRC reference frequency. The maximum allowable error for the 6.000300 MHz reference of 1 Hz is

| | Non-Aviation Band Rules (pre-1977) | 1st Report and Order (1977) | 2nd Report and Order (1984) |
|---|---|---|---|
| Frequency accuracy | +/- 25 KHz | +/- 25 KHz | +/- 5 KHz in aircraft bands |
| Frequency offset in COM bands | n.a. | 100 KHz offset from active COM band frequencies | 12.5 KHz offset from all COM band frequencies |
| Frequency offset in NAV bands | n.a. | 50 KHz offset from active NAV band frequencies | 25.0 KHz offset from all NAV band frequencies |
| HRC system special considerations | none | conflicting ch. frequencies cannot be used | basic ref. freq. is 6.0003 MHz +/- 1 Hz |
| IRC system special conciderations | none | conflicting ch. frequencies cannot be used | cannot phaselock chs. 42, 98, 99: wrong offset |

Table 1- FCC Frequency Rules Progression

the same as 1.67 x 10-7 or 0.16 maintained within this limit over a practical operating temperature range and over a reasonable service interval. It has been frequently suggested that a rubidium frequency standard is the only means for accomplishing this. A rubidium standard based reference would, in fact, meet the requirement with a large margin, having a long term stability of about 0.0001 parts per million per year. A most cost effective solution is available in the form of a precision ovenized quartz crystal oscillator. These are available with long term stabilities as high as about 0.034 parts per million per year, which corresponds to a calibration life of about 5 years. It should be noted that individual headend channel modulators and processors should not require modification since the outgoing frequencies are determined entirely by the reference generator and the small frequency shifts should be well within the capability of any existing phaselocking system.

## SYSTEM OPERATION WITH INCREMENTALLY RELATED CARRIERS

A reference frequency generator for IRC operation must produce a comb of carriers whose frequencies conform to the FCC rules for aeronautical communications bands. In other words, they must be offset from normal assignments by 12.5 KHz with an accuracy of +/- 5 KHz. Note that it is not necessary that all comb signals be accurate to within +/- 5 KHz, only those that fall between 120 and 400 MHz. Since channels 42, 98 and 99 are actually within aircraft navigation bands rather than communications bands, the FCC frequency rules for these bands are not met when these channels are phaselocked to the reference comb. The result is that for IRC operation, these channel assignments are unusable. As with HRC system operation, compliance with FCC rules results from the use of an FCC specified comb generator and does not require modifications to modulator or processor equipment. In the case of phaselocked i.f. to channel converter systems that also have a non-phaselocked crystal controlled mode of operation, an operator may desire to make modifications to obtain FCC compliance in this mode if it is used for backup operation. Phaselock type converters used in crystal controlled mode for non-phaselocked applications must be modified.

## NON-PHASELOCKED SYSTEM OPERATION

The output frequency requirement for non-phaselocked systems amounts to meeting the COM band and NAV band offset rules on a channel-by-channel basis. Channels 14-16, 24-41, and 43-53 must be offset by 12.5 KHz and channels 42, 98 and 99 must be offset by 25 KHz.

### Crystal Control of Output Frequency

For any crystal controlled headend equipment the required offset can be obtained by replacing the crystal that controls the i.f. to output channel frequency conversion. Obtaining the required frequency accuracy will be more difficult. The frequency inaccuracy of a crystal oscillator is comprised of two factors: the initial or setting accuracy and the drift. The important components of drift are the aging rate, which may be significant for long term operation, and the temperature stability, which determines the environmental requirements. Both the crystal characteristics and the oscillator circuit design influence these factors. Crystals used in premium headend converters have a setting accuracy of 0.001% which corresponds to a 4.4 KHz error at channel 53. Since this error nearly equals the FCC accuracy spec without even having allowed for circuit error or drift errors, it is necessary to be able to trim the frequency in circuit to compensate for the crystal error. This means, in this case, that a crystal oscillator design that permits the oscillation frequency to be pulled a few kilohertz may be advantageous. The acceptable limit on initial error is a matter of judgement; the smaller the setting error the more room for subsequent drift.

### Headend Modulators

The two sources of frequency error in a modulator are the generation of the i.f. picture carrier and the i.f. to channel frequency conversion. In general, the modulator's internal crystal-controlled 45.75 MHz oscillator should not be a major source of frequency error. Acceptable accuracy for the i.f. to channel upconversion should be possible by a combination of precise setting of crystal oscillator frequency and control of the equipment operating temperature. A practical error budget might allocate 0.5 KHz to basic i.f. error, 1.5 KHz to upconverter l.o. basic error and 3 KHz to total drift error. Where i.f. program switching is used the external i.f. picture carriers must also be precise in frequency. Off air processors present a special problem in i.f. frequency control, as we shall see.

### Headend Processors

The problem of frequency conversion error is compounded in heterodyne RF processors because these devices employ at least two frequency conversions, each with an associated frequency error. This means that a heterodyne processor is fundamentally twice as inaccurate as a modulator so that each conversion would have to be twice as accurate. In many cases, the input conversion will be from a UHF channel requiring an l.o. frequency as high as 847 MHz. This further reduces the allowable l.o. tolerance because a total input conversion frequency error of 2 KHz corresponds to an l.o. accuracy of about 2.5 part per million. Adding to all of this is the realization that the broadcast signal itself can contain a significant frequency error, either from an assigned +/- 10 KHz offset or from the basic inaccuracy of a low grade source. While it may be possible to select an input conversion crystal that compensates for the broadcast offset and an output crystal that provides for the FAA offset and then trim and maintain the frequencies of both oscillators within very small errors, this is certainly not a comfortable, confidence inspiring approach.

There are other methods for accommodating broadcast channels that produce no more difficulty or risk than with origination channels. The first and easiest is strategic: Don't convert broadcast channels to aeronautical band channels. If VHF and UHF broadcasts can be placed onto channels 2-13 and 17-23, the nineteen channels not subject to the rules, then the processor problems are neatly avoided. Where this is impossible, demodulator-modulator processing is an effective solution. An additional approach utilizes processors equipped for output phaselock. If such a processor is phaselocked to a reference generator whose frequencies meet the FCC rules then the other sources of frequency error in the processor are automatically removed. If several such processors shared a comb generator, the cost per channel might compare favorably to the demod-remod approach.

## UPGRADING EXISTING HEADENDS

Channels that were in operation or were approved when the new rules became efective are grandfathered under the old rules until January 1, 1990. Grandfathering is applied on a frequency basis rather than a system basis so that new channel additions to a grandfathered system that fall into the aeronautical bands must comply with the new rules for frequency usage. In addition, systems extending their service radii or adding communities will fall under the new rules so that operators will want to upgrade to the requirements of 76.612 well before the 1990 deadline.

In systems employing harmonically related or incrementally related coherent carriers, the headend output picture carrier frequencies are determined by the reference comb generator. If a comb generator is employed whose frequencies conform to the FCC rules, then the system carriers will also conform and no changes to the headend equipment are required. The small offsets from the normal picture carrier frequency assignments should not be incompatible with tuning or phaselock operation of the headend i.f. to channel converters.

### Harmonically Related Carrier Headends

HRC comb generators employ a single 6 MHz oscillator plus circuitry to generate harmonics of this basic 6 MHz signal. Such a comb generator is made FCC compliant by substituting a precision 6.000300 MHz oscillator unit for the conventional crystal oscillator. The precision oscillator unit may be located within the comb generator's chassis or external to it, depending on a particular manufacturer's preference. As an example, Jerrold's Model CPG-HHS comb generator is produced from the non-FCC version by installing a precision oscillator unit within the main chassis of the comb generator. The precision oscillator is powered from the generator's internal DC supply and its output is connected to the comb generation module via the existing plug-in coaxial interface. The comb module is internally modified such that the harmonic generation circuit is driven by the external (to the module) 6.0003 MHz signal instead of the built-in crystal oscillator. It should be possible to similarly modify other existing HRC comb generators.

### Incrementally Related Carrier Headends

IRC comb generators also use a crystal controlled 6 MHz oscillator and harmonic generator to produce a basic comb signal. This comb is combined with a second crystal controlled local oscillator signal to produce a final comb with a 1.25 MHz offset fom the HRC comb. The additional frequency shift required for compliance with the rules for operation in aeronautical communications bands is obtaied by replacing the second l.o. crystal. The actual crystal offset will depend on circuit design details. It is necessary that both the 6.000 MHz and second l.o. crystal oscillator frequencies be set very precisely and that both oscillators exhibit sufficient stability to permit operation over a practical temperature range and for a reasonable period of time without retrimming.

The Jerrold Model CPG-IHS IRC reference generator will serve as an example. In the predecessor model, a 6.000 MHz crystal oscillator is used to generate a harmonic comb that extends to 198 MHz. This is mixed with a 253.25 MHz local oscillator to generate an IRC comb extending from 55.25 MHz to 451.25 MHz. The 253.25 MHz l.o. is the result of doubling the frequency of a 126.625 MHz crystal oscillator. The aeronautical communications bands 12.5 KHz offset is introduced by utilizing a 126.63125 MHz crystal to generate a second l.o. frequency of 253.2625 MHz. Circuit modifications are made to improve the temperature stability of both oscillators and each is set very accurately on frequency. The reference frequency most susceptible to error is channel 53 which corresponds to the 24th harmonic of 6 MHz. This means that the maximum frequency error attributable to the 6 MHz oscillator is 24 times the actual error at 6 MHz. This oscillator is set to an initial error of less than 40 Hz so that its contribution to the initial overall error is less than 1 KHz. Any error in the second l.o. frequency is added directly to each reference frequency therefore this oscillator is trimmed to within 1 KHz of the 253.2635 nominal frequency.

## OPERATION AND MAINTENANCE

The adoption of the new FCC rules for frequency usage further increases the value of thoughtful headend system preventative maintenance. Assuring compliance with 76.612 may require upgrading both the equipment environment and the maintenance and adjustment procedures.

### Frequency Monitoring

Monitoring of channel-by-channel output levels is a routine maintenance activity for most headend systems. Monitoring of picture carrier frequencies has become equally important. The accurate measurement of these frequencies is substantially more difficult, however. In general, it will be desired to measure the carrier frequencies using the same headend system common test point that is used for level monitoring. A frequency counter cannot be connected directly to the system test point because many r.f. carriers are present and because counters in general do not function predictably with amplitude modulated signals. The usual solution to this measurement problem is to use the transfer oscillator or 'zero beat' method in which a stable CW generator is adjusted until its frequency accurately matches that of the picture carrier in question and then the generator's frequency is measured with the counter. The frequency matching is done by combining the generator output with the system test point output and observing the combined signals with a spectrum analyzer. None of these three pieces of test equipment are commonly found in use in today's headends. Considering the need, the reemergence of specialized frequency measurement equipment seems likely. As is the case for system levels, it is recommended that the frequencies be measured and logged often and on regular intervals until drift behavior is characterized and atypical units are identified. An initial interval of one week is suggested, after which the interval can be increased in accordance with the measured long term drifts.

Operators of IRC or HRC coherent carrier headends will have an easier time of it. For IRC systems, a single picture carrier frequency measurement will generally suffice. The carrier to be measured will depend upon the design of the reference comb generator. In the case of Jerrold's CPG-IHS-450, the largest frequency error will occur at the aviation band picture carrier that is furthest from 253.2625 MHz. For example, on systems with channel carriage extending to 400 MHz or higher, the frequency of channel 53's picture carrier is measured. If its error is less than +/- 5 KHz then all phaselocked aircraft and channels will meet the rules as well. In cases where selected IRC channels, such as channel 42, are not locked to the reference comb, these channels must be individually measured as for the standard headend system above.

In the case of an HRC headend system, a single measurement of the 6.000300 MHz standard is all that is required. The time base of a frequency counter that would be used to check the HRC reference would have a stability that is similar to that of the reference being checked. Consequently, this frequency counter must have been calibrated recently enough so that its error is small compared to the required measurement accuracy. A minimum frequency counter accuracy of 1 x 10E-8 or 0.01 parts per million is recommended. It is also desireable that the calibration be traceable to the National Bureau of Standards. The time interval between measurements will depend somewhat on the expected drift rate of the precision reference but a three month cycle seems desireable in any case.

## Frequency Adjustments

The magnitude of the frequency errors permitted under the new rules is several times less than previously allowed, therefore the need for occasional frequency trimming will be real. Vigilant and careful logging and analysis of frequency drift data carriers and reference generators will allow the frequency adjustment needs to be forecast and planned. Output converter adjustment will consist of trimming the crystal controlled local oscillator frequency until it is close to its nominal value in order to obtain maximum tolerance for future long term drift. The crystal oscillators in an IRC comb generator would be similarly reset to nominal frequencies. While a frequency counter with an error of 1 part in 10 million will suffice for the other measurements and adjustments, remember that an order of magnitude greater accuracy is required for HRC reference measurements and recalibration adjustments, due to the very stringent 1 Hz maximum allowed error. When indicated by the measured drift data, the quartz crystal based precision HRC reference oscillator unit should be retrimmed to 6.0003000 MHz +/- 0.1 Hz.

## Headend Environment Temperature Control

Regulating the temperature of the environment in which electronic equipment is installed is always advisable in terms of long term reliability or failure rate. Nevertheless, this practice is still not followed in all headends. The need to maintain very high standards for headend frequency accuracy brings temperature control closer to necessity. In a recent study of the temperature drift behavior of headend systems and equipment, it was found that by reducing the environmental temperature limits from the typical unregulated values to a 15 to 40 degree range, the amount of temperature drift associated with temperature variation was halved. This provides greater margins for long term aging drift and initial setting errors. This temperature range is well within that of a typical controlled headend and should not impose any additional requirement there. Operators of headends without control will certainly find their maintenance chore increased.

## CONCLUSION

New FCC regulations for the carriage of aeronautical navigation and communications band frequencies on CATV distribution systems are in effect. Compliance with these rules places burden on both equipment manufacturers and system operators. Equipment manufacturers must modify and respecify current headend product designs in accordance with the details of part 76.612. Future products must have compliance built-in.

System operators will have to recognize and implement new headend preventative maintenance procedures, including environmental temperature control, to minimize the risk of frequency rules violations. For long term compliance, some periodic re-optimization of frequency determining circuits will be a fact of life.