The Potential Benefits of Precise Frequency Control of Television Transmitters

John A. Pranke

Theta-Com

When the present television channel assignments were made by the FCC in 1952, the visual carrier frequency tolerance was specified as ± 1 KHz, with provision for a ± 10 KHz offset where necessary to minimize co-channel interference. These assignments have, with exceptions, proved satisfactory for twelve channel reception and cable transmission, since all second order products fall out of band and the magnitude of triple beats had not been a limiting factor. Recent industry efforts to standardize on a channeling plan for expanded channel systems and an off air, cable compatible receiver have pointed out a number of problems with the present transmission assignments. This paper reviews the various plans proposed within CTAC and other organizations, their advantages and limitations, and concludes that operation of broadcast transmitters on precise frequencies or phase locked to a national standard could effect a major improvement in off air and cable television performance. Methods to achieve such frequency control are also reviewed.

Before going into the main subject matter of this paper, it is desirable to briefly review the history of television channel frequency assignments in the United States. The FCC first assigned frequencies for commercial television broadcast in 1937. At that time the channel width was made 6 MHz, and the form of transmission was double sideband AM, with the picture carrier 2.5 MHz above the lower band edge and an AM modulated sound carrier located 3.25 MHz above the picture carrier. In 1940, the original assighments were slightly modified, and, with the exception of Channel 1, retained the original format of 6 MHz channels with the channel edges on multiples of 6 MHz. The form of transmission was changed to vestigial sideband with FM sound as we know it today. The upper spectrum of Figure 1 shows the 1940 assignments, which provided 18 channels. It is interesting to note that in 1940 this band of frequencies was called UHF.

After the Second World War, the FCC made extensive changes in the 40-300 MHz band, which resulted in the television assignments we have today, shown in the lower spectrum of Figure 1. Again, with the exception of Channels 5 and 6, the format of 6 MHz channels with band edges on 6 MHz multiples was retained. In retrospect, it almost appears that the 1940 assignments were preferable to those of today, since we would not have the problem of Channels 5 and 6. It is also regrettable that the carrier frequencies, instead of the band edges, were not put on 6 MHz multiples, but then hindsight is 20-20.

From 1940 to 1948 (with the exception of the war) the standard picture carrier assignment was 1.25 MHz above the lower channel edge, with a tolerance of ± 1 KHz. In the period from 1947 to 1948, following the war, an ever increasing number of stations went on the air. With more and more stations, reports began to come in about unexpected interference due to long distance propagation. (Marconi had predicted this as early as 1932.) (1) Consequently, in September, 1948, a "freeze" was put on further station construction until the problem could be studied.

After four years, in 1952, it was concluded that the interference could be considerably reduced by the use of ± 10 KHz "offset carriers" for some channels to minimize co-channel interference, and assignment locations based on increased knowledge of VHF propagation. However, as we know, the solution was far from perfect. In 1952, the "freeze" was lifted, and there was a rapid increase in VHF station construction, principally in the late 50's and early 60's.

(1) Alexander A. McKenzie, "The Three Jewels of Marconi", IEEE Spectrum, PP 46-49, December 1974

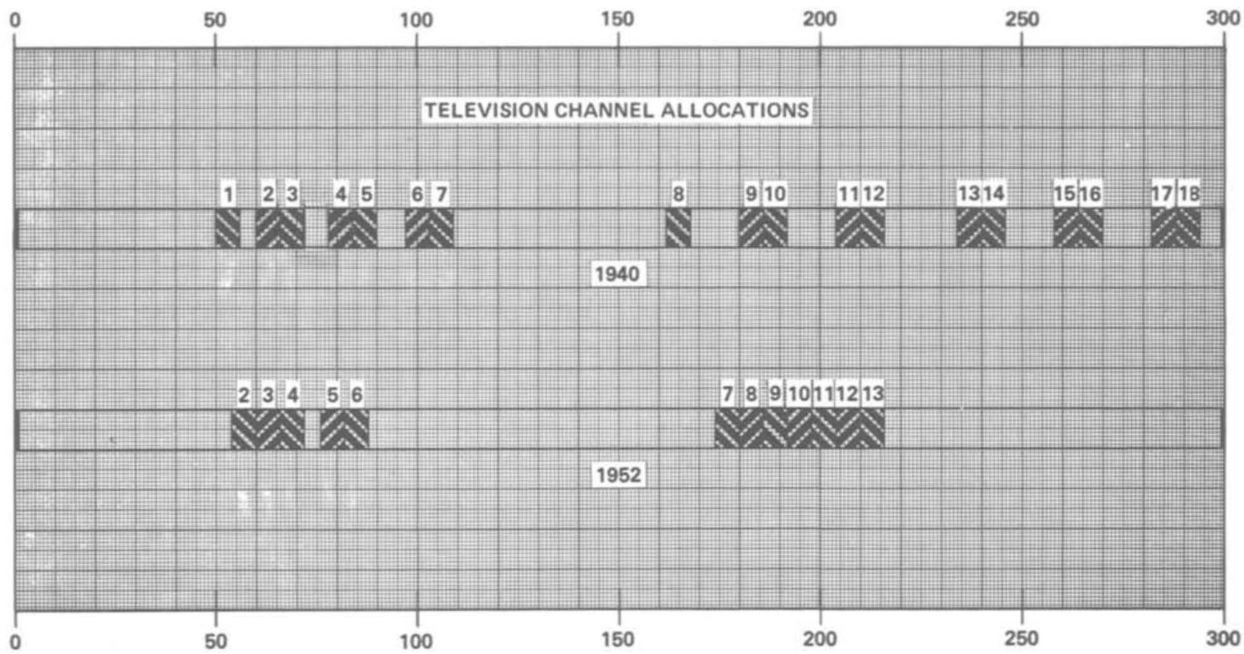

FIGURE 1.

These assignments have, with exceptions, proved satisfactory for twelve channel reception and cable transmission, since all second order products fall out of band and triple beats have not been a limiting factor. However, in the late 1960's, CATV started moving into the larger metropolitan areas and a demand arose for greater channel capacity both where the VHF plus UHF complement of stations exceeded twelve, and to provide extra services to attract revenue. With the advent of push-pull amplifiers, use of the midband for these extra channels became feasible, since the push-pull configuration reduced second order distortions below the interference level. There was some brief interest in single octave systems (120-240 MHz) but they never gained popularity since a standard TV receiver would be restricted to only seven channels on the dial. The most generally accepted channelling plan was simply an extension of the existing FCC allocations both up and down from the high VHF band.

Recognizing the need for additional channels, the FCC, in its Cable Television Report and Order of February 2, 1972, required that cable systems built after that date have a minimum of 20 channel capacity, and that by 1977 all systems over a certain size have 20 channel capacity. In the same Report and Order, the FCC also created a Cable Television Technical Advisory Committee (CTAC) to deal with engineering and operational facts and make recommendations to the Commission regarding technical standards for cable services, limitations on signal degradation, measurement techniques, and in the formulation of future policies in these areas. One of the more important charters of CTAC was to recommend a channeling plan and receiver requirements which would result in a compatible off-air and cable television receiver having minimum economic impact on the consuming public.

Nine working panels were set up within the CTAC organization to investigate different aspects of the problem, and to coordinate with other organizations such as EIA, IEEE, and various governmental departments. CTAC Panel 5 was specifically charged with the task of recommending a channeling plan for cable television use. This paper is based on the work of Panel 5, as viewed by the author, and should not be construed as representing all points covered or the final panel report to the CTAC Steering Committee.

As a starting point, the panel first reviewed all of the previous ideas and proposals for channeling plans from other groups of which it had knowledge.

The majority of these were discussed in the paper "Channel Allocation Options" by Robert S. Powers of the Office of Telecommunications, presented at the 1972 NCTA convention.

After the first few meetings of Panel 5, it became obvious that what at first appeared to be a relatively simple task was indeed going to be a formidable one. This was because of the many areas that would be impacted by the choice of any channeling plan, some of them subtle, and some of them not so subtle. One of the not so subtle facts was the large population of existing TV receivers, coupled with the mobility of the American citizen. A more subtle item was the limitations of the receiver manufacturers in producing a compatible set without undue economic impact. While a beautiful engineering solution could be achieved with relative ease, the panel had to spend a great deal of time considering the other factors involved.

Following the review of the various channeling plans brought forward, it was the consensus of the panel that only three merited further, in-depth study. Briefly, these plans may be described as follows:

Plan 1 - Augmented FCC assignments with standard tolerances and offsets. This is essentially the "de-facto" situation currently in use by most CATV systems using the mid and super bands.

Plan 2 - Constant interval assignments based on a 6N + 1.25 MHz comb of frequencies. This would put all picture carriers on the system in a phase stable condition, but requires rather complicated equipment at the headend.

Plan 3 - Harmonically Related Coherent (HRC) assignments based on a 6N MHz comb of frequencies. (Other frequencies close to 6 MHz could also be considered.)

The picture carrier frequencies resulting from these plans are shown in Table 1. Here the mid band channels, A through I, and the super band channels, J through W, are shown with their common alphabetic designation. For practical considerations affecting tuner channel identifications, a national standard for a 20 channel receiver might employ a numeric system such as 92-99 for the eight augmented channels.

Channeling plans, with respect to CATV system performance, primarily affect three areas:

A) Direct off-air pick-up
B) Second order distortions
C) Third order distortions

In the case of direct off-air pickup, Plan 1, assuming the cable is locked to the local, presents only the problem of leading ghosts, since the broadcast and cable frequencies are the same. Plans 2 and 3 could create co-channel type interference since there is a frequency off-set.

Second order distortions (F1 ± F2 and 2F1 products) are a problem with Plans 1 and 2, and especially with regard to Channels 5 and 6. HRC is the only plan with potential for reducing these interferences, but it in turn creates problems in receiver compatibility and off-air pickup. Second order distortion is generally not a limitation with modern push-pull equipment in expanded channel systems, but is quite serious in older single ended equipment.

Third order distortions (F1 ± F2 ± F3 and 2F1 ± F2 products) are a problem with Plan 1 since the carriers are not on precise frequencies and the resultant beats appear as sidebands or "busy background". The number of these beats and their visible effect increase very rapidly as the number of channels is increased. (2) Plan 2 substantially reduces this interference since the majority of carrier beats are zero beats and only have a minor effect on luminance. Plan 3 (HRC) makes all visual carrier beats zero beats. (Note: Cross modulation is a special case of third order distortion and will occur with any channeling plan.)

During discussions of the full panel, it was evident that certain members of the panel, especially those concerned with receivers, preferred Plan 1 because of compatibility problems with an off-air and cable receiver. Plan 2, the constant interval assignment, with the exceptions of Channels 5 and 6, results in channel frequencies which are the same as Plan 1, but with the added requirement that all of the carriers be phase stable. This immediately suggests an eminently practical compromise to the off-air cable compatibility problem. Namely, in order to utilize the interference reduction potentials of Plan 2 in the most economical and nationally standardized manner, that the FCC adopt a 6N + 1.25 MHz constant interval channeling plan, but with <u>all broadcast transmitters on precise frequencies or phase locked to a national standard.</u>

(2) "A New Approach to Evaluating CATV System Triple Beat Performance" - John A. Pranke, April 1974

(Proposals for handling Channels 5 and 6 will be discussed below.) In 1952, precise control of carrier frequencies would have been very difficult to achieve. Today it can be quite easily accomplished, particularly with the availability of atomic frequency standards at moderate cost. In fact, some broadcast transmitters now are using Rubidium standards as their carrier source, complete with ± 10 KHz off-set if required by their channel assignment.

Precise control of broadcast transmitter frequencies would have some very significant advantages:

1. Off the air reception would be improved by substantial elimination of co-channel interference. This would definitely be in the public interest.

2. Since all channels would be on precise frequencies, receiver design, for both off-air and cable could be improved through the use of crystal stabilized frequency synthesizer local oscillators and improved traps on exact frequencies.

3. Cable system performance would be improved since the large majority of carrier triple beats would be zero beats.

4. If a WWV type national standard were employed, sync reference information could be included to effectively gen-lock all transmitters, further reducing the effect of third order distortions.

5. Locally originated channels could also readily be locked to the precise frequencies with the same advantages.

The major problem with the constant interval plan, as with the augmented FCC plan, is the 2 MHz offset of Channels 5 and 6. Initially, for some period of time such as five years, these channels could be put on precise frequencies or phase locked to a 6N + 5.25 MHz comb. (or equivalently all channels to a 2N + 1.25 MHz comb.) while provision is made to ultimately move them up 2 MHz to fit the 6N + 1.25 MHz comb in perhaps 5 to 10 years.

Moving Channels 5 and 6 up 2 MHz would mean the loss of 2 MHz in the FM band, or half of the portion reserved for educational stations. There are currently approximately 250 stations operating in these 2 MHz, most of very low power, and the impact of reassigning them would have to be carefully studied. In the meantime, system operators could move them themselves if receiver tuning or off air does not prove to be a problem. If converters are used, they could be placed in other parts of the band to solve off air problems.

With today's technology, putting all broadcast transmitters, both VHF and UHF, on precise frequencies is very feasible and represents a very cost effective method of achieving a major improvement in our television transmission methods for both off the air and cable reception. Rubidium controlled signal sources are available from several manufacturers with frequency stability which is quite impressive. For example, typical specifications are:

Long Term Stability: $<2 \times 10^{-11}$ per month
Systematic Trend: (typically 1×10^{-11} per mo.)

Short Term Stability: $< 7 \times 10^{-12}$ rms
One Second Averages:

Applying the short term stability to Channel 13 one can calculate the frequency error as:

$$(211.25 \times 10^{6})(7 \times 10^{-12}) = .0015 \text{ Hz rms}$$

With this type of stability it would take 666 seconds, or over 11 minutes for a beat to move across a television receiver's screen. It is well known that stationary or very slowly moving interferences are less objectionalbe than rapidly moving ones, and the above stability is several orders of magnitude better than typical quartz oscillators.

The use of individual atomic frequency standards at each transmitter may be considered as a first step toward putting all transmitters on a true precise national standard. A second step might be the establishment of regional "master" stations to which all other stations in the area could be slaved, including sync information. By making all of the blanking intervals in a given region coincident, the effects of sliding frames, cross modulation and triple beats due to sidebands could be even further reduced. Finally, all of the regional master stations could be tied together, establishing a national standard.

In conclusion, our present television system has served the nation well for almost three decades, but has obvious defects in terms of current needs. The above proposal could effect a major improvement for both off-air and cable reception for many years to come. Eventually there will be a demand for a system having higher definition, three dimensional capability and who knows what else. That will require a massive effort by the entire communications industry, but in the meantime we should employ every technical advance possible to improve our present system.

TABLE 1

NOMINAL VISUAL CARRIER FREQUENCY

	1	2		3	
Channel	Nominal FCC Visual Carrier	Constant Interval Carriers		Harmonically Related Carriers	
		n	(6n + 1.25)	n	(6n)
2	55.25	9	55.25	9	54.00
3	61.25	10	61.25	10	60.00
4	67.25	11	67.25	11	66.00
5	83.25	13	79.25*	13	78.00*
6	83.25	14	85.25*	14	84.00*
A	121.25	20	121.25	20	120.00
B	127.25	21	127.25	21	126.00
C	133.25	22	133.25	22	132.00
D	139.25	23	139.25	23	138.00
E	145.25	24	145.25	24	144.00
F	151.25	25	151.25	25	150.00
G	157.25	26	157.25	26	156.00
H	163.25	27	163.25	27	162.00
I	169.25	28	169.25	28	168.00
7	175.25	29	175.25	29	174.00
8	181.25	30	181.25	30	180.00
9	187.25	31	187.25	31	186.00
10	193.25	32	193.25	32	192.00
11	199.25	33	199.25	33	198.00
12	205.25	34	205.25	34	204.00
13	211.25	35	211.25	35	210.00
J	217.25	36	217.25	36	216.00
K	223.25	37	223.25	37	222.00
L	229.25	38	229.25	38	228.00
M	235.25	39	235.25	39	234.00
N	241.25	40	241.25	40	240.00
O	247.25	41	247.25	41	246.00
P	253.25	42	253.25	42	252.00
Q	259.25	43	259.25	43	258.00
R	265.25	44	265.25	44	264.00
S	271.25	45	271.25	45	270.00
T	277.25	46	277.25	46	276.00
U	283.25	47	283.25	47	282.00
V	289.25	48	289.25	48	288.00
W	295.25	49	295.25	49	294.00

*Special consideration must be given to these channels.