A STUDY OF CO-CHANNEL AND ADJACENT CHANNEL INTERFERENCE OF TELEVISION SIGNALS

PART I

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
PRINCETON, N. J.

E W ENGSTROM
VICE PRESIDENT IN CHARGE OF
RESEARCH

January 17, 1950.

Mr. T. J. Slowie, Secretary
Federal Communications Commission
Washington 25, D. C.

Re· Docket Nos. 8736, 8975,
9175 and 8976
Part II

Dear Sir

In our progress report of December 30, 1949, on the subject dockets, we summarized results of tests made by RCA on co-channel and adjacent-channel interference of black-and-white and color television signals. We attached to that progress statement a report covering the co-channel portion of the tests (Part A - Item 1 of attachments to progress report of 12/30/49). This report, "A Study of Co-Channel and Adjacent-Channel Interference of Television Signals, Part I" has been put in bulletin form for wider distribution. In keeping with the procedure for earlier bulletins, one hundred copies of this seventh bulletin* are filed herewith. Copies of this bulletin will be mailed to the list of persons and organizations attached to Mr. Robert Zeller's letter of October 26, 1949.

This bulletin in Part 1 includes a summary of the work done by RCA on reduction of co-channel interference for black-and-white television and for color television. Part 2, which is in preparation, will cover work done on measurements of adjacent-channel interference for color television.

The following is quoted from our progress statement of December 30

"The results indicate that the specific character of the video modulation is not of primary significance in determining co-channel requirements but rather that it is the carrier itself which is determining. Our tests indicate that for the color systems under consideration there are no practical differences between these color systems and black-and-white. We believe that, for these color systems, and for the purposes of allocation, co-channel and adjacent-channel requirements will be the same as for black-and-white."

Very truly yours,

E. W. Engstrom

E. W. Engstrom

*Bulletins previously filed and distributed

"A 15 by 20-Inch Projection Receiver for the RCA Color Television System" (letter dated October 20, 1949)

"Synchronization for Color Dot Interlace in the RCA Color Television System" (letter dated October 31, 1949)

"A Two-Color Direct-View Receiver for the RCA Color Television System" (letter dated November 9, 1949)

"An Experimental UHF Television Tuner" (letter dated December 12, 1949)

"A Three-Color Direct-View Receiver for the RCA Color Television System" (letter dated January 9, 1950)

"An Experimental Determination of the Sideband Distribution in the RCA Color Television System" (letter dated January 17, 1950)

A Study of Co-Channel and Adjacent Channel Interference of Television Signals

Part I

Radio Corporation of America

January 1950

Contents

List of Illustrations

Page

A Study of Co-Channel and Adjacent Channel Interference of Television Signals

Part I

Introduction

In the fall of 1948 when the FCC held hearings on the problem of co-channel interference of VHF television stations estab ished the Ad Hoc Committee to review the available data on tropospheric propagation in order to arrive at an acceptable method of predicting interference and instituted the "freeze" on new television station construction the Radio Corporation of America accelerated its program of development on a television carrier synchronizing system At the engineering conference December 2 RCA reported on the laboratory tests concerning television carrier synchronization and described the equipment used in the Princeton laboratory to synchronize WNBT New York with WNBW Washington

Early in 1949 the synchronizing equipment was moved to a field site midway between New York and Washington and field observation of the operation of the system were made for a period of several months Concurrent with these tests further laboratory development was progressing which resulted in "offset carrier" operation This latter method was simpler in operation, was more economical of equipment and yielded results superior to television carrier synchronization Field experience with a number of Channel 4 stations followed In the summer of 1949 RCA cooperated with JTAC in obtaining quantitative data in the laboratory, with a large number of observers to determine the probable desired-to-undesired signal ratio for unsynchronized signals for synchronized signals and for signals using offset carriers These laboratory tests as well as much field experience firmly established that offset carrier was a simple and effective method of reducing co-channel interference

It is the purpose of this report to describe the early work on television carrier synchronizing to discuss the offset carrier method and describe field observations of the method to discuss briefly the JTAC observer tests and to describe more recent work carried out by RCA in determining the desired-to-undesired signal ratios for offset carrier operation as applied to the RCA color television system and the CBS field-sequential color television system and in attempting to determine the appropriate ratios for the CT line-sequential color television system

Preliminary Experiments with Synchronized Television Carriers

When two co-channel television stations are operated normally the carrier frequencies may differ by only a few cycles by fifty to one hundred cycles and at times by several hundred cycles The resultant beat between the carrier of the desired signal and the carrier of the interfering signal appears as horizontal moving black bars in the television picture With increased interfering signal the undesired picture appears in the background of the desired picture Experience has shown that the horizontal bars due to carrier beat become ob ectionable when the undesired picture in the background is barely visible With the two carriers precisely synchronized in frequency the moving bars are completely eliminated and the undesired picture becomes the next source of interference to be considered Under this condition of precise synchronization the improvement to be obtained depends upon the relative phases of the two carriers at the receiving point If the two carriers could be held precisely in time quadrature the largest improvement would be secured The least improvement is achieved when the carriers are in phase or in phase opposition Hence in observer tests carried out in the laboratory to determine improvement ratios it seemed desirable to determine the improvement ratios which applied in the least favorable phase condition

A laboratory test was conducted with twenty-five observers The observers were shown a television picture with an unsynchronized signal as a source of interference The interfering signal was ad usted to a value which the observer indicated to be objectionable Then the carrier frequencies were synchronized adjusted to the least favorable phase and the undesired signal increased until the observer felt that the interference was of the same degree of ob ectionableness as for the unsynchronized condition The improvement factor was taken as the number of decibels which the undesired signal was increased from the unsynchronized case to the synchronized case The results of this laboratory test are shown in Fig 1 expressed as a probability distribution in terms of the percentage of observers noting an improvement greater than the corresponding ordinate value It may be noted from Fig 1 that fifty per cent of the observers experienced an improvement of 17 decibels in favor of carrier synchronization

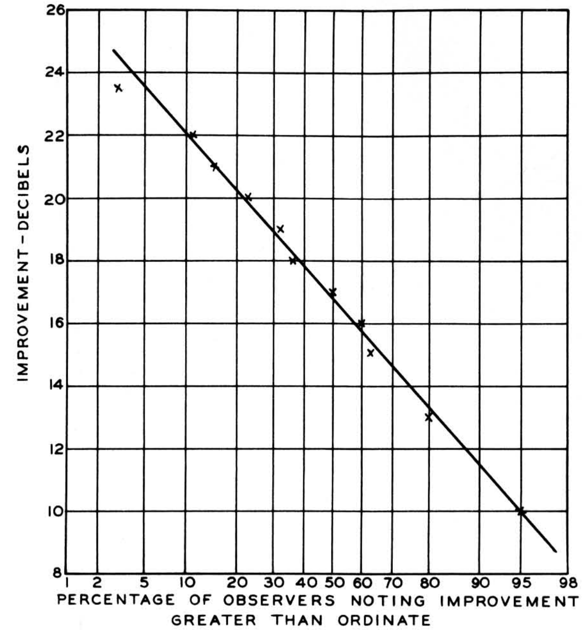

Fig 1 - Improvement in reception of a television signal in the presence of a co-channel interfering signal (The improvement factor is that obtained with synchronized carriers in the least favorable relative phase, with non-synchronous operation used as the reference standard)

To obtain field experience under home receiving conditions equipment was assembled which made possible the carrier synchronization of Television Station WNBT New York, with WNBW in Washington The equipment used in conducting the synchronizing test consisted of two units The first unit was located in the RCA Laboratories in Princeton New Jersey and the second was located at Station WNBT in New York The equipment at the Princeton Laboratories included two narrow-band superheterodyne receivers The voltage from a single local oscillator was applied to the first detectors of both receivers thus the frequency difference between the two incoming signa s was retained The output signals from the two intermediate-frequency amplifiers were mixed in a phase discriminator the output voltage of which was a measure of the phase difference between the two incoming carriers The output voltage of the phase discriminator was used to frequency modulate an RC oscillator plus or minus 300 cycles about a mean frequency of 1000 cycles This frequency-modulated 1000 cycle tone was the control signal which was transmitted from Princeton to New York over a norma telephone line To receive the radio signal from WNBT a dipole antenna with reflector was used This arrangement did not receive enough signal from Washington to interfere with the control circuits The second antenna used to receive WNBW was a bridged dipole and reflector combination It had an excellent front-to-back ratio but was not sufficiently good for the purpose To further improve the discrimination against the New York signal some signal from the New York antenna was introduced into the transmission line coming from the antenna directed at Washington This in ected signal from New York was adjusted in amplitude and phase so as to further reduce the undesired New York signal on the output terminals of the Washington receiver

In New York the frequency-modulated 1000 cycle tone was reconverted by a frequency discriminator to a control voltage corresponding to the output of the phase discriminator on the output of the two receivers in Princeton This control voltage was applied to a reactance tube in the transmitter crystal circuit in such a way as to shift the crystal frequency as much as plus or minus 300 cycles The general arrangement is shown in the block diagram of Fig 2

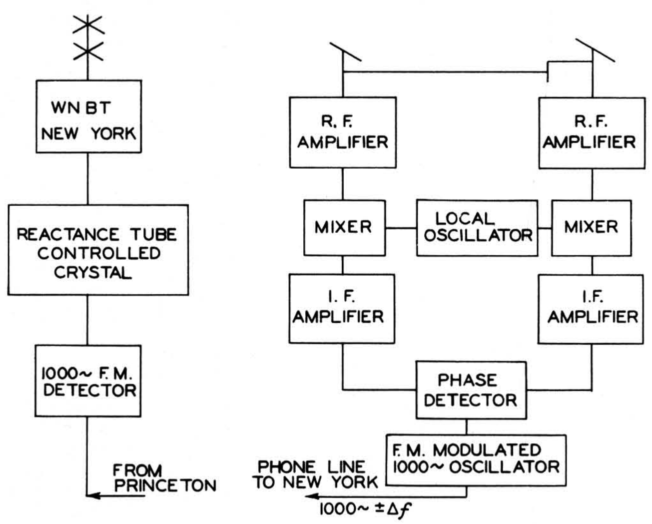

Fig 2 - Block diagram of the television carrier synchronizing system used to synchronize WNBT with WNBW.

The operation of the system was as follows Signals from New York and Washington were compared in the phase discriminator at the output of the two receivers located in Princeton The information regarding relationship of the two carriers was carried as frequency modulation of the 1000 cycle tone by telephone line to New York The frequency shift of this tone was utilized to change the frequency and phase of the New York carrier to maintain a fixed phase relationship between the New York and Washington carriers as observed at Princeton

During the months of November and December 1948 and part of January 1949 the apparatus of Fig 2 was used to synchronize WNBT with WNBW and observations were made at many home receiver locations in the vicinity of Princeton A schedule was arranged so that for a number of short periods through the evening hours the stations were operated unsynchronized with interference bars appearing in the received picture It was demonstrated that carrier synchronization brought about a very real improvement in reception of WNBT in the Princeton area a distance of 40 to 45 miles from New York In some ocations the interference from WNBW in the unsynchronized condition was so severe that the picture from WNBT was not usable At these same locations synchronization generally improved the picture to such an extent that it was quite acceptable

While these Princeton tests demonstrated the soundness of the principle of television carrier synchronization real practical operating difficulties existed because of the strong WNBT signal and the weak WNBW signal at the receiving point where the synchronizing receivers were located Even with the best balancing arrangement that could be devised it was not always possible to balance out the WNBT signal in the receiving antenna used to receive WNBW A decision was soon reached to move the receiving apparatus to a point where the signals from the two stations would be of approximately the same value Arrangements were made to use the building and land avai able at the Western Union microwave relay site at Brandywine a few miles north of Wilmington Delaware This property was midway between the two transmitting stations 103 miles from WNBT and 103 miles from WNBW Two large receiving antennas were erected on poles 50 feet in height as shown in Fig 3 The antenna at the right in this picture was used to receive WNBW while the one on the left received WNBT The relative horizontal field patterns of these antennas are shown in Fig 4 The proximity of the Western Union tower reduced the back signal of the WNBW antenna so that the WNBT signal in this antenna system was of no consequence The antenna receiving the WNBT signal was in an open field and had a back lobe of 12 per cent, so the antenna was turned slightly to further suppress the WNBW signal.

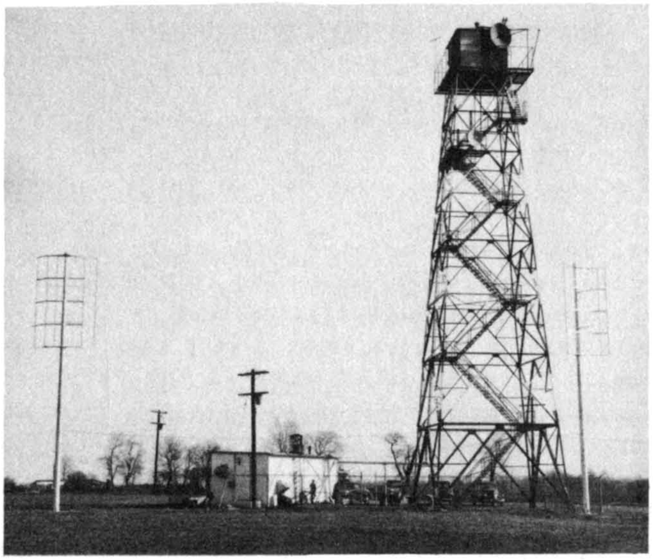

Fig. 3 - The receiving equipment site at Brandywine, near Wilmington Delaware.

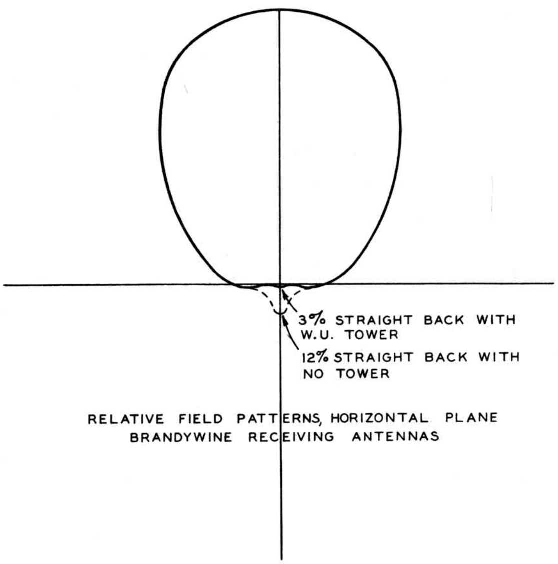

Fig. 4 - The relative field patterns in the horizontal plane of the Brandywine receiving antennas

The transmitter control gear was installed at WNBW and a telephone line connected the receiving equipment at Brandywine with WNBW control equipment. Both the transmitter control equipment and the receiving equipment was that previously used at Princeton Synchronization of WNBW and WNBT, using the Brandywine installation, began on January 22, 1949, and continued for several months. Shortly after the start of operations at Brandywine, the RCA Victor Division of the Radio Corporation of America supplied new equipment of a more advanced design for use at Brandywine and at WNBW. This equipment included refinements not used in the original equipment, and in addition provided the means for synchronizing three stations This was done in anticipation of the time when WGAL-TV, in Lancaster, Pa., would begin broadcasting on Channel 4. This latter receiving station synchronizing equipment and the transmitter control units are shown in Fig 5 and and Fig. 6, respectively

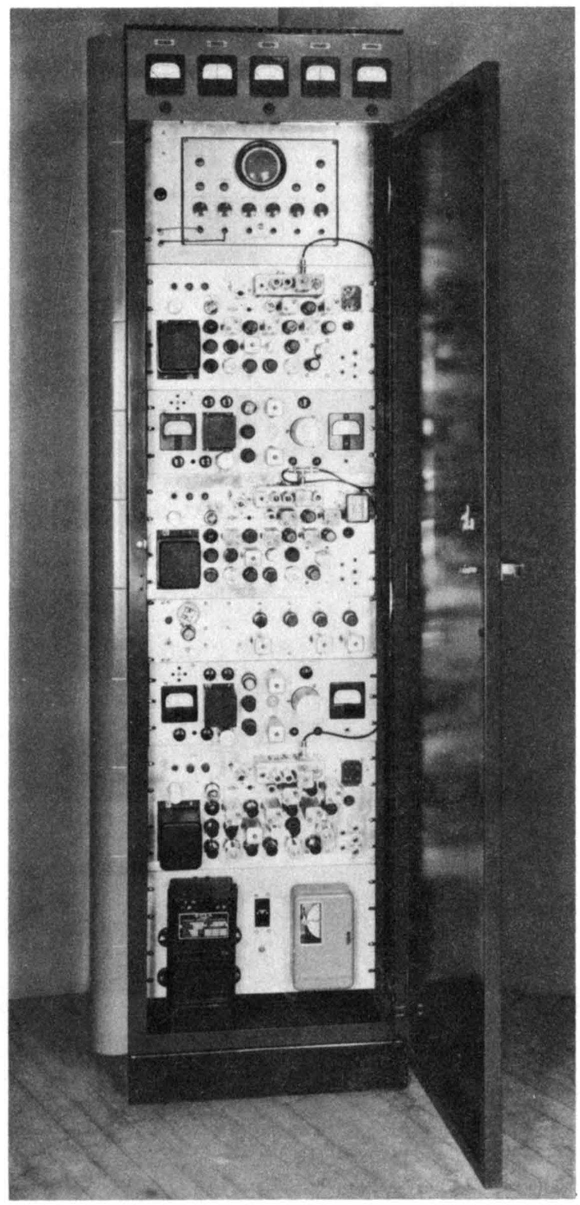

Fig. 5 - Television carrier synchronization equipment, receiving station rack.

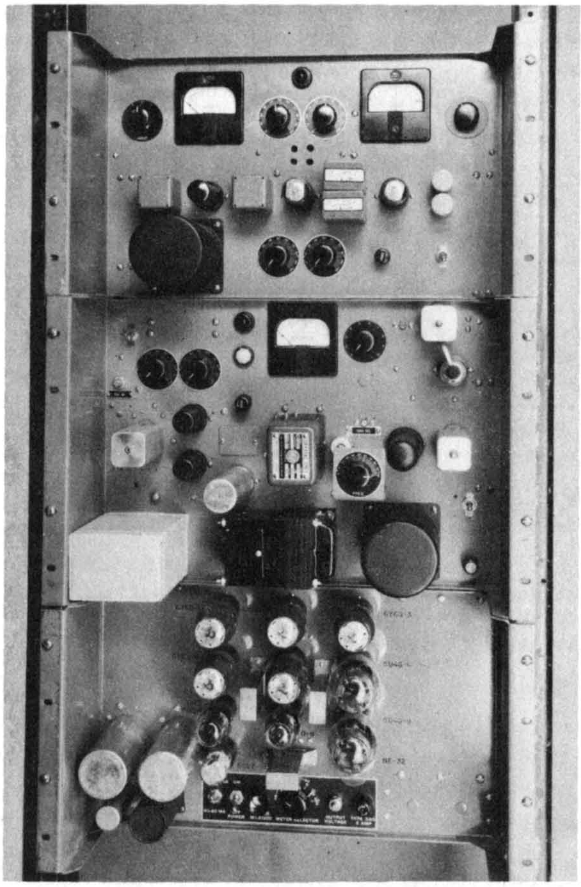

Fig. 6 - Television carrier synchronizat on equipment, transmitter control units.

Continued observations of signal recept on in the fringe areas of WNBT and WNBW showed that the appl cation of carr er synchronizat on had ndeed proven benef cial to viewers who had been troubled by co-channel interference. As a result of the experience gained with the Brandywine installation, plans were made with the General E ectric Company and the Westinghouse Radio Stations, nc , to establ sh a receiving po nt at Wilbraham, Massachusetts, with the necessary equipment to synchronize WBZ-TV in Boston and WRGB in Schenectady with WNBT. Receiv ng antennas were erected and some equipment was installed at Wilbraham in preparation for this next step This project was ha ted by the advent of "offset carrier" operation, which had resulted from continued research at RCA Laboratories on the problem of co-channe interference. Since it was soon apparent that offset operation was extremely simple, very economical, and yielded results superior to television carr er synchronization, the Wilbraham project was dropped, the Brandyw ne operation ceased, and offset carrier experiments were immediately started with WNBT and WNBW.

Experiments with Offset Carriers

For the condition of non-synchronous operation where there are four or five horizonta black bars in the picture, there are sections of posit ve and negative nterfering pictures correspond ng to the cycles of the beat between the two carriers. With this observation as a basis, it was concluded that if the beat difference between the two carriers were made to correspond exactly to one-ha f the line frequency, a condition would be obtained where not only the beat between carriers would be a very fine pattern, but also the odd and even lines wou d contain interfering pictures of opposite polar t es, w th a tendency to integrate out when observed at normal view ng distance. To check this condition, an experimental arrangement was made n the laboratory where the carr er of the local signal was offset by precisely 7,875 cycles w th respect to the interfering signal A group of twenty-five observers were used to obtain the data shown n Fig. 7,

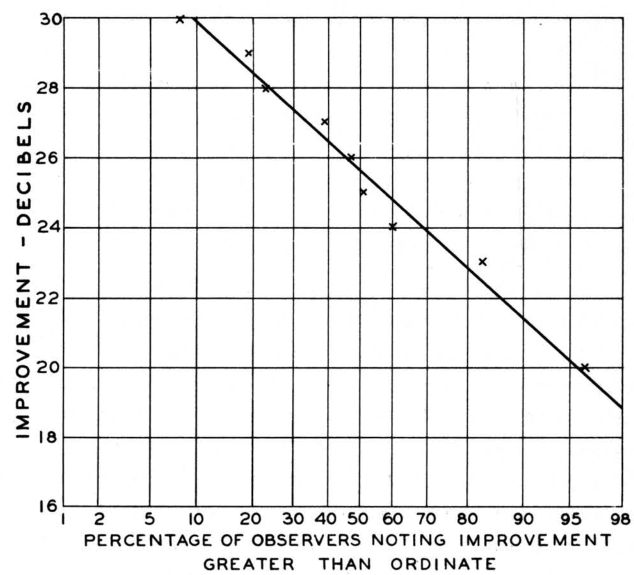

Fig. 7 - Improvement in reception of a television signal in the presence of a co-channe interfering signal. The improvement factor s that obta ned with carriers offset by one-half ine frequency, 7875 cycles, with non-synchronous operation used as a reference standard.)

which shows the improvement obtained by this precise offset method with respect to the normal unsynchronized condition It may be seen from Fig 7 that fifty per cent of the observers experienced an improvement of at least 25 decibels This was an improvement of approximately 8 decibels over the synchronized carrier condition

To operate two stations under this condition requires the same equipment as used for carrier synchronization plus a few items of auxiliary equipment required to produce the precise displacement of one-half line frequency or 7 875 cycles obtained by dividing the actual received line frequency by 2 The precision of frequency control required to obtain the full advantage of this method of operation requires that the synchronizing generators at both transmitters be operated from crystals rather than from 60-cycle power supplies which may not be tied into the same power network

At the completion of this series of laboratory tests it was thought that perhaps the frequency tolerance specified above for the half-line frequency condition could be reduced in exchange for some of the 8 decibel improvement obtained over the synchronized condition In other words if the frequency tolerance for the half-line frequency operating condition could be made the same as the normally-specified transmitter crystal stability the 8-decibel improvement over the synchronous condition could be sacrificed to obtain this simple operating condition If this arrangement were at least equal to the synchronized condition it would be without the equipment difficulties telephone line charges personnel and plant facilities required for synchronized operation

To determine the improvement as a function of the difference frequency between the two transmitter carriers additional laboratory measurements were made A group of observers made observations at a number of offset carrier frequencies The curve of Fig 8 was the result To obtain this data the difference frequency between the two carriers was ad usted to give the fine horizontal black bars their most ob- ectionable appearance that is they moved slowly either up or down in the picture The data presented in Fig 8 is for the worst condition that could be realized for a given nominal offset or difference frequency between the two carriers From the curve of Fig 8, it is seen that at a nominal half-line frequency difference between the two carriers, an improvement of approximately 20 decibels is obtained as compared to the 25-decibel improvement obtained at the precise half-line frequency

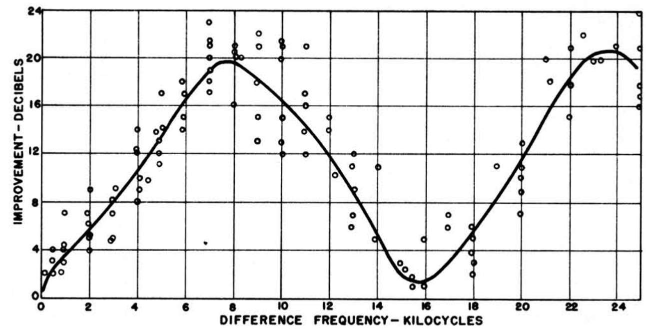

Fig 8 - Improvement in reception in the presence of a co-channel interfering signal as a function of the frequency difference between carriers (Fine adjustment of frequency for maximum visibility of interference.)

From Fig 8 it is seen that as the difference frequency between the two carriers is further increased a minimum improvement is approached at line frequency, and again another favorable interference condition is reached at one and one-half times line frequency With the data of Fig 8 in mind it is seen that in a situation where three stations are involved one station could be on frequency the second station displaced half-line frequency above, and the third station displaced half-line frequency below With this arrangement the interference between stations 1 and 2 and between stations 1 and 3 would be at a minimum However the interference between stations 2 and 3, which would have a carrier difference corresponding to line frequency could be very severe or at best little if any improvement would be noticed To overcome this difficutly in a three-station situation it was proposed that a displacement in carrier frequency of not half-line frequency but 10 5 kilocycles be used Again referring to Fig 8, it is seen that with an offset of 10 5 kilocycles an improvement of approximately 15 decibels is obtained Also the frequency difference between stations 2 and 3 is now 21 kilocycles with an improvement of approximately 15 decibels

In order to put laboratory experience to a field test in the simplest form it was only necessary to obtain a new crystal for the WNBT picture transmitter and another new crystal for the WNBT frequency monitor and to secure permission from the FCC to make this slight shift in frequency for experimental purposes During the late spring of 1949, observations in home receiving locations were made in the Princeton area It was soon apparent that this simple offset carrier method was extremely effective in reducing co-channel interference on Channel 4 in the fringe area Many demonstrations were made during this period where the WNBT frequency was periodically returned to its normally assigned value The improvement due to offset carrier operation was indeed striking

On June 17 1949 WNBT in New York was returned to its normally assigned frequency At the same time WBZ-TV WRGB and WNBW were offset 10 5 kilocycles from WNBT Station WGAL-TV Lancaster Pa began offset operation on June 24 Thus by late June, these five Channel 4 stations were operating n offset conditions planned to yield substantial mutual protection The offset frequency conditions are listed in Table I

An RCA Laboratories panel truck was equipped with measuring gear for making observations and measurements in the field An RCA-8TS30 television receiver an RCA-WX1A Field Intensity Meter with Esterline-Angus recorder a Hewlett Packard 200C audio oscillator and an RCA-TMV122B oscillograph were included The field intensity meter together with the oscillograph and audio oscillator afforded a simple and accurate means of determining the frequency difference between pairs of stations

Picture observations were made in fringe area cities, localities where average field intensities ranged from 200 to 800 microvolts per meter In each of the fringe area cities the field intensity meter and recorder were used to make a survey through the particular city to determine the range of variation of field intensity and the median field intensity Figs 9 and 10 show the fringe area cities visited during the summer of 1949 Table II shows the results of field intensity measurements in these cities

While observations were being made in each locality the desired station and the nearest co-channel interfering station were operated first with nominally the same frequencies but non-synchronous and secondly with carriers offset 10 5 kilocycles Thus direct comparisons of the two modes of operation were made under like receiving conditions

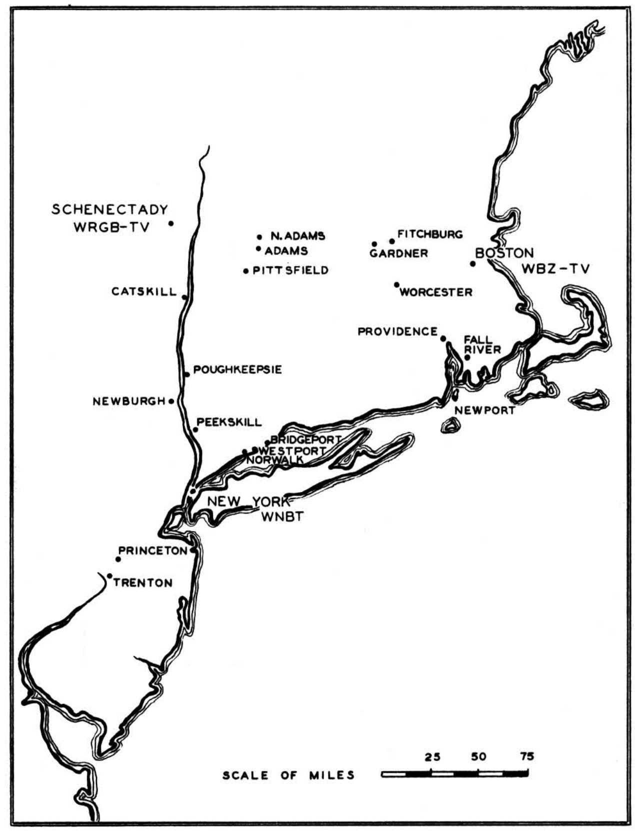

Fig. 9 - Fringe area cities where observations of co-channel interference were made

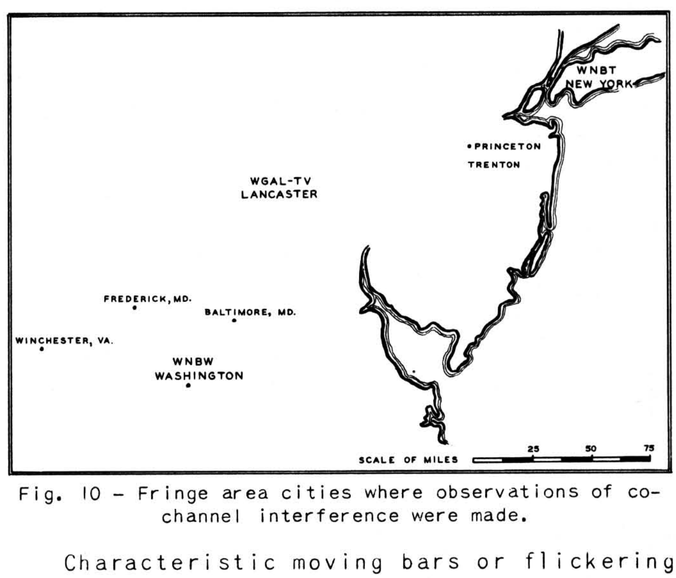

Fig. 10 - Fringe area cities where observations of co-channel interference were made.

Characteristic moving bars or flickering pictures were generally seen in the first case and fine bars in the second In every case where it was possible to see the fine bars of offset carrier operation the picture deterio-

TABLE I

Offset Carrier Conditions of Channel 4 Stations

Station	Effective Radiated Power kw	Antenna Height Above Average Terrain ft	Frequency kc
WRGB Schenectady N Y	18 25	832	67 250+10 5
WBZ-TV Boston Mass	14 3	547	67 250-10 5
WNBT New York	7 0	1280	67 250
WNBW Washington D C	20 5	330	67 250-10 5
WGAL-TV Lancaster Pa	1 0	260	67 250+10 5

TABLE II

Field Strength in Fringe Area Cities

	Length of Survey in Miles		Field Intensity Corrected to 30 ft Microvolts/Meter		
		Station	Median Field	Min	Max
Adams Mass *		WRGB			
Baltimore Md	13	WNBW	320	80	1200
Bridgeport Conn	3 2	WNBT	240	80	480
Fall River Mass	2 5	WBZ-TV	150	80	400
Frederick Md	2 2	WNBW	300	60	400
N Adams Mass *		WRGB			
Newburgh N Y	1 7	WNBT	120	40	280
Newport R I	0 8	WBZ-TV	90	60	140
Norwalk Conn	3 3	WNBT	500	240	1200
Peekskill, N Y	1 4	WNBT	1100	240	8000
Pittsfield Mass	2 1	WRGB-TV	320	100	520
Providence R I	5 4	WBZ-TV	120	40	400
Westport Conn	1 0	WNBT	590	240	1200
Worcester Mass	4 3	WBZ-TV	300	80	1400

*Field Strength too Low to be Usable

rated severely when the operation was shifted to the same nominal frequencies The change was conspicuous and was seen repeatedly The observers were thoroughly convinced by many field demonstrations of the value of offset carrier operation

It should be pointed out that the most objectionable thing about non-synchronous operation is either the movement of the bars or the overall changes in average brightness of the picture which appears as flicker when the frequency difference is between frame frequency and zero beat

During the field tour WNBT picture was received well in Peekskill Newburgh and Poughkeepsie except in depressions WRGB is evidently quite well eliminated from this area by the Catskill Mountains which are also responsible for poor reception in Catskill New York of WRGB Only a few miles east in Hudson New York WRGB was received well with little WNBT interference In and to the north and south of Catskill New York WNBT interference was very severe with either non-synchronous or offset operation In many places in this locality WNBT field strength exceeded WRGB In western Massachusetts WRGB was received well in Pittsfield and poorly in Great Barrington Adams and North Adams There was very little co-channel interference day or night probably because of the proximity of the Berkshires All of these towns are surrounded by large hills

Reception of WBZ-TV in Fitchburg Worcester Providence and Fall River was very good with only slight traces of fine bars due to co-channel interference with offset operation Severe interference from WNBT was observed in Newport at times but again the improvement due to offset carrier operation was apparent

WNBT was received well in Bridgeport and Norwalk There was interference from WBZ-TV in Norwalk and interference from both WBZ-TV and WRGB in Bridgeport However with offset carrier operation the pictures from WNBT were quite satisfactory Good pictures from WNBT over 110 miles across Long Island Sound were seen in Mystic Connecticut in spite of strong WBZ-TV interference

Very acceptable pictures were received from WNBT in Princeton and Trenton New Jersey throughout the summer Close scrutiny of the received picture revealed fine lines due to co-channel interference when offset carrier operation was used while non-synchronous operation usually resulted in a far from sat sfactory picture

The RCA Service Company reports that the Washington area co-channel interference problem has never been serious Fringe area cities include only Baltimore Annapolis and Frederick Maryland Baltimore television owners are discouraged from use of Channel 4 because it is noisy relative to Baltimore stations Therefore co-channel interference complaints have been very few In Frederick Maryland the Channel 4 pictures are very noisy with no complaints of co-channel interference Annapolis co-channel interference complaints have been greatly reduced by offset carrier operation

During the f eld tour no co-channel interference was seen in Baltimore but slight interference was observed a few miles north of Baltimore No co-channel interference was observed in Frederick or reported by the local RCA dealer

Severe co-channel interference was observed in Winchester Virginia where field strengths of WNBW are seldom over 300 microvolts per meter Again offset carrier operation proved beneficial

Observer Tests of Co-Channel Interference, in Collaboration with JTAC

In the research phases of the program on television carrier synchronization and on offset carrier operation observer data were obtained which showed the improvement of the two methods in terms of non-synchronous operation To be useful for allocation purposes the data must consist of ratios of desired-to-undesired signal for a given method of operation rather than of an improvement factor of one system over another The assembly of such data requires a large amount of equipment and observations by many observers under controlled conditions

In July 1949 the facilities and assistance of RCA Laboratories was made available to the Joint Technical Advisory Committee of the IRE and RMA in order to accumulate the desired data

The television system tested was the standard black-and-white signal using 60 fields and

TABLE III

Minimum ratios of desired RF signal to undesired RF signal as obtained for fifty per cent of the observers in the JTAC observer tests July 1949

	Type of Interference		
	Non-synchronous	Synchronous	10 5-kc Offset
Threshold ratio	54 5 db	40 0 db	36 0 db
Tolerable ratio	44 6 db	32 4 db	27 2 db

525 lines interlaced in the usual manner One hundred observers were used in the tests and threshold and tolerable ratios of desired-to-undesired signal were obtained for three conditions of operation 1 non-synchronous 2 synchronous and 3 10 5-kilocycle offset A complete description of the tests and delineation of the data is contained in Proceedings of JTAC Vol 4 September 26 1949 *Comments on The Proposed Allocations of Television Broadcast Services* A summary of the pertinent data is shown in Table III

These observer tests showed that synchronous operation was twelve decibels better than non-synchronous operation with respect to tolerable ratios of desired-to-undesired signal while 10 5-kilocycle offset was seventeen decibels better than non-synchronous operation The results of these extensive JTAC tests fully demonstrated the soundness of the philosophy behind the principle of offset carrier operation

Observer Tests of Co-Channel Interference with Color Television Systems

During the course of the hearings before the FCC in the fall of 1949 three color television systems were advanced namely the field-sequential system proposed by the Columbia Broadcasting System the line-sequential system of Color Television Inc and the dot-sequential system of the Radio Corporation of America in order to establish a television allocation plan which included one of the above color systems as well as the present monochrome system it will be necessary to have knowledge of the tolerable desired-to-undesired co-channel interference ratios for the color system in question as well as for the color system versus a standard monochrome system Experiments were begun in October 1949 at RCA Laboratories to obtain data on this important question for the three color systems under consideration

A Field-sequential color television system

In the standard monochrome te evision system with 525 lines 60 fields and 30 frames the line frequency is 15 750 cycles per second Fig 8 showed that the maximum improvement in the operation of the offset carrier system occurred at one-half of line frequency or 7 875 cycles per second A minimum improvement appeared at 15 750 cycles where beats occurred between the line frequency and the interfering carrier It may be recalled that an offset of 10 500 cycles was chosen as a compromise which also gave protection in a three-station plan The field-sequential system proposed by Columbia Broadcasting System has 405 lines 144 fields, and 72 frames Hence the line frequency is 29 160 cycles per second From previous experience with offset operation one quickly arrives at the conclusion that for maximum protection to this field-sequential system when the interfering signal is a similar field-sequential signal the carriers should be offset by 14 580 cycles and that little improvement would be achieved with the carriers offset 29 160 cycles It would seem reasonable to expect that 10 500 cycles and 21 000 cycles of offset carrier would be as effective for the field-sequential system as it was for standard monochrome

The Columbia Broadcasting System has proposed that a dual set of standards be established which would permit some stations to operate in color with the field-sequential system, while others continued to operate on the present monochrome standards. It seemed desirable to first investigate the interference conditions for this dual-standards condition.

An experiment was made with a small number of observers, using a field-sequential color signal as the desired signal and a standard black-and-white signal as the source of interference. Threshold (perceptible interference) ratios were determined as a function of difference between carrier frequencies. The results are shown in Fig. 11, with the least interference occurring at a separation of 14,580 cycles, one-half the line frequency of the desired picture, and with practically no improvement over non-synchronous operation at a separation of 29,160 cycles. It may be seen that 10,500 and 21,000 cycle offset is effective for a field-sequential signal. Since the interference is largely caused by beating of the undesired carrier with frequency components in the desired signal, it seems logical to conclude that the shape of a curve like that of Fig. 11 is largely determined by the characteristics of the desired signal and that the interfering signal may be field-sequential, line-sequential, dot-sequential, or standard black-and-white without changing the major interfering effects.

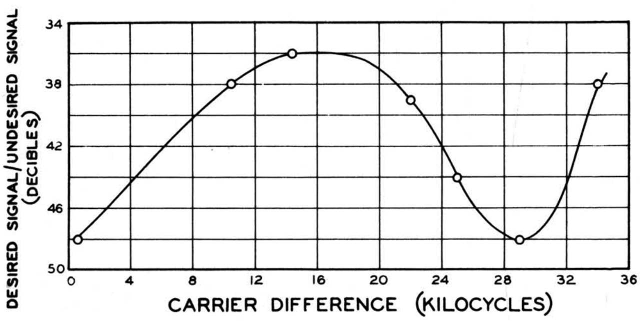

Fig. 11 - Ratio of desired signal to interfering signal for threshold perceptibility as a function of the difference between carrier frequencies. The desired signal is field-sequential color. The interfering signal is standard monochrome.

It may be observed that a limited number of observers found a ratio of 38 decibels to be just perceptible for this combination with carriers offset by 10.5 kilocycles, while in the JTAC tests with 100 observers the corresponding ratio with standard monochrome for both the desired and undesired signals was found to be 36 decibels.

A group of fifteen observers was then assembled for a series of tests to determine co-channel ratios for a variety of conditions. Because of the great amount of time necessary for these types of tests and because Fig. 11 showed the large improvement obtained by offset frequencies of 10.5 kilocycles, the remainder of the data was taken only for this condition of carriers.

The receiver used for observing the field-sequential pictures consisted of a modified chassis from an RCA-9T240 television receiver, a ten-inch tube with a picture size equivalent to a seven-inch tube and a magnifying lens to give the equivalent of a ten-inch picture. A rotating color wheel was included.

For observations where the desired picture was standard monochrome, an unmodified RCA-9T240 television receiver was used.

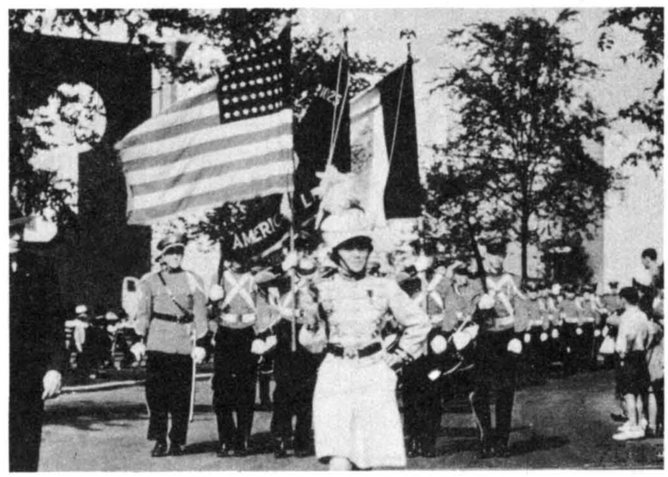

Fig. 12 - Black-and-white reproduction of the color slide used as the desired picture in the co-channel tests.

A color slide was used for the desired picture in all cases. This slide is reproduced in Fig. 12. The receivers were adjusted to achieve a high-light brightness of 15 foot-lamberts. The ambient room illumination was maintained at approximately four foot-candles.

Three signal combinations of the field-sequential system and standard monochrome were used to determine the threshold and the tolerable ratios. At the same time, ratios were obtained using a standard monochrome signal interfering with a standard monochrome signal. The results for this latter condition are shown as Curves 5, Fig. 14C and Fig. 15C, where Fig.

14 applies to threshold ratios and Fig 15 applies to tolerable ratios

Line Sequence B

Line ↓ / Field →	I	II	III	IV	V	VI	VII
1	RED		GREEN		BLUE		RED
2		GREEN		RED		BLUE	
3	GREEN		BLUE		RED		GREEN
4		BLUE		GREEN		RED	
5	BLUE		RED		GREEN		BLUE
6		RED		BLUE		GREEN	
7	RED		GREEN		BLUE		RED
8		GREEN		RED		BLUE	

Line Sequence C

Line ↓ / Field →	I	II	III	IV	V	VI	VII
1	RED		GREEN		RED		GREEN
2		BLUE		RED		BLUE	
3	GREEN		BLUE		GREEN		BLUE
4		RED		GREEN		RED	
5	BLUE		RED		BLUE		RED
6		GREEN		BLUE		GREEN	
7	RED		GREEN		RED		GREEN
8		BLUE		RED		BLUE	

Fig 13 - Line-scanning sequences of the line-sequential color system Sequence C was used to obtain Curves 8, Figs. 14C and 15C.

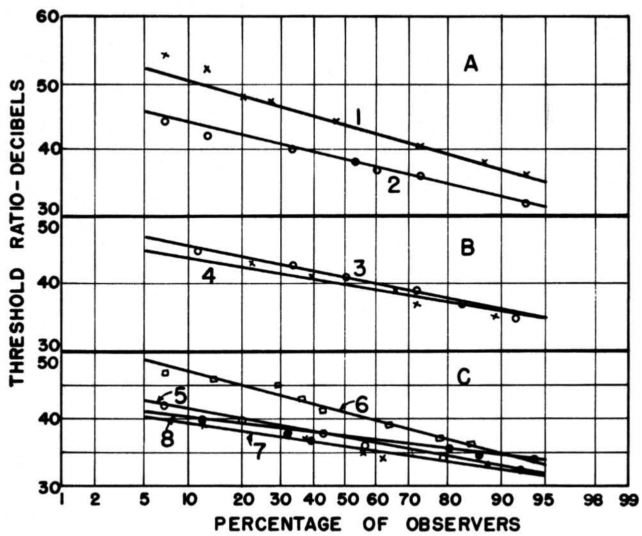

Fig 14 - Threshold values of co-channel interfering television signals, as a function of the percentage of observers requiring ratios greater than the ordinate values.

Data were taken with a field-sequential picture as the desired signal and with another field-sequential signal as the interfering signal The results are given by Curves 3 Figs 14B and 15B

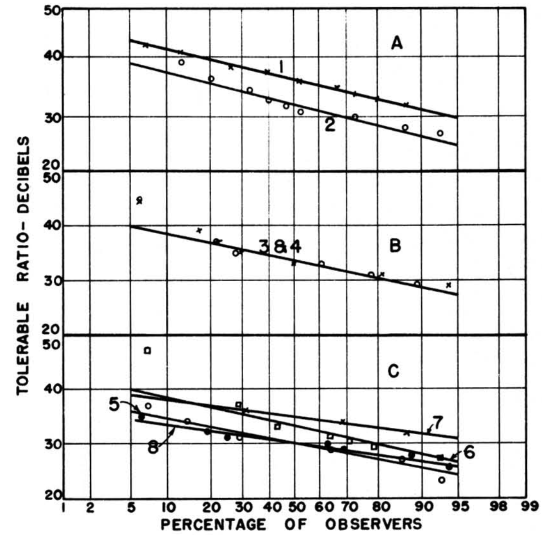

Fig 15 - Tolerable values of co-channel interfering television signals, as a function of the percentage of observers requiring ratios greater than the ordinate values

Next the desired signal continues to be the field-sequential picture viewed on a color receiver with standard monochrome signal as the interference Curves 4 Figs 14B and 15B depict the results of this test

Then a standard monochrome signal was viewed on the black-and-white receiver with a field-sequential signal as the source of interference with the ratios displayed as Curves 6 Figs 14C and 15C

Some difficulty was experienced when the field-sequential color picture was the desired signal since many of the observers complained of flicker in the desired picture and felt that it was difficult to separate this effect from the interfering effects

B Line-sequential color television system

The line-sequential system proposed by Color Television Inc uses the standards of normal monochrome as far as the number of lines and scanning fields A flying spot scanner developed by RCA to produce color signals of the simultaneous type was used as a picture source together with suitable circuitry to provide sequential line selection from first the red signal then the green signal and then the blue signal The receiver unit was similar to the one shown in Fig 10, Exhibit 209 *A Six-Megacycle Compatible High-Definition Color Television System* Radio Corporation of America

September 26 1949 The necessary circuits were added to the receiver to select the proper line sequence according to the transmitted synchronizing information The sampler normally present in the RCA color television receiver was not used and the scanning and video signals were applied to the red green and blue kinescopes in sequence The two line scanning sequences used in these tests are shown in Fig 13 When viewed on the color receiver scanning sequence B was seen to have very coarse line structure and flickered badly on small ob ects or on nearly horizontal lines Sequence C exhibited coarse line structure and had very poor vertical resolution The pictures for either sequence were so poor in character that to determine interference ratios appeared to be without meaning and no data were taken on this phase

Interference ratios were determined where the desired signal was a standard monochrome picture viewed on a standard television receiver with the line-sequential signal using sequence C, Fig 13 as the interfering signal The results are shown in Curves 8, Figs 14C and 15C

C Dot-sequential color television system

Interference ratios pertaining to the color television proposed by the Radio Corporation of America were next determined The direct-view receiver shown in Fig 16 Exhibit 209 *A Six-Megacycle Compatible High-Definition Color Television System* Radio Corporation of America September 26 1949 was used for observations In the first run the color picture was viewed on this receiver with a standard monochrome signal as the interference Curves 1, Figs 14A and 15A) Then the same color picture was viewed on the RCA-9T246 monochrome receiver shown in Fig 16 of Exhibit 209 again with a standard monochrome signal as the interference with the results shown in Curves 2 Figs 14A and 15A

A third test was made where a standard monochrome picture was received on a standard television receiver with the dot-sequential signal as the interfering signal Curves 7 14C and 15C)

The results of the observer tests on the three systems field-sequential line-sequential and dot-sequential are summarized in Table IV It may be seen that the tolerable ratios average five decibels higher than the corresponding ratio obtained in the previous JTAC tests using standard monochrome for both the desired and undesired signal This may be because only fifteen observers were used in these later tests on color television while one hundred observers were used in the JTAC tests

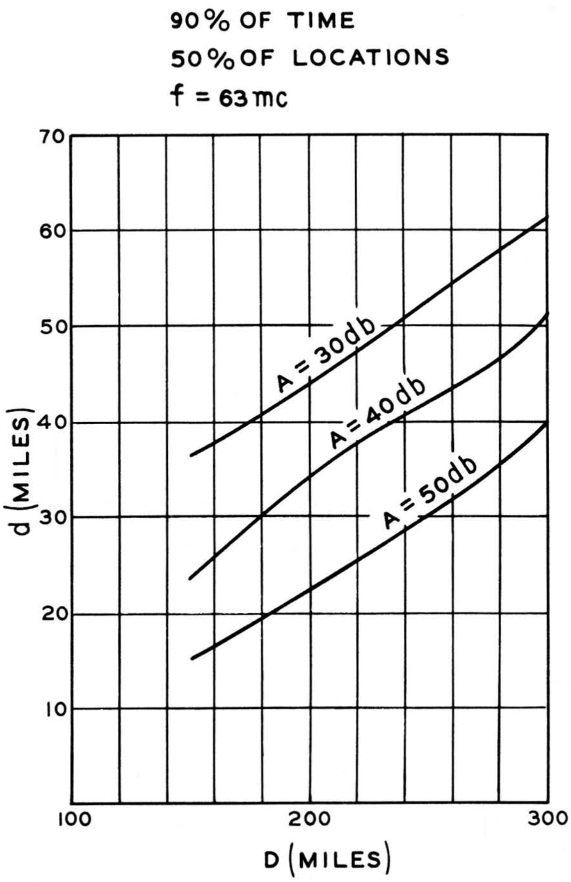

Fig 16 - Protection ratios A decibels existing at 50 per cent of the locations for 90 per cent of the time at a distance d miles from the desired station on a line toward the undesired station, with the stations separated D miles. The frequency is 63 megacycles.

The JTAC tests showed an average required ratio of approximately 45 decibels for monochrome pictures using non-synchronous operation of carriers The observer tests conducted by RCA on the color television systems as well as the JTAC observer tests both groups of tests with 10 5 kilocycles for the offset value, indicate that a ratio of 30 decibels is a very acceptable value in round numbers Figs 16, 17 18 and 19 have been prepared to assist the reader in relating these interference ratios in terms of co-channel station separa-

TABLE IV

Summary of Tolerable and Threshold Ratios of Desired to Undesired Co-Channel Television Signals with Carriers Offset 10 5 Kilocycles

Curve	Figures 14 & 15	Symbol	Desired Signal	Undesired Signal	Average ratio required by the observers (decibels) Threshold	Tolerable
1	A	×	Dot-sequential color viewed on color receiver	Standard monochrome	42 0	36 0
2	A	○	Dot-sequential color viewed on standard monochrome receiver	Standard monochrome	37 0	32 0
3	B	○	Field-sequential color viewed on color receiver	Field-sequential color	40 0	33 0
4	B	×	Field-sequential color viewed on color receiver	Standard monochrome	39 0	33.0
5	C	○	Standard monochrome viewed on standard monochrome receiver	Standard monochrome	36 0	29 0
6	C	□	Standard monochrome viewed on standard monochrome receiver	Field-sequential color	40 0	32 0
7	C	×	Standard monochrome viewed on standard monochrome receiver	Dot-sequential color	35 0	29 0
8	C	●	Standard monochrome viewed on standard monochrome receiver	Line-sequential color Sequence C	36 0	30 0
			Standard monochrome viewed on standard monochrome receiver (JTAC results)	Standard monochrome	36 0	27 2

tion These curves were prepared by methods described in the report of the Ad Hoc Committee *

In the above figures only the effects on a line oining the desired station with the undesired station are considered D is the distance between the two transmitters d is the distance from the desired station to the receiving point along the line between the stations and A is the ratio in decibels of the desired to the undesired signal All four figures relate to the probability of the particular ratio A occurring at 50 per cent of the locations for 90 per cent of the time Figs 16 and 17 are estimates for a frequency of 63 megacycles and may be considered to apply for Channels 2 to 6 inclusive while Figs 18 and 19 are for the frequency of 195 megacycles and may be considered to apply for Channels 7 to 13, inclusive

Report of the Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning the Television and Frequency Modulation Broadcasting Services in the Frequency Range Between 50 and 250 Mc, Vol I, May, 1949

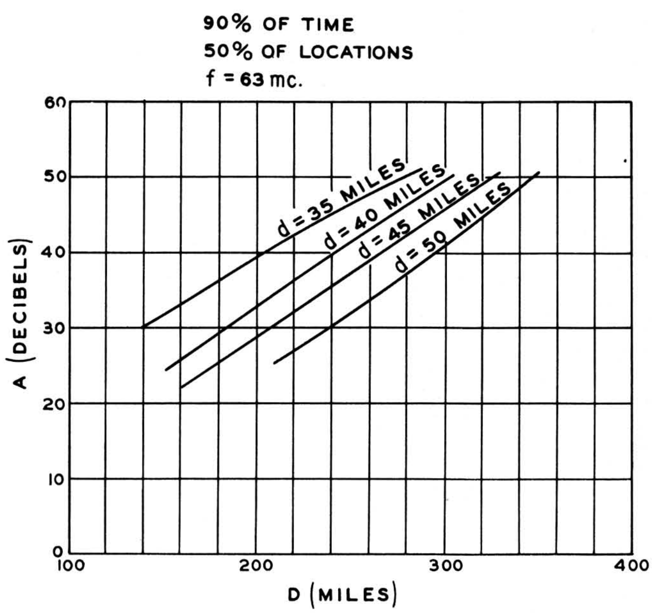

Fig 17 - Protection ratios A decibels existing at 50 per cent of the locations for 90 per cent of the time at a distance d miles from the desired station on a line toward the undesired station, with the stations separated D miles. The frequency is 63 megacycles

The reader may wish to draw conclusions of his own from these figures together with a number of interference ratios As an example of the type of information which may be readily extracted from these figures we may assume a separation of two co-channel stations of 200 miles If the stations are operating with offset carriers of 10 5 kilocycles and a ratio A of 30 decibels is assumed, Fig 16 shows that this protection value holds for 50 per cent of the locations and 90 per cent of the time out to a service radius of 43 5 miles on the line toward the interfering station If the two stations are operating non-synchronously, the protected distance is shrunk to 28 miles if an interference ratio of 45 decibels is assumed for the non-synchronous operation On the other hand it may be noticed that if the stations are non-synchronous and it is desired to give the same order of protection for the non-synchronous operation as for offset operation the stations should be separated by a distance of 300 miles The above observations apply to a frequency of 63 megacycles or to the five lower television channels

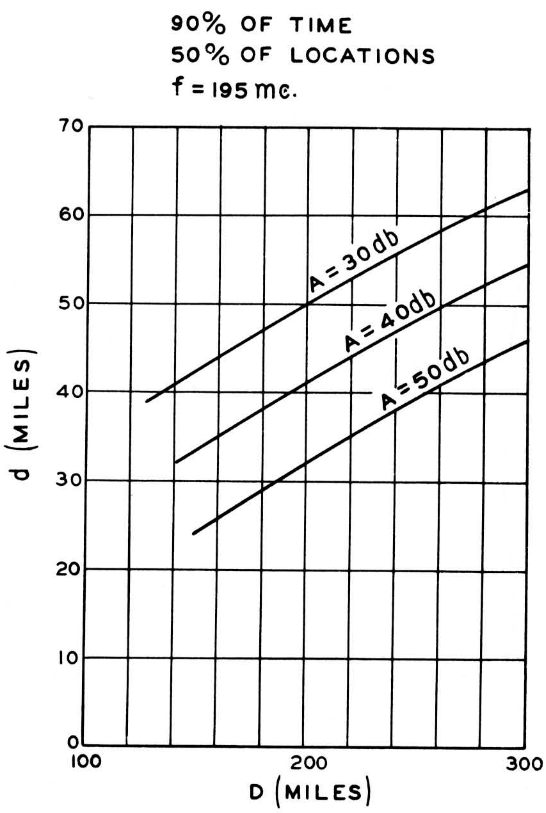

Fig 18 - Protection ratios A decibels existing at 50 per cent of the locations for 90 per cent of the time at a distance d miles from the desired station on a line toward the undesired station, with the stations separated D miles. The frequency is 195 megacycles.

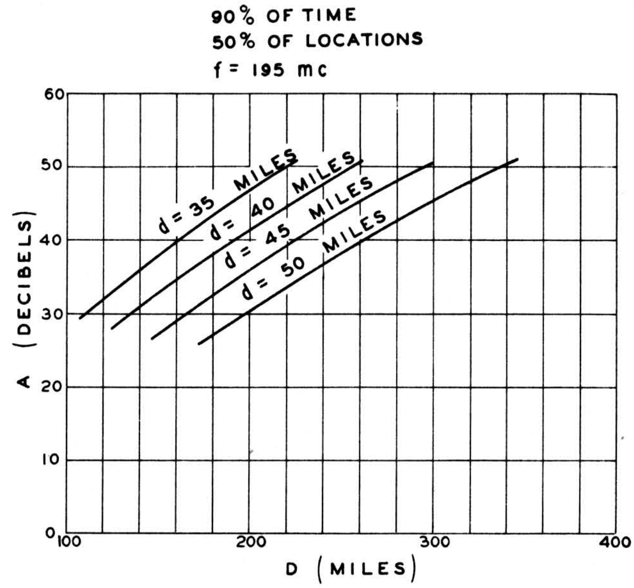

Fig 19 - Protection ratios A decibels existing at 50 per cent of the locations for 90 per cent of the time at a distance d miles from the desired station on a line toward the undesired station, with the stations separated D miles. The frequency is 195 megacycles.

A similar inspection of Fig 18 reveals that at a frequency of 195 megacycles or the upper seven television channels) offset carrier operation gives protection to a distance of 50 miles, with a protection ratio of 30 decibels and a station separation of 200 miles With the same station separation, a protection ratio of 45 decibels non-synchronous operation) exists to a distance of 36 miles Again if the stations are non-synchronous, the station separation must be 300 miles to secure a protection ratio of 45 decibels out to a distance of 50 miles

A rough rule to apply seems to be as follows 1 with a fixed separation of stations, offset carrier operation extends the service radius in the direction of the undesired station by about 50 per cent over non-synchronous operation or 2, for a fixed protected radius, non-synchronous operation requires an increase in station separation of approximately 50 per cent over the separation required for offset carrier operation

Conclusion

Television carrier synchronization has been demonstrated to be extremely advantageous in reducing co-channel television interference Offset carrier operation has been shown to be superior in results and more economical to apply than television carrier synchronization

Extensive application of offset carrier operation to existing television stations, many observations in a mobile laboratory and in homes, and the JTAC observer tests have fully demonstrated a remarkable improvement in television service when compared to conventional non-synchronous operation

Limited observer tests conducted by RCA demonstrate that offset carrier operation is equally applicable to standard monochrome transmissions, the dot-sequential color television system of RCA and the field-sequential color television system of CBS Limited data indicate that the line-sequential color television system of CTI interferes with a standard monochrome signal to the same extent as an interfering standard monochrome signal No observer tests using a line-sequential signal as the desired picture were made for the reasons stated earlier

It is recommended that for either standard monochrome or for color transmissions the amount of carrier offset shall be 10 5 kilocycles, or in a three-station combination one station shall remain on the assigned frequency the second station shall be offset 10 5 kilocycles above the first, while the third shall be offset 10 5 kilocycles below the first