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REDUCTION OF CO-CHANNEL TELEVISION INTERFERENCE BY PRECISE FREQUENCY CONTROL OF TELEVISION PICTURE CARRIERS

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Approved

Stuart Wm Seeley

Reduction of Co-Channel Television Interference by Precise Frequency Control of Television Picture Carriers

The visibility of co-channel interference has maxima and minima at carrier offset frequencies which are multiples of frame frequency. Subjective tests at RCA Laboratories determined the reduction in visibility of co-channel interference which might be achieved by precise carrier frequency control and established the stability requirements on the carrier frequency.

Precise-frequency sources have been developed which are believed adequate for the requirements. Experimental equipment was installed at WRCA-TV (New York) and WRC-TV (Washington, D.C.). Field tests were conducted to verify the laboratory relationships previously obtained.

Introduction

Offset-carrier operation of television stations to reduce co-channel interference has been in use for a number of years. An observer of co-channel interference views the desired picture through a superimposed pattern of regularly spaced horizontal bars of light and shade. The frequency of the bars corresponds to the difference frequency of the two picture carriers. The visibility of the bars as a function of the difference frequency varies in a cyclical manner with alternating minima and maxima having a separation of 30 cycles. This is illustrated[1] in Fig. 1; the curve is only an illustrative sketch. One can see that in addition to the rapid variations of visibility the minima are a function of the horizontal line frequency, with the least minima occurring at approximately odd multiples of half horizontal line frequency.

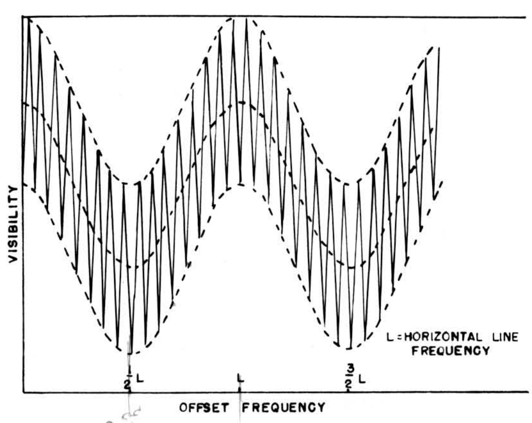

Fig. 1 – Visibility of co-channel interference as a function of the offset frequency.

An allocation plan for television stations cannot utilize the optimum offsets corresponding to the least minima since two stations in a group of three stations would be offset by an even multiple of half line frequency which results in maximum interference. However, stations may be offset by approximately 10 kilocycles with approximately equal though somewhat reduced benefit to each. The offset of 10 kilocycles adopted by the Federal Communications Commission was not specified with a view of taking advantage of one of the minima near 10 kilocycles. In fact, the data[2] taken at that time, to determine the offset frequency and tolerable ratios for an allocation plan, were taken at one of the points of maximum visibility near 10.5 kilocycles. This was done because presently used broadcast crystals do not have the required stability for holding the frequency offset within a few cycles of the optimum. At present, the FCC rules specify a carrier frequency accuracy of ± 1000 cycles.

Recent developments in crystal techniques and oscillator circuits made it worthwhile to investigate the reduction in the visibility of co-channel interference through the use of precise picture carrier frequency control; that is, to take advantage of one of the minima around 10 kilocycles.

Advantage

It was known that the minima of visibility occurred when the frequency difference between the carriers was an even multiple of the frame frequency. Since the frame frequency of color television is 29.97 cycles, a multiplier of 334 yields 10,010 cycles as an appropriate offset frequency. The solid line in Fig. 2 shows the results of subjective tests made for offset frequencies around 10,010 cycles. The data shown is what an average observer considered a tolerable ratio in decibels of the desired carrier to the undesired carrier as a function of the offset frequency. A minimum tolerable ratio of *21 db* is obtained at 10,010 cycles, and a maximum of *33 db* at 10,035 cycles; thus there is an improvement of *12 db*. An inspection of the minimum shows that a ± 5 cycle variation in the offset frequency would have little effect on the tolerable ratio.

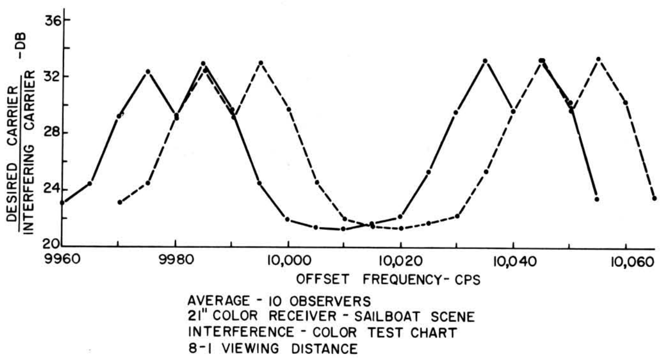

Fig. 2 – Carrier ratio for tolerable interference.

If three stations were operating on the same channel, station *A* would be assigned a carrier frequency F_0, station *B* might be assigned a frequency F_0-*10,010*, while station *C* might be assigned a frequency F_0+*10,010*. Then stations *B* and *C* would differ in frequency by *20,020* cycles. This frequency difference is also an even multiple of frame frequency. The solid line in Fig. 3 shows the results of subjective tests made for frequency differences around *20,020* cycles. Note that this offset is no more desirable than the previous offset of *10,010* cycles, as they both have the same tolerable ratio of *21 db* for the minimum. However, the maximum is *39 db* and there is an improvement of *18 db*. Inspection of the minimum again indicates that a stability of ± *5* cycles in the offset frequency has little effect on the tolerable ratio.

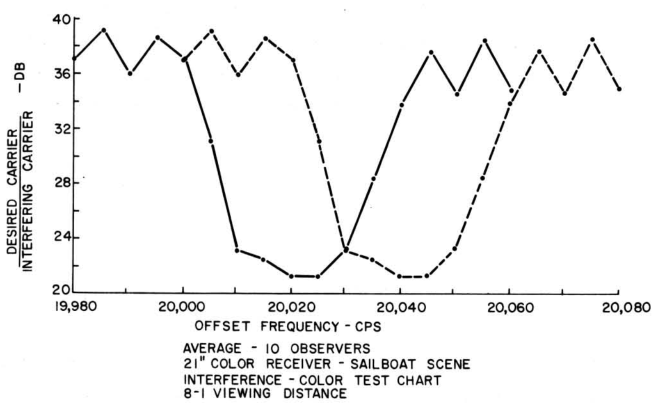

Fig. 3 – Carrier ratio for tolerable interference.

The improvements of *12 db* for *10,010* cycles and *18 db* for *20,020* cycles are from the extreme maximum peak of the tolerable ratio curve to the minimum of the curve. The precise carrier control system does not give these magnitudes of improvement over the presently used system in the sense that the present system is not at all times at the offset frequency which produces maximum visibility. The present frequency difference of two picture carriers changes with time. Thus, at times the difference frequency may be at the value for minimum visibility and at other times at the value for maximum visibility, and covers all points in between these two.

Present Monochrome Transmissions

It would be well to discuss the effects on the visibility of co-channel interference for black-and-white transmissions when the offset frequency chosen is the one to produce the maximum improvement for color transmissions. At the present time, the standards for color television prescribe a frame frequency of *29.97* cycles, with an accuracy of approximately three parts per million. However, for black-and-white television, there is only a nominal value of *30* cycles specified, with no tight control on stability. If a value of *30* cycles is assumed, multiplication by *334* gives an offset frequency of *10,020* cycles, and a value of *20,040* cycles between stations *B* and *C* in a three station arrangement. Referring to the dashed line in Fig. 3 which is the curve for a *20,040* cycle offset and is the optimum offset frequency for transmissions using a frame frequency of *30* cycles, one can see that operating at an offset frequency of *20,020* cycles (the optimum offset frequency for transmissions using a frame frequency of *29.97* cycles) produces almost maximum visibility of the interference. Referring to the dashed line in Fig. 2 which is the curve for a *10,020* cycle offset (the optimum offset for transmissions using a frame frequency of *30* cycles) one sees that operating at an offset frequency of *10,010* cycles produces almost minimum visibility of the interference for a frame frequency of either *30* cycles or *29.97* cycles.

Thus, for the plan of precise control to be completely and properly used, it is necessary to use the same frame rate, controlled with the same accuracy, for all television transmissions, color or black-and-white. Each television station would then require in addition to the stable carrier frequency, an accurate control for all sync generators.

Stability Requirements

The arbitrary stability requirement of ± *5* cycles on the offset frequency imposes a relative stability on the picture carriers for the low VHF channels of plus or minus three parts per hundred million. The high VHF channels require a relative stability of plus or minus one part per hundred million. Two oscillators having this stability were constructed for NBC's Channel 4 stations, WRCA-TV in New York and WRC-TV in Washington, D.C.

Oscillators

The oscillators are similar to those published by P. G. Sulzer.[3] Fig. 4 shows a simplified diagram of the oscillator. The oscillator is extremely stable; its stability is essentially independent of circuit changes and depends almost entirely on how well the natural resonant frequency of the crystal can be maintained. Extreme stability is produced by using the crystal in an oscillator circuit and also in a bridge circuit.[4] The crystal is used in the bridge circuit as a means of indicating when a phase shift has occurred in the oscillator circuit due to changes in components.

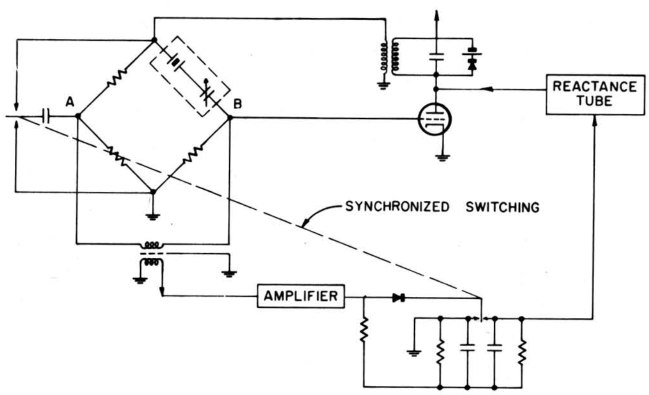

Fig. 4 – Crystal oscillator.

The plate circuit has an amplitude limiter to maintain constant current through the crystal. Feedback for the oscillator is obtained between grid and ground across one of the resistors in the bridge circuit. When the crystal is at its natural series resonant frequency the bridge is balanced. If the crystal is operating at a frequency slightly different than its resonant frequency, to compensate for changes in phase shift around the oscillating loop, an output is obtained from the bridge. Information as to whether the crystal is operating above or below its natural resonant frequency is obtained by switching the small capacitor across one arm of the bridge and then the other arm. When the bridge is balanced it has equal outputs for each position of the capacitor. If the crystal is operating on the high side of its natural resonant frequency the bridge output will be higher when the capacitor is across the upper arm than when it is across the lower arm. The output of the bridge is maximum for the capacitor across the lower arm if the crystal is operating below its series resonant frequency. The circuit for detecting the amplified output signal of the bridge circuit has a switch which is synchronized with the switching of the capacitor across the arms of the bridge. This switch connects a different *R-C* circuit into the detection circuit for each position of the bridge capacitor. The voltages across the *R-C* cicruits add with respect to ground and are applied to a reactance tube which corrects the oscillator circuit.

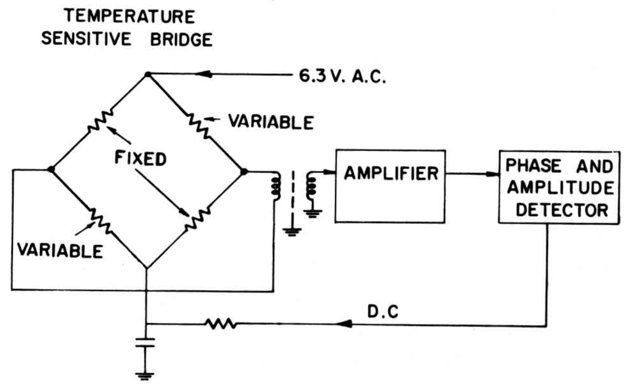

Fig. 5 – Method of controlling the temperature of the crystal oven.

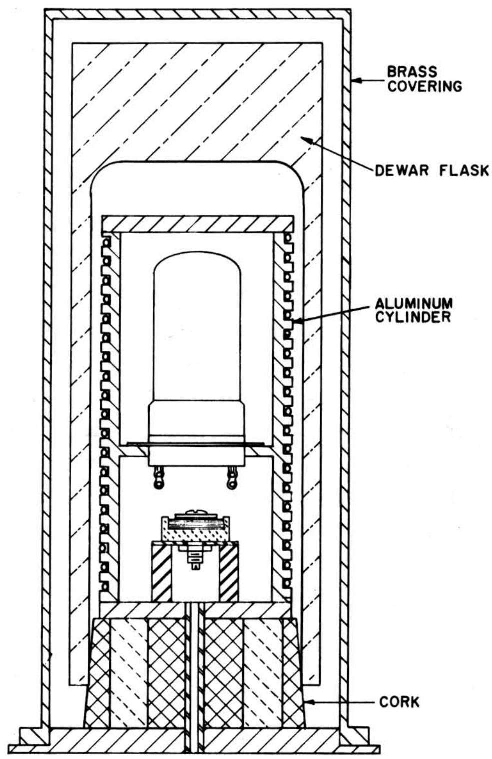

Fig. 6 – Crystal oven.

The method of maintaining the crystal at a constant temperature is shown in Fig. 5. A temperature sensitive bridge is used to supply the necessary heat to the oven, and to detect temperature changes within the oven. Two arms of the bridge (labeled FIXED) have resistances which do not change with temperature. The other two arms (labeled VARIABLE) change resistance with temperature.

At the operating temperature of the crystal the resistances are made equal. An a-c voltage is applied across the bridge. If the ambient temperature decreases, causing the winding temperature to decrease, a *60* cycle output is obtained from the bridge. The output is amplified and detected; the detector provides a d-c current to the bridge and increases the heat into the oven. The detector is also phase sensitive to prevent the bridge from operating at a temperature above the balance temperature; its output is zero if the bridge output signal changes phase by 180 degrees.

A cross-section of the crystal oven is shown in Fig. 6. The crystal and the capacitor in series with it are mounted inside an aluminum cylinder. The ends of the cylinder are closed by aluminum caps. The temperature sensitive bridge wire is wound in the slots on the outer wall of the aluminum cylinder. This aluminum unit is mounted on a cork and enclosed by a Dewar flask. A brass covering encloses the entire unit.

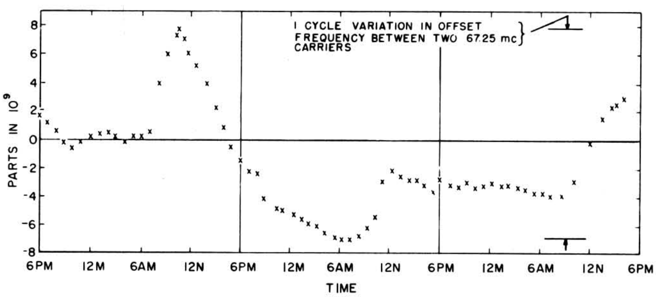

Fig. 7 – Relative stability of the two frequency units.

The relative stability of the two frequency units was measured in the laboratory for a 70-hour period, and the results are given in Fig. 7. Frequency variations over this period were ± 7 parts in 10^9 and were due to an ambient temperature change of *10* degrees *C*. It is known that the units changed frequency in the opposite direction with increasing temperature; thus the frequency difference between them increases with increasing temperature. The stability is better than required, as the marks on the right of the drawing indicate a one cycle variation in the offset frequency between two Channel 4 carriers.

Field Tests

Unit No. 1 was installed at WRCA-TV, and the relative stability of WRCA-TV's picture carrier, as received at the Princeton Laboratories, and Unit No. 2 located at Princeton, was measured over a 48-hour period. Fig. 8 gives the measurements made every hour that WRCA-TV's carrier was on the air. There was a change of ± 0.2 of a cycle in the offset frequency; this is a relative stability of ± 3 parts in 10^9.

With the equipment being tested it was convenient to use an offset frequency of *9,950* cycles. This is the first even multiple of frame frequency (*29.97* cycles) below *10,010* cycles. Subjective tests in the laboratory showed that this offset frequency would reduce the visibility of the co-channel interference by the same amount as *10,010* cycles.

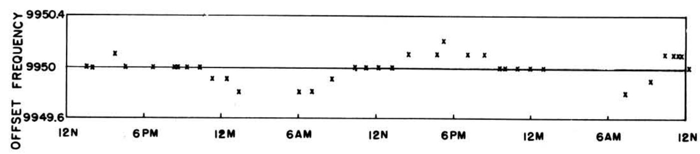

Fig. 8 – 48 hour stability test.

The Washington unit was then installed at WRC-TV and the offset frequency checked by the method shown in Fig. 9. This shows WRCA-TV in New York with the picture transmitter, driven by the precise frequency source, transmitting a signal to WRC-TV at Washington. The procedure is to take the Washington transmitter off the air, and receive the New York signal on the Washington transmitting antenna. A special receiver was used to compare the New York carrier with the output of Unit No. 2 (the precise frequency source in Washington). The output signal of the special receiver is such that its frequency is the offset frequency between the New York and Washington picture carriers. This sine wave output of the receiver is applied to the vertical plates of the oscilloscope. The oscilloscope's sweep circuits are triggered by vertical drive obtained from a sync generator which is locked to a color subcarrier generator. It is then possible to adjust the precise frequency source to an exact even multiple of frame frequency by adjusting for a stationary sine wave pattern on the oscilloscope. The offset is then a multiple of field frequency and thus an even multiple of frame frequency.

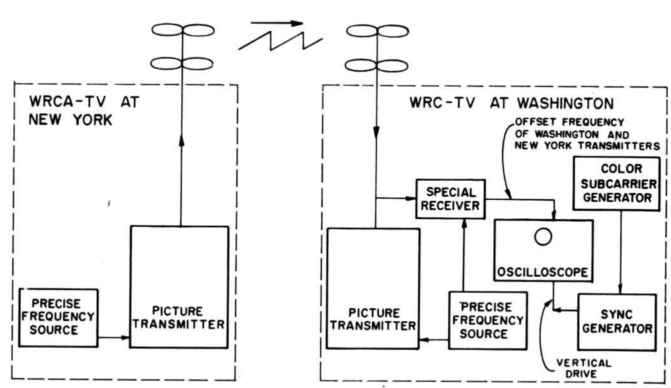

Fig. 9 – Method of setting Washington picture carrier to correct offset frequency.

Figure 10 shows the special receiver used at Washington for setting the offset frequency. A *10 kc* amplifier is shown; the tuning of this was changed to *9,950* cycles. The receiver has a sensitivity of *10* millimicrovolts and

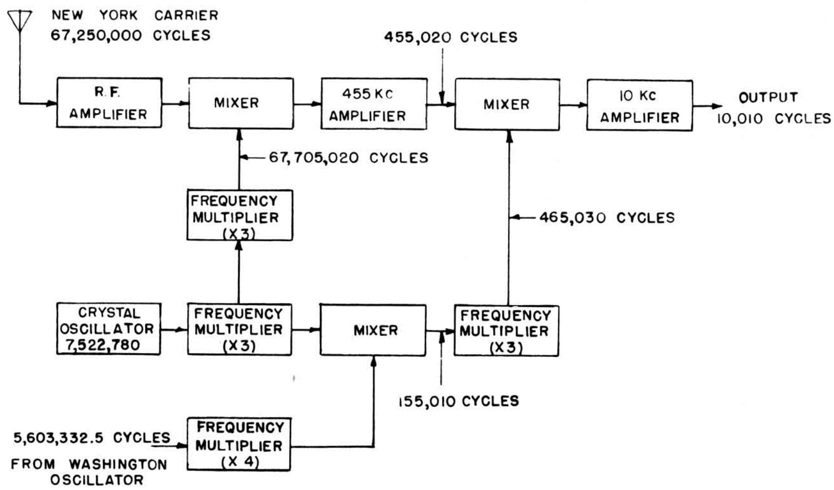

Fig. 10 – Washington receiver.

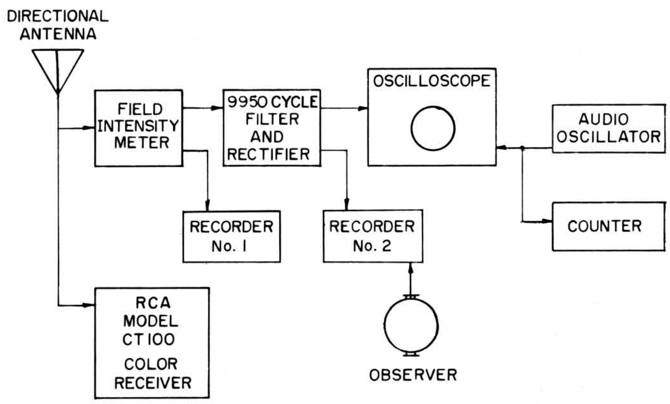

Fig. 11 – Field truck equipment.

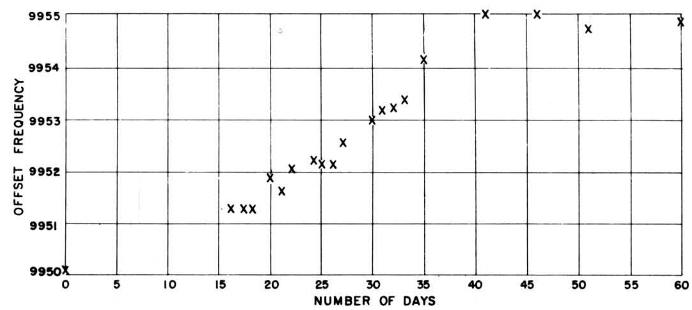

Fig. 12 – Change in offset frequency after units were installed in TV stations.

a bandwidth of *60* cycles at the final output frequency. A high gain is obtained by the use of a *455 kc* amplifier; the frequency variations of the local oscillator are removed by the double mixing process. Frequency multiplication factors were such as to prevent the generation of unwanted components at the receiver input frequency and at *455 kc.*

For observations of the improvement obtainable with the precise frequency sources, an oscillator was installed at WRC-TV which was frequency controlled by the Washington precise frequency source at such a frequency that the carrier produced by it was *90* cycles higher in frequency than the carrier produced by the precise source. Thus the carrier which was higher by *90* cycles produced an offset frequency equal to an odd multiple (*329*) of the frame frequency or *9,860* cycles. During color programs the transmitter operator at Washington switched the transmitter to each of these frequency sources at predetermined time intervals. The results of the previous laboratory subjective tests indicated the offset of *9,950* cycles should produce the minimum visibility of co-channel interference, and the offset of *9,860* cycles would produce nearly maximum visibility of the interference.

Since installation of the units field tests have been made over a period of six weeks including sixteen color programs. These programs were observed at several homes and at the laboratories in Princeton and at one home in Seaside Park, N. J. Princeton is approximately *40* miles from New York and *150* miles from Washington. Seaside Park is *55* miles from New York and *165* miles from Washington. All of the shows were not observed at all of the viewing locations, but when observed and co-channel interference was noticeable, a definite improvement was reported by all observers for the offset frequency equal to an even multiple of frame frequency.

Also, for purposes of field testing a truck was equipped as shown in Fig. 11. The field intensity meter was tuned to the Channel 4 picture carrier from New York, and its field strength recorded on recorder No. 1. At the audio output of the field intensity meter the output signal contained the *9,950* cycle beat between the Washington and New York picture carriers. A filter selected the *9,950* cycle component and applied it to the vertical plates of the oscilloscope. The output signal of the filter was also rectified and the d-c current applied to recorder No. 2, to produce a record of the beat amplitude. The output of the audio oscillator was used to trigger the sweep circuits of the oscilloscope. A counter measured the frequency of the audio oscillator. An operator adjusted the audio oscillator to maintain a stationary sine wave pattern on the oscilloscope for the 10 seconds required by the counter to measure the frequency of the audio oscillator. It was possible to repeat the frequency measurements to plus or minus one tenth of a cycle. With this setup the effects of propagation on the frequency stability of the offset frequency could be observed. Spot checks were made at various times at different locations and at no time were frequency changes observed which would cause a reduction in the improvement obtainable by precise picture carrier control.

The offset frequency was measured by the previously described technique over a period of 60 days. A frequency change of 5 cycles was measured; the results are given in Fig. 12. No adjustments of any kind were made on either of the frequency control units during this period. At the end of the sixty day period the crystal bridge in each unit was balanced and the offset frequency reset to 9,948 cycles. Since this adjustment the frequency has changed 0.6 of a cycle, in two weeks.

The field truck was also equipped with a color receiver which was used for observations at various locations and also for subjective tests. Tests were made on six observers to obtain an improvement factor comparing transmissions using an offset frequency at an even multiple of color frame frequency (9,950 cycles) to transmissions using an offset frequency at an odd multiple of color frame frequency (9,860 cycles). Black-and-white transmissions were used for the tests as they were available when desired, and if the frame frequency was adequate to give an improvement, a greater improvement would be expected at a frame frequency of 29.97 cycles. Also, for a limited number of transmissions it would be known whether the 30 cycle frame frequency was such as to produce an improvement. The tests covered only two afternoons of transmissions. However, the program material included studio programs, film, and remote pickups. The entire test period for one observer and part of the test period for another observer were made on the Republican Convention program originating in San Francisco.

The persons tested observed 15 minutes of program for each offset frequency. Some observers were tested for more than one period of each condition. The observer was seated at a viewing distance equal to eight times picture height, and instructed to push a button supplied to him,

OBSERVER	% OF TIME 9860 CYCLES	% OF TIME 9950 CYCLES
A	44.4	14.8
B	89.5	24.2
C	52	2.4
D	43.5	0
E	45.5	3.2
F	89	11.4
AVERAGE	61	9

Fig. 13 – Percent of time co-channel interference was observed for a 9860 cycle offset and for a 9950 cycle offset.

if he saw the bars due to the interference. This produced a record, on the recording of the beat amplitude, as to the time when each observer could see the co-channel interference. This test did not measure the tolerable ratio, but simply indicates if an improvement is obtained for the 9,950 cycle offset. It is a visual acuity and perception test and depends upon the conditions of the experiment.

For a number of reasons a good way of using the data is simply to determine the percentage of time the observer saw the interference for each of the offset frequencies. The results are given in Fig. 13. Each observer saw a definite improvement for 9,950 cycles, compared to 9,860 cycles. The average observer saw the interference in the picture 61 percent of the time for the offset of 9,860 cycles, compared to only 9 percent for 9,950 cycles.

As long as synchronizing signal generators for monochrome transmissions are locked to the power line, the improvement obtained with black-and-white pictures will be a function of the stability of the power line frequency in the areas involved. As previously indicated, in a three-station arrangement no improvement can be expected between the two stations that are nominally 20,000 cycles apart as long as the power line is the sync generator reference.

Several black-and-white broadcasts were observed for an hour at different locations. For all locations and broadcasts an improvement was observed.

For this plan of precise picture carrier frequency control to be universally used, and to obtain the optimum improvements, it is necessary on black-and-white transmissions to lock the sync generator to the color subcarrier generator, or some equivalent source, to produce a frame frequency of 29.97 cycles of adequate stability.

W. L. Behrend

Appendix

The desirability of making additional subjective tests to check the expected improvement when using precise carrier-frequency control has been recognized. It also was brought to our attention that another group had simulated the effect of precise control and, using a test procedure different from ours, had found a somewhat different improvement factor. For these reasons a new series of tests were run using our precise off-set laboratory system (two modulated picture carriers) and a test procedure similar to that of the other group.

A set-up was made to measure the improvement by the "method of equality." This means that the observer could change the viewed scene back-and-forth between a reference picture (with a fixed interference level) and the same scene with the interference at a different offset frequency and an adjustable interference level. Measurements were made by varying the amount of interference in the test picture until the viewer indicated no preference for either picture. The improvement is then expressed as the difference in decibels between the signal levels of the two interfering signals.

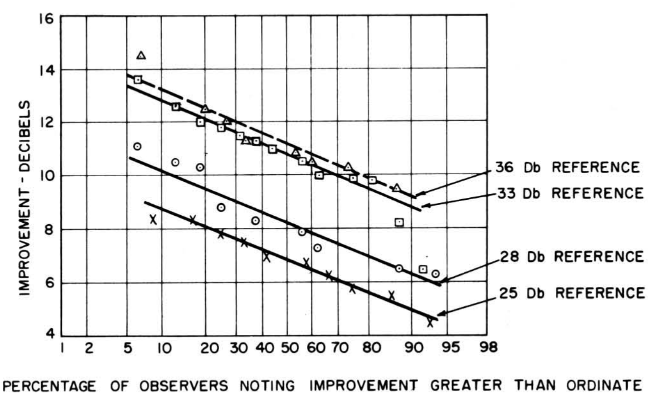

Fig. 14 – Reduction in visibility of co-channel interference for a 10,010-cycle offset frequency compared to a 9985-cycle offset. The desired picture was the sailboat scene. The interfering picture was color bars.

The tests were made using four different receivers. These were an RCA 21-inch* color receiver; and RCA 17-inch black-and-white set; and two other black-and-white receivers: a 17-inch and a 21-inch. Observers were tested for off-set frequencies of 10,010 cycles and 20,020 cycles; with slides (the *sailboat scene,* as used for previous tests, as the desired picture and color bars as the interfering picture) and with off-the-air moving pictures; and for several reference ratios. The results are summarized in Figs. 14, 15, 16, and 17. The original test results given in Figs. 2 and 3 show a maximum ratio of 33 db required at 9985 cycles and a minimum ratio of 21.5 db at 10,010 cycles to give an improvement of 11.5 db. This checks remarkably well with the 10.8 db improvement measured for 50 per cent of the observers when a 33 db reference was used with this new test method. The 20 kc data shows a similarly close check between the two methods. It is quite evident from the data given that the improvement measured will be a function of the quality of the reference picture.

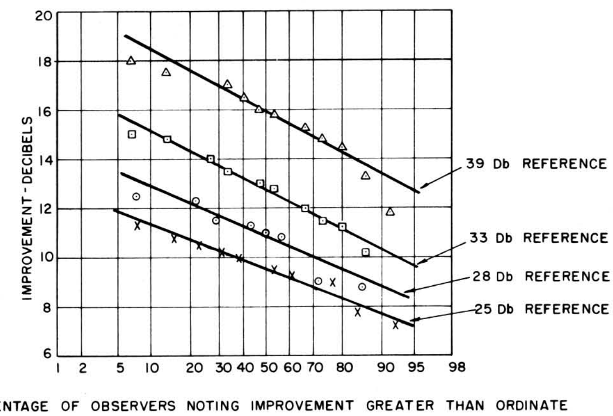

Fig. 15 – Reduction in visibility of co-channel interference for a 20,020-cycle offset frequency compared to a 19,995-cycle offset. The desired picture was the sailboat scene. The interfering picture was color bars.

As an example, to show how the tests were conducted, consider a 28 db reference level at an offset of 9,985 cycles. The observer was seated at a viewing distance of eight times picture height from four different television receivers. Tests were made on each receiver and the order in which the receivers were viewed by the observers was random. The observer was given a switch. For one position of the switch the observer viewed a picture which had a ratio of desired signal to undesired signal of 28 db with the undesired carrier offset by 9,985 cycles. The other position of the switch produced a picture with the interference at a 10,010 cycle offset and a ratio of desired signal to undesired signal that could be varied by the person conducting the test. The observer viewed each picture as often as desired and the level of the interference at the 10,010 cycle offset was changed until the observer stated that the two pictures were equal. This procedure was repeated for each of the four television receivers. The improvement was then taken as the difference between 28 db and the signal ratio obtained at the 10,010 cycle offset.

Using still pictures, twelve to fifteen observers were tested for each condition shown in Figs. 14 and 15. Eight to ten observers were used for each condition shown in Figs. 16 and 17 which utilized off-the-air moving pictures.

It is interesting to examine the results obtained with the different sets. Although individual observers sometimes found differences between sets, when all observers

*Diagonal measurement.

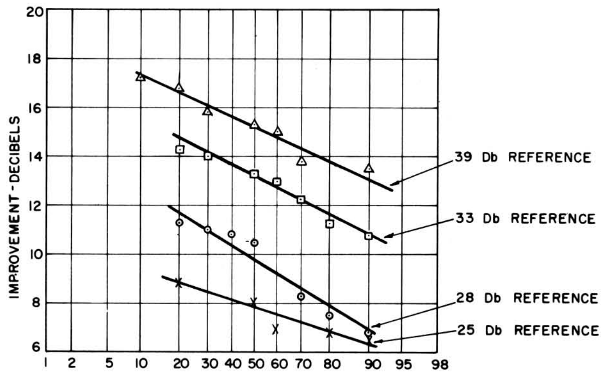

Fig. 16 – Reduction in visibility of co-channel interference for a 20,020-cycle offset frequency compared to a 19,995-cycle offset. Desired picture was color program material from a commercial TV station. The interfering picture was program material from a commercial TV station.

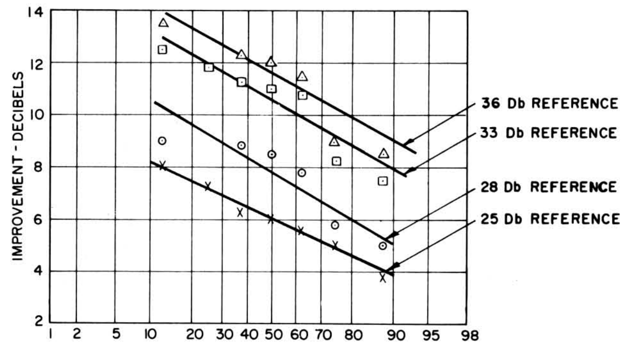

Fig. 17 – Reduction in visibility of co-channel interference for a 10,010-cycle offset frequency compared to a 9,985-cycle offset. Desired picture was color program material from a commercial TV station. The interfering picture was program material from a commercial TV station.

were averaged, the differences were small. For the 10 kc tests, each set gave an improvement that was within 1 db of the others. At the 20 kc offset, the difference between sets varied from less than 1 db to just over 3 db. For these 20 kc tests the color receiver tended to give about 1 db less improvement than the black-and-white sets.

From the data presented it is evident that the *anticipated improvement* due to the use of precise frequency control will be a function of the interference level considered tolerable with the present system. Two relatively independent tests of improvement have now been made and the two methods have been found to check. An examination of Figs. 14, 15, 16, and 17 shows that the improvement decreases as the ratio of the desired signal to the undesired signal decreases. The reduction in improvement is probably due to the observer becoming aware of the interfering picture in the background. A consideration of the data presented in this bulletin and past experience indicates that a tolerable ratio of 20 db is satisfactory when precise carrier frequency control is used.

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