"Split Channels" for More

Results obtained from field tests conducted in Syracuse, N. Y. show how an can be made to operate on adjacent channels when index of modulation and

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AS soon as a radio service receives public acceptance, the inevitable problem of too many users for too few channels arises. In the 25-50 MC and 152-174 MC bands the number of new users seeking authorization and the interference already occurring due to the sharing of channels by users in the same locality, such as taxi channels, make it imperative to seek an answer to the problem of how to increase utilization of these bands.

The solutions that have been suggested fall into three general groups or combinations of them.

1. Channel sharing using geographical separation to prevent interference.
2. Use of a system of modulation requiring less bandwidth than FM, such as single sideband AM.
3. Channel splitting; that is, reducing the index of modulation and the channel width so that more channels can be accommodated in the same band.

The first one would require reassignment of the frequencies on the 152-174 MC band, as they have been assigned on a block basis. Such a step is basically a problem for the FCC and the users and does not call for engineering analysis in this discussion.

The second would be far more drastic and would require the eventual replacement of all existing equipment and careful planning for the transition period.

The last is the solution that is most attractive as it would result in the least disruption of present frequency assignments, provided each existing channel is split into an integral number of channels. We will describe this method in detail, including the related factors of channel spacing and deviation, testing techniques, adjacent channel interference and intermodulation.

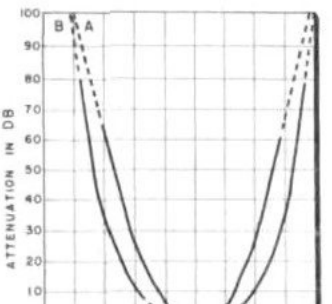
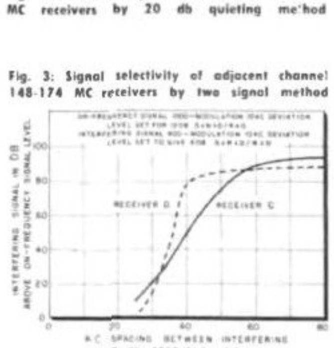


Fig. 1: IF selectivity of narrow band 152-176 MC receivers by 20 db quieting method

Fig. 3: Signal selectivity of adjacent channel 148-174 MC receivers by two signal method



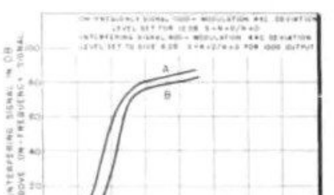
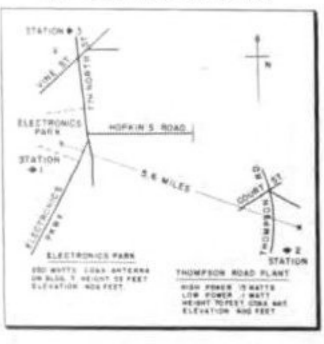


Fig. 2: Signal selectivity of narrow band 148-174 MC receivers by two signal method

Fig. 4: Station layout for field tests



Channel Splitting

Proposals for channel splitting have usually been for 20 KC channels on the 25-50 MC band and 30 KC or 20 KC channels on the 152-174 MC band. Requirements are different on the two bands due to propagation differences. On the low band the sky wave produces skip interference at long distances. For instance, West Coast stations caused interference in Michigan, New York, and other eastern states. On the high band there is practically no skip interference.

Channel splitting on the low band to prevent skip interference has been advocated for several years and has been demonstrated to be practical with no measurable loss of range or intelligibility.[1] Under this plan, systems in areas which were subject to skip interference would be placed on 40 KC channels that were displaced 20 KC from the 40 KC channels used in the areas causing interference. However, it was not proposed to operate systems in the same area on 20 KC channels except where the adjacent channel stations are from 5 to 7 miles apart and operation is not required in the immediate vicinity of the adjacent channel antenna.

Generally, these restrictions cannot be applied to same area operation of high band equipment. Since skip interference is not a problem on the high band and because of the large number of users within small urban areas, channel splitting on this band to be effective must be applicable to systems in the same immediate area. Here, therefore, is where the real problems of split channel operation are found. For these reasons the balance of this

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increased number of stations channel width are reduced

article will be restricted to high band operation.

A receiver, A, with a selectivity of about 100 db at ±20 KC, as measured by the 20 db quieting method, which will give acceptable adjacent channel operation on split channels even if the channel spacing is reduced to 20 KC was obtained. As an additional check, a second receiver, B, was modified to have approximately the same i-f selectivity using multiple tuned i-f transformers.

The 20 db quieting curves for these two receivers are shown in Fig. 1. The two signal selectivity curves in Fig. 2 were taken by the IRE Standard Method, but with 4 KC deviation instead of 10½ KC. These are a much better indication of the adjacent channel performance of these receivers provided signal generators with low noise level are used; that is, a noise level lower than that found today on standard station transmitters.

The two signal selectivity curves indicate that for adjacent channel operation on 30 KC and 20 KC channels with 5 KC peak deviation that receiver A would be superior, but that on 20 KC channels the rejection of adjacent channels for both would be poor.

For comparison the two signal selectivity curves on two high selectivity receivers for adjacent channel operation on 60 KC channels is given in Fig. 3. Receiver C has a nominal i-f selectivity of 100 db at ±45 KC as measured by the 20 db quieting method, and receiver D 100 db at ±30 KC.

To establish the effectiveness of the narrow band receivers A and B on split channels a series of field tests were performed.

Fig. 5A: Station wagon used in field tests

Field Test Set-Up

A permanent field test system has been set up at the Syracuse plant of the General Electric Co. Station #1 has been set up at the Electronics Park plant, #2 at the Thompson Road plant, and #3 at a test area .9 mi. north of Electronics Park. See Fig. 4. 25-50 MC and 152-174 MC stations are installed at each location with remote control for the Thompson Road and test area stations located in the same laboratory as the Electronics Park transmitters.

Power outputs for the 152-174 MC stations are as follows: 250 watts at Station #1, 15 watts at Station #2, and 50 watts at Station #3. Coaxial dipole antennas are used at Stations #1 and #2 and a high gain antenna at Station #3 giving an effective output of approximately 175 watts. The power output at Station #2 can be switched by remote control from 15 watts to approximately .1 watt.

The elevations at Stations #1, #2, and #3 are 406, 400, and 450 ft., respectively, with no elevation greater than 480 ft. between them, and the antenna heights are 53, 70, and 52 ft., respectively. The area is suburban with residential areas and farm lands, and no high buildings.

A station wagon has been equipped as a test car as shown in Fig. 5. Up to five mobile control units are mounted on a bracket just below the roof to the rear of the front seat. Switches on the bracket provide selection of any four of these control boxes for connection to a transfer switch mounted on the panel. The transfer switch performs the following functions: Connects output transformer of set under test to speaker mounted on the dash panel; switches outputs of the other three to resistor loads; connects microphone push-to-talk switch to equipment; actuates coaxial relays at the equipment rack at the rear of the car to switch the antenna to the equipment under test; connects three metering leads from the receiver under test to meter box mounted under edge of dash. These leads are also brought out to phone jacks on the panel so that other meters can be used if desired. Additional meter leads and jacks that do

Fig. 5B: (left) Dash panel with (l to r) selector switch, transfer switch, speaker, and meter below Fig. 5C: (right) Bracket for control boxes.

Fig. 5D: Test car equipment racks in rear of station wagon

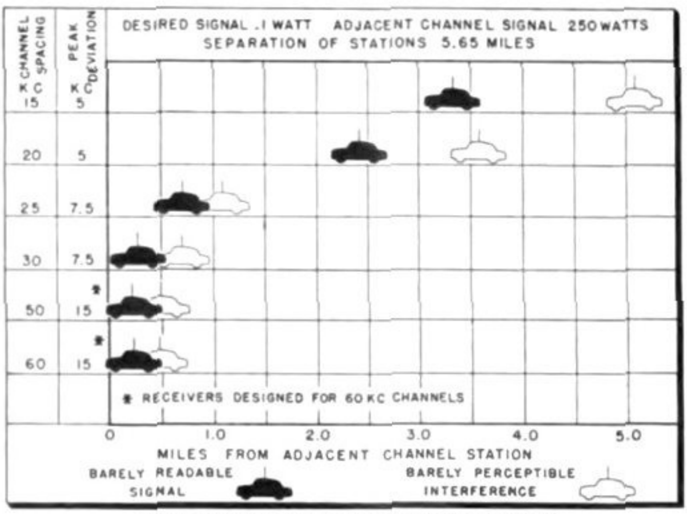

Fig. 6: Effects of interfering station in split channel field tests

not pass through the transfer switch are provided for any special metering requirements. A switch and a phone plug are provided so that an alternate speaker can be plugged in and the receiver outputs switched to it.

A series of adjacent channel performance tests were made using Station #2 as the desired signal and Station #1 as the adjacent channel interfering station. The equipments under test were mounted in the test car and the car run from Station #2 toward Station #1 until interference was experienced. Tests were made for normal adjacent channel separation (60 KC), for bisected channels (30 KC), and trisected channels (20 KC). Since, in the field, it is extremely difficult to set a station exactly on its nominal frequency and the FCC allows a .005% tolerance, tests were made with the transmitters set exactly on the nominal spacing and then later re-run at a closer spacing. The FCC tolerance would allow ±7.75 KC departure from nominal frequency at 155 MC, so that the extremes of separation between two stations could be 44.5 KC to 75.5 KC. 50 KC was selected as representing the extreme condition that could be expected in practice.

Likewise, considering that tighter tolerances would have to be held on split channels, 25 KC and 15 KC spacings were selected as extremes for 30 KC and and 20 KC channels.

The tests were made for both 50 and 250 watts power output from the adjacent channel station and 15 watts and .1 watt power output from the desired channel station.

On each test two locations were determined for each of the two receivers under test. One, the point where the interference from the adjacent channel was just perceptible, and the other where the desired signal could barely be read due to the interference. These represented the extremes of reception with interference present. In the first case, any increase in distance from the adjacent channel station resulted in reception without any trace of interference. In the second case, any approach nearer to the adjacent channel station would result in the desired signal becoming unintelligible. The actual point at which the interference would be considered objectionable would be between these, the exact point depending on the personal judgement of the user.

The split channel field tests verified the two signal selectivity measurements in that the adjacent channel performance in 20 KC or 30 KC channels of receiver A was better than that of receiver B. In presenting the data graphically, the point of just perceptible interference was plotted for receiver B, and the point of barely audible signal for receiver A, giving the extremes for the two conditions.

Field Test Results

Fig. 6 gives the results using 250 watts output for the interfering stations and approximately .1 watt and 15 watts for the desired signal. Voice modulation was used on both stations, text being read on the desired signal, and a tape recorded repetitive phrase used on the interfering station so that the two modulations could be readily identified. For 50 KC and 60 KC channel spacings the modulation controls were set for 15 KC peak deviation; for 25 KC and 30 KC channels they were set for 7½ KC peak deviation; for 15 KC and 20 KC channels they were set for 5 KC peak deviation.

With the output of desired signal Station #2 set for approximately .1 watt, the signal level in the vicinity of the interfering signal Station #1 is of the order of 1 microvolt at the receiver terminals.

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If the midway point between just perceptible interference and barely readable signal is taken arbitrarily as the point of maximum tolerable interference, then it is apparent that this point moved from .35 mi. for good adjacent channel receivers such as C and D, in 60 KC channels, to .5 mi. for narrow band receivers such as A and B, on 30 KC channels, while for 20 KC channels with the latter receivers it moves out to 3.0 mi.

It should be remembered that as the distance from the interfering station is increased, the desired signal increases while the interfering signal decreases so that at the 3.0 mi. point the desired signal at the receiver input is about 3 uv and the interfering signal about 20 db higher.

The effect of departure from nominal spacing is very greatly increased as the channel spacing is reduced. There is no appreciable difference between operation on 60 KC and 50 KC spacing, but for 25 KC spacing the point of maximum tolerable interference moves from .5 mi. to .9 mi. as compared to 30 KC, while for 15 KC spacing it moves from 3.0 mi. to 4.15 mi. compared to 20 KC spacing.

This points out the need for improved methods of setting the stations on frequency and on very great frequency stability of equipment for split channel operation. Even if the frequency setting was maintained with 1 KC for both stations and the frequency stability of all equipment was ±1 KC (.00065%) over the extreme temperature range to be encountered, there would still be a very considerable impairment of adjacent channel performance even on 30 KC channels if these tolerances happened to add together to reduce the spacing to 26 KC.

The importance of the degree of accuracy in setting the station on exact nominal frequency for split channel operation is highlighted by the problem encountered in setting up the field test. At first, the stations were set on frequency for 15, 20, 25, and 30 KC spacings using high quality commercial frequency meters and FM monitors. The results of the field tests then were completely inconsistent. The spacing of the stations was checked by setting a station receiver on the desired frequency and tuning in the low i-f with an accurately calibrated, very low frequency receiver loosely coupled to it. The desired signal was then switched off and the interfering signal put on and the shift in the low i-f measured.

This measured the frequency separation very accurately and the inconsistencies previously experienced were found to be due to the fact that we had not been able to set the stations closer than ±2 KC using the commercial measuring equipment. While monitoring the i-f provided a very satisfactory method of setting station frequencies for the field tests, it is practical for general use. To set up stations on 20 or 30 KC channel spacings will require commercial measuring equipment of moderate cost with greater accuracy than those currently used for the average mobile communication system.

Millivac Instrument Moves to Larger Quarters

Millivac Instrument Company, precision measuring equipment manufacturers, have moved to quarters three times larger than their old quarters. Their new address is 444 Second Street, Schenectady, N. Y.

"Split Channels" for More

Results obtained from field
can be made to operate on

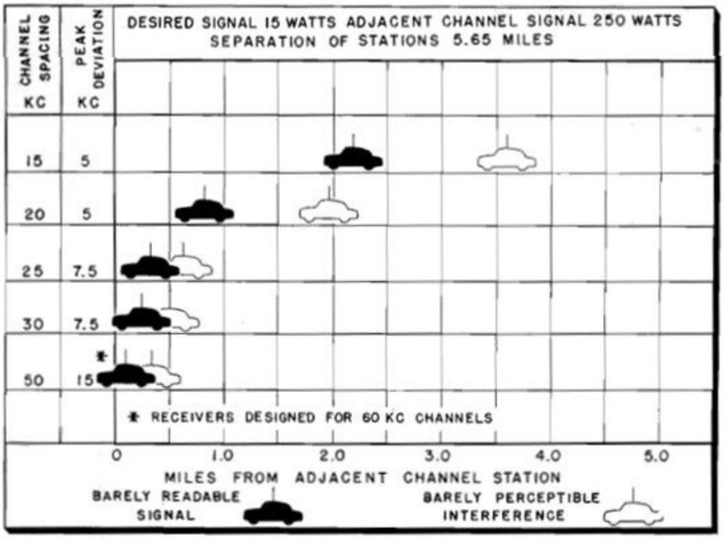

Fig. 7: Effects of interfering station in split channel field tests

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THE data for a desired signal power output increased to 15 watts (Fig. 7), which gave a signal of about 10 uv in the vicinity of the interfering Station #1, show similar results. The distances for the two interference criteria are reduced as would be expected, but the relative severity of interference is about the same.

Fig. 8 gives the results of the same tests for split channels 15, 20, and 25 KC spacing, except that the power of the interfering station was reduced to 50 watts. It will be seen again that there is a great impairment in adjacent channel performance in going from 30 KC to 20 KC channels (using 25 KC and 15 KC as minimum spacings).

There is a significant change in the character of the adjacent channel interference as the channels are split. For channel spacings down to 30 KC, the interference was due to increased noise from desensitization and the interfering transmitter noise.

For the closer channel spacing the modulation of the interfering signal began to be evident. With 15 KC spacing and 50 watts interfering signal output, the interference was predominantly due to break-through of the unwanted modulation.

Graphical Analysis

As a verification of the results of the field test, graphical analysis of adjacent channel performance was made of these receivers. Receiver interference characteristics were prepared (Fig. 9) and transmitter sideband distribution curves made for voice modulation with 5, 7½, and 15 KC peaks (Fig. 10).[2]

If templates are made of the transmitter sideband distribution curves, occurrence and cause of adjacent channel interference can be determined. The template is placed on the graph of receiver interference characteristics with the ordinate corresponding to the carrier frequency superimposed on the ordinate corresponding to the channel spacing in question and raised vertically until the sideband characteristic intersects the receiver interference characteristic at some point.

If the section of the sideband marked O-P intersects first, the interference is an increase in noise due to the noise output of the transmitter.

If N-O intersects first, it is noise but it is pulsed with the cadence of the interfering modulation.

If in the region of N, then it is break through of the interfering modulation. Finally, if M touches first then desensitization is the first to occur.

The exact level of interfering signal to produce a given amount of interference cannot be determined by this graphical method until a means of correlating the amount of area intersected with the amount of interference is determined. However, the relative performance of different receivers can be established and the nature of the interference that a given receiver will first experience can also be determined.

Using receivers A and C, the better, respectively, of the split channel and 60 KC adjacent channel receivers under test, we find the following results:

1. With receiver C for both 50 KC and 60 KC spacing, adjacent channel interference first occurs due to transmitter noise.

2. Using peak swings of 7½ KC and channel spacings of 30 KC, receiver A suffers interference first from the same cause and at approximately the same level of interfering signal. However, for 25 KC spacing the area of interference changes to area N-O and is evidenced as pulsed noise and occurs at a level of interfering signal about 20 db lower for equivalent interference.

3. Using peak swings of 5 KC and channel spacings of 20 KC, receiver A experiences interference first from the intersection of region N-O well up towards N, characterized by pulsed noise with perhaps some modulation break-through. This occurs at a level of interfering signal about 30 db lower than the equivalent interference level for receiver C on 50 KC channels. With the channel spac-

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tests conducted in Syracuse, N. Y. show how an increased number of stations adjacent channels when index of modulation and channel width are reduced

ing of 15 KC the intercept is in the region of N, and character of interference is modulation breakthrough. The level of the interfering signal is about 55 db lower for equivalent interference than for the receiver C on 50 KC channels.

The field test data taken agree substantially with these predicted results.

Now, if 5 KC peak swing is used with receiver A on 30 KC channels, the source of noise is still transmitter noise and the interfering signal level approximately the same as receiver C on 50 KC spacing. If the channel spacing is reduced to 25 KC, the same pulsed noise begins to appear but the interfering signal level is reduced only about 3 db. This indicates that split channel operation with 30 KC channel spacing and 5 KC peak swing is practical with little degradation of performance over that now obtained on 60 KC channels with the best equipment.

Receiver Interference Curve

To investigate what would be required to produce a receiver to give equivalent performance on 20 KC channels, a receiver interference curve can be drawn on Fig. 9 which will be the profile of the 5 KC peak sideband template with the carrier set on 20 KC. This curve is marked "hypothetical 20 KC channel receiver E." It is shifted over 3 KC to 5 KC from the curve for receiver A. Since the i-f selectivity of A as measured by 20 db quieting has a bandwidth of 10 KC at 6 db, it can be seen that this hypothetical receiver would have an i-f bandwidth of 2 KC to 4 KC at 6 db. Of course, this would be much too narrow to pass intelligence up to 3000 cps with peak swing of 5 KC. Furthermore, in this determination no allowance has been made for drift or for accuracy of setting of stations, so even if the peak swing were reduced to 3 KC, the minimum practical for a top audio frequency of 3000 cps, the nose width would still have to be too narrow to give normal reception.

Split channel operation makes the rejection of intermodulation interference more difficult as signals producing the interference are closer to the desired signal and can penetrate deeper into the receiver before the high i-f selectivity can attenuate them sufficiently. This can be overcome by improvements in front end design, but with split channels the number of stations which can combine to give intermodulation will be increased. Even with the improvement mentioned above, much more frequent occurrence of intermodulation interference can be expected.

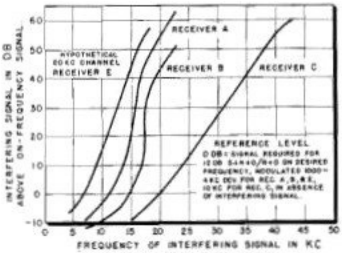

Fig. 9: Interference characteristics of narrow band receivers at 152-174 MC

Conclusions

1. Adjacent channel operation in fully overlapping service areas on 30 KC channels in the 152-174 MC band using 5 KC peak deviation appears practical. The shift to 30 KC channels could be made readily and quite rapidly. However, once made it would be very difficult to make a further increase in the number of channels in the band, for instance, by going to 20 KC channels.

2. Adjacent channel operation in fully overlapping service areas on 20 KC or narrower channels does not seem to be practical at the present state of the art with angular modulated signals (FM or PM).

3. A limited system of adjacent channel operation on 20 KC channels is practical. In this system, stations in service areas that do not overlap or where the overlap is only for regions of low signal level would operate on 20 KC spacing.

In fully overlapping service areas, stations would operate on alternate channels of 40 KC. Such a system would leave the door open for an ultimate change to unlimited use of 20 KC channels, without disruption of frequency assignments, if

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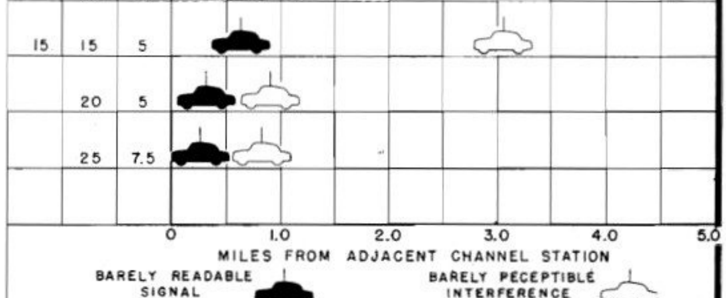
Fig. 8: Effects of interfering station in split channel field tests



optional. They provide phase ratio detection which may be more immune to noise than the simple detection of the other circuits.

The twin series version is an adaptation of the monocyclic square which was described in detail by the late Charles Proteus Steinmetz.

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the design problems can be overcome. Requirements for frequency stability and frequency setting would not be as severe as for 30 KC channels and many of the 60 KC adjacent channel equipments now in use could be used on 40 KC channels

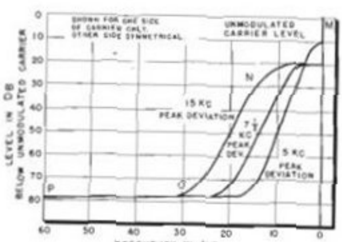

Fig. 10: Voice modulated transmitter sideband distribution for three deviations

without too much increase in interference, if the deviation were reduced. This system would require shifting of the frequency assignment of some of the present channels, which is not required if 30 KC channels were used.

4. Intermodulation interference is increased with split channel operation whether 20 KC or 30 KC.

5. With either 20 KC and 30 KC channel splitting plans, a great deal of thought on the part of the FCC and the industry must be given to how a change-over can be made, especially in the more crowded parts of the band, without too rapid obsolescence of equipment already in use.

The author wishes to express his indebtedness to a number of his associates in making this study. Particularly to Mr. G. A. Kious for his assistance in making the field tests, Mr. R. P. Gifford for much of the work on graphic analysis, and Mr. C. M. Heiden for overall guidance in the project.

In Part I of this article appearing in the March issue of TELE-TECH, for clarity the first paragraph on page 65 should be amended to read as follows: A receiver, B, with a selectivity of about 100 db at + 20 KC *as measured by the 20 db quieting* method, was obtained. It has been a common belief that such a receiver would give acceptable adjacent channel operation even on 20 KC spacing. As an additional check, a second receiver, B, was modified to have approximately the same i-f selectivity using multiple tuned i-f transformers.

1. C. A. Priest, C. M. Heiden and D. C. Pinkerton, "Narrow Band FM Doubles Number of VHF Channels For Mobile Use," *Tele-Tech*, Sept. & Oct. '50.
2. H. H. Davids, "*Selectivity and Desensitization* of Communication Receivers," *FM and TV Radio Communication*, Sept. '51.