A NEW SYSTEM OF I. F. AMPLIFIER SELECTIVITY VARIATION.

The new "MULTIBAND" system gives a new conception of "selectivity ratio", or intelligibility vs. extreme selectivity.

By McMurdo Silver *

During recent months the author has engaged in considerable research in an analysis of the means of obtaining selectivity in super-heterodyne receivers. The purpose has been to evolve means which would in a single radio receiver provide the extreme and intermediate degrees of selectivity today recognized as desirable if not essential, and particularly to devise means of improving the still elemental orders of SELECTIVITY RATIO which have had to be tolerated in obtaining extreme selectivity for voice and music reception.

In terms of high-quality all wave broadcast receiver, practice to date has indicated that four choices of selectivity are desirable. These four choices, to be available at the wish of the operator through a simple control knob, involve band widths in terms of substantially flat audio response of 32 kc., 12 kc., 8 kc., and 4 kc., which choices correspond to 16,000 cycle, 6,000 cycle, 4000 cycle and 2000 cycle audio tone modulation ranges. (This is because the selectivity curve must be twice as wide as the desired audio tone range in order to admit both upper and lower modulation side bands).

These four choices obviously satisfy every practical broadcast reception need. The 32 kc. band width will accept modulation up to 16,000 cycles, or higher than can today be profitably used on the great majority of "high-fidelity" stations modulating only up to the 9,000 to 10,000 cycles. More important, such selectivity is broad enough to make the tuning to and holding of none too stable ultra-high frequency stations easy and practical. Audio response range between 16,000 and 6,000 cycles, the next selectivity choice, is most easily regulated to the listener's taste by a treble audio tone control. This next choice of 12 kc. band width is the most generally usable one for "high-fidelity" reception, involving as it does a 6,000 cycle audio tone range. This range is dictated by two factors. The first is that 6,000 cycles is the customary upper limit of chain broadcasting, and most programs are so brought to the listener. The second governing factor is the prevalence of deep modulation by broadcast stations, resulting in regular over-modulation causing most annoying harmonic distortion in the range above 6,000 cycles, even in the rare cases when modulation frequencies above 6,000 cycles are present in programs.

The next choice is the one most valuable to all except urban listeners, for it gives to rural listeners dependent upon relatively distant stations for their entertainment, the ability to clearly select one station at a time without interference from in their case comparably strong adjacent channel signals. This third choice will be an 8 kc. band width, giving the full 4,000 cycle fundamental audio tone range and clean elimination of adjacent channel interference. The fourth choice must be a 4 kc. band width giving 2000 cycle audio tone range to satisfy the DX fan who demands the ability to split 5 kc. channels, and cleanly pull out of the crowded 49 meter band, for example, the very maximum of stations free from customary interference due to excessively close station spacing.

Previous selectivity measurements and ratings have almost completely ignored the vital factor which the author chooses to term SELECTIVITY RATIO. In rating selectivity as "absolute 10 kc.", only the band width at, say, 10,000 times "down" has been considered, with little thought given to the breadth of the curve peak. It is this breadth of peak that conveys signal intelligence, band width 10,000 times down measuring only the degree of adjacent channel interference rejection. Of what value is it to reject interference if in so doing desired signal

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intelligibility is badly impaired or ruined? Yet this is exactly the price heretofore paid for extreme selectivity - the loss of intelligence. So considered, it is apparent that a new and additional method of rating selectivity is necessary to paint a true picture. This rating may be SELECTIVITY RATIO, or the ratio of the width of the intelligence-conveying peak of a selectivity curve to its width 10,000 times down. The lower this ratio, the closer the approach to the ideal band-pass rectangular curve. The higher the selectivity ratio, the poorer is the tone quality obtained for any extreme degree of selectivity. The best previously obtained selectivity ratios have been about 8:1. The new system described herewith improves this by over double, giving a selectivity ratio of better than 4:1 where it is most needed at extreme selectivity. It improves both direct adjacent channel selectivity and gives an entirely new conception of intelligibility or program brilliance at this greater selectivity.

Satisfying as they do every present and probable future selectivity need of broadcast and even amateur voice reception, the question is how to obtain these four orders, not of side band cutting V-shaped but of flat-topped true band-pass selectivity. Examining the maximum to minimum ratios involved, we find the result to be 4 to 32 kc. band widths, or a ratio of 8:1. Using the conventional methods of varying i. f. amplifier selectivity by varying primary to secondary coupling of i. f. transformers either mechanically, or electrically by switching auxiliary coupling coils, the answer is far from ideal. Transformers of high enough coil Q to give the desired maximum, will when over coupled to give the minimum selectivity of 32 kc., show two very pronounced double peaks with an excessively deep valley in between them. They are capable of giving in good practice only three of the necessary four selectivity choices. Additionally, it is next to impossible in actual use to avoid detuning as coupling is varied, which results in lop-sided curves.

The next method of varying i. f. amplifier selectivity would be to detune in opposite directions either successive primaries and secondaries or successive i. f. transformer stages. This being essentially only a variant of the coupling variation method, still fails to give an adequately flat-topped curve to insure absence of audio discrimination when adjusted to 32 kc. band width if coil Q is initially high enough to give desired maximum selectivity.

Regarded in this light, it is apparent that no single cascaded sequence of i. f. transformers in a conventional i. f. amplifier can be varied to give acceptably flat-topped curves over the desirably wide 8:1 selectivity range of 4 to 32 kc. What is needed is individual and different i. f. amplifiers, one for each selectivity choice. This is further indicated by the increasing lack of symetry which disadvantageously creeps in as i. f. transformer selectivity is broadened. Not only does this appear as quite dissimilar steepness in the two different sides of the selectivity curve, but it also appears in the form of a no longer flat or only slightly "sway-backed" curve, but as a distinct slope from one side to the other of a none too flat curve peak or top. This is the final objection to coupling variation to obtain an ideally large range of selectivity, for through the introduction of audio distortion it tends to destroy the fidelity benefits to be gained by a broad i. f. amplifier.

All these disadvantages may be eliminated through separate fixed, not variable, i. f. amplifiers or transformers switched into circuit to vary selectivity, and vitally important additional benefits may be obtained. These have to do with SELECTIVITY RATIOS at maximum selectivity, as in the 8 kc. and 4 kc. band width choices. Intelligibility and brilliance of speech and music is a direct function of the degree to which high audio frequencies are admitted. Interference rejection is the function of how far "down" the sides of the selectivity curve are immediately outside the desired admittance band. The ideal selectivity curve will have a flat top and vertical sides - it will be a rectangle in shape, not the usual V-shaped curve. If we can obtain such an ideal band pass curve, we can realize an entirely new order of intelligibility and tone quality at extreme selectivity. Additionally, we can eliminate that old bug-a-boo of microphonic howling on short waves, for it is the invariable accompaniment of sharp and V-shaped selectivity curves, but disappears when the i. f. curve becomes in ideally flat-topped U-shaped rectangle.

Upon the basis of recent evaluations of selectivity discrimination adequate to eliminate ordinarily encountered adjacent channel interference, we may consider that if our selectivity curve sides are 5000 times "down" from peak response, all will be well. Actually, considerably less than this will usually do the job. But let us take the doubly safe assumption that the curve "skirts" should be 10,000 times down to insure elimination of adjacent channel interference. We cannot obtain such discrimination with a flat-top to our curve 4 kc. wide (to give the 2000 cycle audio tone range essential to good speech intelligibility free of "boominess") even with four under-coupled i. f. transformers using coils of the highest currently available Q of about 130. If we are to obtain this ideal useful audio tone range at maximum selectivity together with steep interference-rejecting skirts, we will need coils of Q much higher than are found in the most selective current receivers. Coil Q's of 200 can be had from iron-cored i. f. tuning with such coils. The first guess of permeability tuning must be rejected because of the absence of adequately stable fixed tuning condensers. For high quality circuit stability air tuning condensers may not be escaped. So much work was done to develop air-core coils of Q 200, with success finally obtained. With this Q or merit improvement of over 50% more than is available in even the best receivers, the ideal becomes within practical reach.

Three i. f. transformers with their primaries and secondaries coupled below optimum, where the double-peaked characteristic of over-coupled circuits just becomes apparent, will give the selectivity curve with the perfectly flat 4 kc. top, quite essential to this new conception of program intelligibility associated with extreme selectivity which we are seeking. The extraordinary coil Q of 200 will cause the sides or skirts of this curve to fall off almost vertically, but not quite vertically enough to satisfy the ideal goal sought. So, in a three stage amplifier, a fourth i. f. transformer will be used, so broad as not to narrow the flat top, but a considerable help in pulling down the skirts on either side of this flat top, and to keep them symetrical (to prevent the high frequency skirt from straying out and failing to duplicate the steepness of the low frequency skirt).

As this system will be used in a fine radio receiver - the only reason for developing it at all - this receiver will of course follow the finally established good practice of using two tuned r. f. stages to eliminate unavoidable first detector-oscillator noise by the only known method of using high r. f. amplification in conjunction with low i. f. amplification. If this two stage r. f. amplifier departs from the customary practice of seeking only to improve image selectivity, we can get quite considerable adjacent channel selectivity from it. This departure from current practice will materially steepen the sides of our flat-topped i. f. curve, and through careful design will not impair this flat-top.

The net result will be curve "D" of Fig. 2. The extraordinary aspect of this curve is its SELECTIVITY RATIO. Its intelligence-conveying flat top is 4 broad where it is flat to 6 db. (easily compensated in audio amplifier circuits) and then it falls off almost vertically to a width of only 15 kc. at 10,000 times down. This is an intelligence-to-interference-rejection ratio of 3.75:1, coupled with the flat-top that eliminates microphonic howling. The improvement this represents is seen by a comparison with dotted line curve "E", a composite of several of the most selective receivers today available. Curve E shows a top only 2 kc. broad, resulting in the very poor to almost unintelligible tone quality unavoidable with the only 1000 cycle audio tone range it allows. Despite its lack of symetry in non-uniform skirt slopes, it is 18 kc. broad 10,000 times down. This is a selectivity ratio of 9:1

- less than half as good as the new system depicted in curve D gives for even greater effective rejection of strong interference.

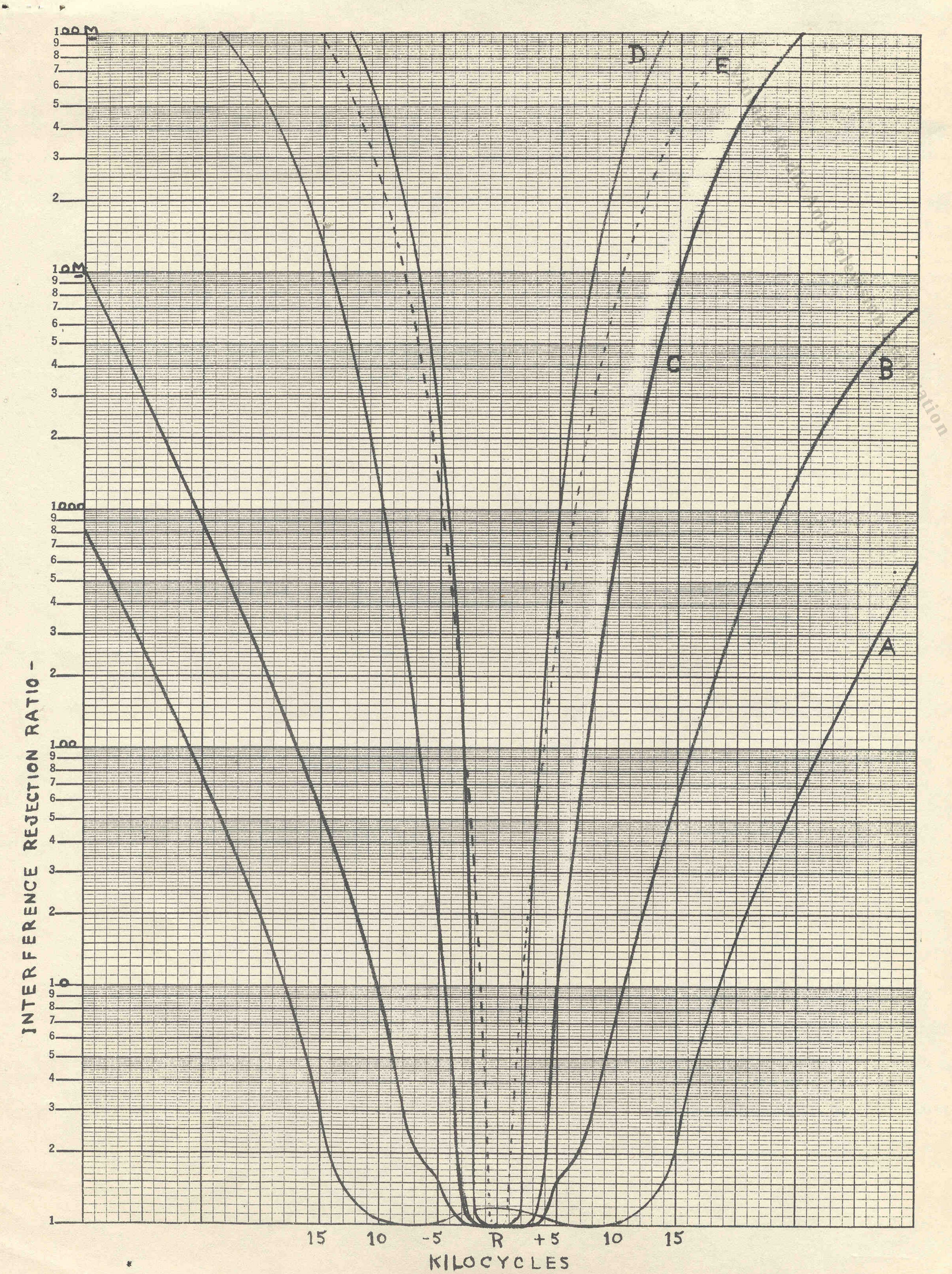
The i. f. transformers that give this new order of selectivity cannot be broadened to give curve "A" of Fig. 2 without serious loss, so we must turn to the sensible course of using entirely different and suitable transformers to obtain the broad band of curve A. Three transformers of coil Q's reduced to 60 are required to get curve "A", which is 32 kc. broad across a top free of the deep center valley caused by high Q coils, and level to 12 db. across this top. This 12 db. departure from an ideal flat top is easily made up by providing a 12 db. treble rise in the following audio amplifier. But to keep it this flat all tuned r. f. circuits but one must be cut out, for no method of broadening them that will not introduce stray couplings and capacities through long leads and incidental associated parts if practical. This is desirable in any case, for upon the broadcast band such a wide admittance band may only be used in reception of strong local stations, and switching out of r. f. gain will insure only such use. On short waves the selectivity of the r. f. amplifier necessarily decreasing with increasing frequency, it may be employed entirely satisfactorily when its additional gain and necessary image rejection may be desirable.

Having now two different i. f. amplifiers by virtue of two different, and symetrical through being permanently adjusted, sets of i. f. transformers, together with selectable degrees of r. f. selectivity, we may through discreet joining of the three systems obtain the two remaining choices of selectivity required to qualify the system as ideal.

Through substituted one sharp i. f. transformer for one of the three broad ones of curve "A", we get curve "B" 14 kc. wide across its top which is flat to the easily audio compensated level of 6 db. It insures the 6000 to 7000 cycle audio tone range which will be most useful in day in and day out "high-fidelity" reception of regular broadcast stations.

Curve "C" is obtained with this same i. f. system to which is added the two stage r. f. amplifier. This curve, 8 kc. broad across its top flat to 6 db. (rendered perfectly flat through audio amplifier compensation), is the most generally useful of the entire four choices, for it is the one which will be used in broadcast band and short-wave reception to give the maximum of tone quality with the maximum of selectivity for stations separated 9 to 10 kc. Its flat band-pass top and extremely steep sides "down" 1000 times for the 10 kc. separated adjacent channels give the selectivity which has heretofore only been obtained at the expense of the tone impairment necessarily associated in the past with side-band cutting.

Such are the wide ranges of selectivity possible through this new i. f. system, which the author has named MULTI-BAND to differentiate it from older systems of selectivity variation. It is possible that this system may lead to further improvement in the older methods of selectivity variation, but not for cheap receivers, for the elimination of the lack of symetry and side-band cutting V-shaped selectivity curves of the old methods can only be obtained by increasing the excellence and number of permanent, not variable, i. f. transformers - a costly but obviously very beneficial process. To obtain the degrees of selectivity seen in Fig. 1, "battleship" construction and assembly is essential to guarantee its permanent retention through elimination of all mechanical variables. I. f. transformer shields must be large to avoid loss of hard-to-obtain high coil Q, which must be further guarded by Isolantite coil mounts, Isolantite insulated air-dielectric trimmer condensers, Isolantite selectivity switch insulation, and effective capacity shielding in i. f. transformers and associated circuits. Such a mechanical example of the MULTI-BAND selectivity system will be found in the new MASTERPIECE VI.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