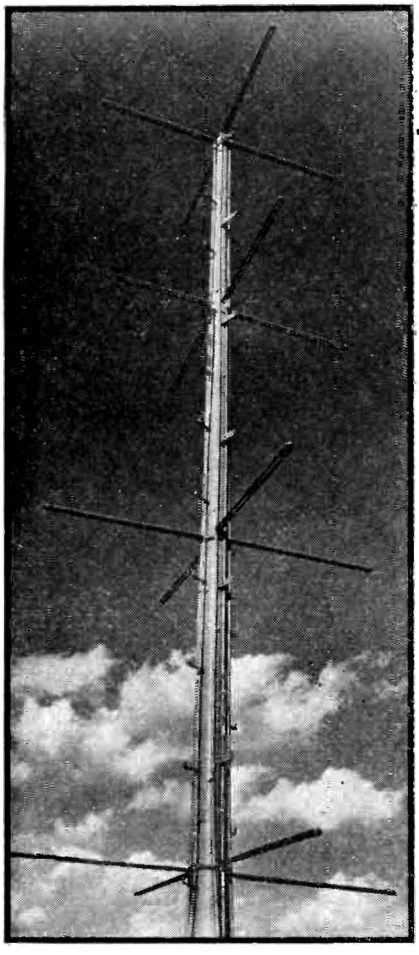
FREQUENCY MODULATION



Analysis of the probable post-war growth of f-m broadcasting in the United States. Twenty million receivers and 2000 transmitters expected to provide high-quality nation-wide coverage, with equal day and night service, five years after the war ends

THERE ARE NOW on the horizon two new services for the broadcaster to offer to his audience. One of these is frequency modulation, the other is television. Both of these had some start before the war and f-m, in particular, made considerable progress. The impact of the war on television, plus its relatively unsettled state before the war, can result in a re-examination of television after the war to the point where it may not become an immediate public service.

Frequency modulation is not encumbered with any problems which will affect service now being rendered to the public or which will delay or hold up its immediate post-war expansion. Since frequency modulation is nearest on the horizon, it is proposed to discuss its possible practical effects on the broadcaster and some of the reasons why the broadcaster should not only do post-war thinking, but post-war planning on f-m in the interest of maintaining himself in business.

The Federal Communications Commission promulgated a complete set of rules for f-m which set it up as a business on the same substantial level as a-m broadcasting. All available channels were snapped up quickly in some parts of the United States by far-seeing interests both in and out of the present broadcasting business.

It is very likely that additional channels will be provided. F-M channels now are situated between 42 and 50 Mc. It is possible that this space may be extended to 56 Mc, which would almost double the present number of channels. This would make possible a great expansion in the numbers of broadcasting stations in any one locality. It would also make possible the entry of new people into the broadcasting business and could also remove inequalities of assignments which some broadcasters feel exist in the older a-m structure. Many broadcasters, now having what they regard as inferior assignments, and anxious to improve their position, would have the opportunity to do so. The soundness of this reasoning has already been proven in at least one large city.

Evaluation of Post-War Broadcasting Industry

To evaluate properly the post-war broadcasting industry, it will be necessary to estimate, as well as one can, the number of f-m receivers and the number of f-m stations which may reasonably be expected to be in operation five years after the war. It will be necessary to make some estimate of the burden which f-m will place on the electromagnetic spectrum.

To be able to convey our proposals for f-m service in terms of a-m service with which the average man is already familiar, some comparisons between the two types of service will also be in order. To orient our thinking in this matter, consider the present status of frequency modulation as given in Table I. Scattered and uncorrelated as this data is, it nevertheless indicates the beginning of a pattern which may be followed in our quest for data on f-m broadcasting.

Based on the experience of a-m broadcasting, Fig. I and Table II provide some clue as to the degree to which United States homes may be provided with radio receivers. Because of the difference in propagation characteristics between the a-m band and the channels available for f-m service, Fig. 1 and Table II cannot be used directly to provide comparable data for f-m broadcasting. If, however, we assume that we can conveniently and economically serve all of the population in the Northeastern States, all in the North Central, all in the Pacific and one half of those in the Southern States, 105,000,000 persons or 28,000,000 homes will be available as a market for f-m broadcasting. This represents the market which, under present conditions, can be served economically.

Not all of the 28,000,000 homes can be served by f-m broadcasting

and Its Post-War Future

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in the period immediately following the end of the war. Economic consideration indicates that the large metropolitan areas will probably be provided with service first.

Estimate of Number of F-M Receivers

Approximately 67,000,000 persons (or 51 percent of the population of the country) live in metropolitan areas and, from a marketing point of view, will be ready for widespread f-m service as soon as it can be provided. This represents 17½ million homes. About 10 percent of these homes will probably not have radio receivers, leaving a total of about 16,000,000 dwellings as an immediate potential post-war market in metropolitan areas. Within five years after the end of the war, the 28,000,000 homes in the regions designated above should be supplied with adequate f-m service.

Within a five year period two-thirds of these families may be expected to own f-m receivers. It may be noted that approximately 90 percent of these homes are already equipped with a-m receivers. A total of 18,600,000 receivers appears reasonable at the end of five years on the basis of a static population. The Census Bureau predicts a 14 percent increase in the number of families from 1940 (for which our statistics apply) to 1950. By 1950 as many as 21,000,000 families may be expected to own f-m receivers. From this reasoning we arrive at a figure of between 18,000,000 and 22,000,000 f-m receivers in American homes within five years after the war.*

There is another factor to take into account which will probably place the figures calculated above on the conservative side. By 1933, after about ten years of a-m broadcasting, more than 20,000,000 homes had radio receivers. This growth took place in a period when the average production of radio sets was about 2,630,000 receivers per year, and when the cost of radio receivers (particularly in the early part of that decade) was relatively high. As a result of considerable development in f-m equipment for war purposes, and more than adequate and well organized production facilities, the cost of f-m receivers in the period following World War II will be far less than the cost of a-m receivers produced after World War I, and they will produce infinitely superior results. Furthermore, Table III shows a pronounced tendency to have more than one radio set in American homes, which would further tend

TABLE I—PRESENT STATUS OF FREQUENCY MODULATION

1. There are 51 f-m stations operating on a commercial program basis
2. There are at least 10 experimental and educational stations on the air
3. More than 50,000,000 people reside in the areas now served by f-m stations
4. Approximately 120 applications for construction permits or re-instatement are now on file with the FCC
5. A recent survey indicates that 144 companies plan to open f-m stations as soon as possible after the war
6. Applications for f-m stations cover districts ranging from the 2500 square miles with a population of 500,000 proposed for Springfield, Massachusetts, to the 69,400 square miles with a population of 4,346,000, eventually to be covered by the Gordon Gray station on Clingman's Peak in North Carolina
7. There are more than 600 principal trading centers in the U. S.
8. There are 137 metropolitan areas, made up of densely populated divisions in and around cities of 50,000 or more inhabitants. These areas include 237 metropolitan counties which contain more than half the nation's population
9. There are over 1000 cities of 10,000 population or more. At least two-thirds of these are sufficiently distinct from the metropolitan areas to support f-m stations
10. Power-for-power, an f-m station will frequently provide superior coverage up to and somewhat beyond the primary service area of regular a-m broadcasting stations
11. The service area of a 250-watt f-m broadcasting station is more than 4 times that of a 250-watt 1000 kc a-m broadcasting station at night

* Data for calculating the number of f-m receivers is taken from the 1940 census. Data for estimating the number of transmitters is taken from population figures for 1943 ration book, Series P3, No. 38, "Estimated Population as of March 1943".

TABLE II — GEOGRAPHICAL DISTRIBUTION OF POPULATION

Northeastern States	35,914,000
North-central States	40,094,000
Southern States	41,504,000
Pacific States	9,675,000
Mountain States	4,133,000

to make the above estimate conservative.

Outlook for F-M Transmitters

Certainly there will be no f-m receivers in operation if there are no transmitters available for originating program material. This brings us to a discussion of the number of f-m transmitters which can be profitably placed into service. Such an analysis can be made by considering only those factors contributing to the public requirements for f-m service. However, any estimates based on this assumption alone must be guided by the availability of suitable f-m channels. Particularly at the present time when problems of frequency allocation are under consideration, study of both of these problems may be useful in appraising the number of channels which should be made available for f-m service.

Based entirely on our present view of radio broadcasting and the services rendered by broadcast stations, it is possible to look forward to a continuous growth until approximately 1,900 f-m broadcasting stations are in operation. Other estimates place this figure at 2,000 stations. The major part of this growth should take place in the five year period following the war. As shown in Table IV, a total of 1899 f-m broadcasting stations (including 250 educational stations) should be built during this period.

Underlying these figures are the following three assumptions which are believed to be reasonable and representative of good engineering and economic practice:

(1) At the present time there are 22 channels allocated to Class B stations designed for coverage of areas comprising a basic trade area and a "principal city". Usually this area is composed of a principal city, one or more cities, and the areas adjacent to these cities. A Class B station would serve such cities as Chicago and New York.

(2) Assuming that a new band of 6 Mc is added to the group of Class B channels from 50 to 56 Mc for example, a total of 52 Class B channels will be provided, each 200 kc. wide. This is shown in Fig. 2.

(3) Good engineering practice dictates that stations in a given area should be separated by at least one channel. Thus, a maximum of 26 channels would be available in any given area.

F-M stations in any given locality are assigned channels on the basis of 3 stations for national network programs in addition to a block of stations based upon the population of the area to be served. For the largest metropolitan areas one station is allotted for every 200,000 persons whereas in the towns having from 50,000 to 100,000 persons, one station is alloted for every 75,000 persons. In Table IV, the mean population is taken as the basis for calculating the number of stations, except for the 12 largest metropolitan areas and the towns 50,000 or less. Calculations for the 12 metropolitan trade areas having a population of 1,000,000 or more are given in Table V.

Of the 250 non-commercial stations, 100 stations are allowed for various colleges and universities throughout the United States. Approximately 135 stations for the principal cities in the major metropolitan districts and 15 stations for smaller cities with active educational programs will be needed.

F-M Stations for Complete National Coverage

To give complete year-round coverage of the United States which will provide every listener with a reasonable choice of programs, at least 800 f-m broadcasting stations must be located in cities having a population of less than 50,000 persons. The geographical distribution of these stations in the various states should be made equitably upon the basis of the rural population to be served. This distribution

TABLE III—RETAIL RADIO SALES IN THE UNITED STATES

Year	Total Sets Sold		Homes With Radio Sets
1937	8,064,780		26,666,500
1938	7,100,000		27,500,000
1939	10,538,000		28,700,000
1940	11,150,000		29,300,000
1941	13,100,000		30,300,000
1942	4,400,000		30,800,000
Total	54,352,780	Increase in Homes With Radio Sets	4,133,500

TABLE IV—ESTIMATE OF REQUIRED NUMBER OF F-M STATIONS FOR U. S. SERVICE

Areas whose population is:	No. of such areas	Est. Mean Population	Population Served by Each Station	No. of Stations on Population basis	No. of National Stations	Total No. of Stations
1,000,000 or more	12	(See Table V)	200,000	145	36	181
400,000 to 1,000,000	27	700,000	175,000	109	81	190
100,000 to 400,000	86	250,000	125,000	172	258	430
50,000 to 100,000	12	75,000	75,000	12	36	48
50,000 or less	..	....	75,000	....	...	800
			Commercial Stations			1,649
			Non-commercial stations			250
			Total			1,899

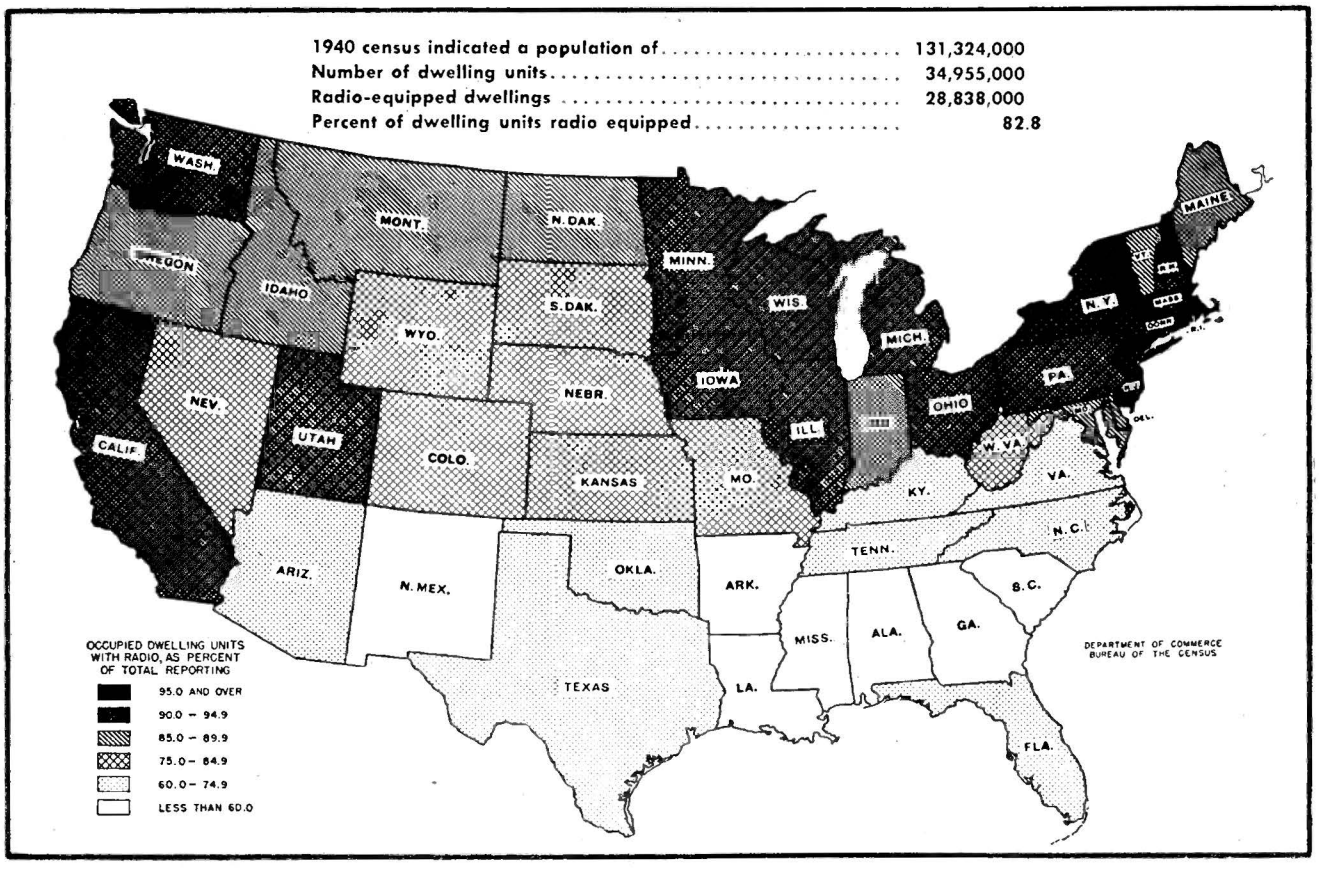

FIG. 1—Home radio receivers in the United States, by States, 1940

may be most easily worked out by subtracting from the total population of each State that population residing in concentrated trade areas serving 50,000 persons or more. Economic considerations may make it difficult to apply this method of reasoning to a few sparsely settled areas, but, generally speaking, the proposed method is believed to be sound in principle and entirely practical in its application.

The method of arriving at the number of stations required for rural population is based on the assumption that adequate service can be maintained by alloting one station for each 75,000 persons. The total civilian population of the United States, based on ration book No. 2 registrations,** was 128,231,000. Of these 68,403,000 persons live in the metropolitan areas of the United States; 59,829,000 persons live in the districts which do not include cities of at least 50,000 population. If we allot one station for each group of 75,000 persons of the 59,829,000 persons living in rural districts, we arrive at the figure of 800 stations required for rural use.†

The above figures, which indicate a rapid growth in the number of f-m stations until a total of something like 1900 is reached, are based on pre-war thinking in regard to transmitter installation and operating costs, and program availability and cost. Progress in these fields would greatly increase the number of stations which would be practical for use in the non-metropolitan areas. Under the f-m broadcasting system, the ability of a trading district to support a transmitter, rather than the availability of frequencies, should be and undoubtedly will be the major factor in determining how many stations will exist in a given area. The growth of f-m broadcasting in the days immediately following the war will be limited only by the availability of transmitters and receivers. At least 60 percent of the predicted growth of the number of transmitters should take place in the first three years following the war.

Comparison of F-M and A-M Service Areas

Many broadcasters have failed to become interested in frequency modulation because of an opinion, now thoroughly disproved, that the transmission range of an f-m station is limited to such a small service area as to represent an uneconomical undertaking. The facts of the case are that power-for-power, an f-m station will frequently provide superior coverage up to, and somewhat beyond, the primary service area of regular a-m broadcasting stations on a day-and-night, 365-day year basis. In fact, at lower powers and in the areas of low earth-conductivity, the service is superior.

The service area of most a-m broadcasting stations is now so limited by heterodynes and interference that an f-m station will offer better service, unless and until the f-m structure becomes so

** This data was issued by the Bureau of Census on October 31, 1943.

† The predicted number of f-m stations required to serve rural areas was originally based on an analysis of population distribution and economic factors existing in a number of typical states. The value of 800 stations arrived at by simple allocation of one station per 75,000 rural population checks closely with the figure secured by the more complicated methods of analysis.

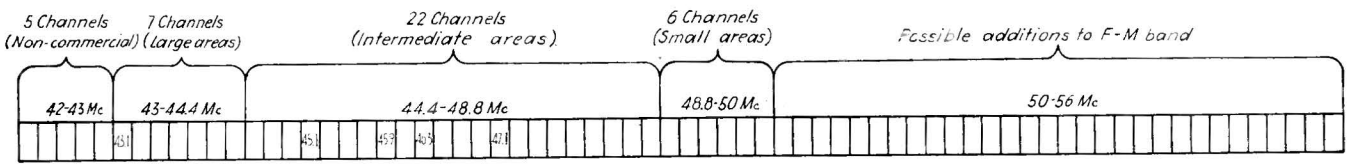

FIG. 2—Allocations in present f-m band and possible extension of the band

burdened with f-m stations as to make proper operation impossible from an engineering standpoint. This can be proven by listening to both services at night at some point fifty to sixty miles outside Chicago or New York, in which cities there are a large number of both f-m and a-m broadcast stations. In general, it will be found impossible to hear the local 100-watt, 250-watt and 1000-watt a-m stations at these distances, or if heard, signals will be burdened with heterodynes to the point where they have no entertainment value. The same situation will generally apply to 5000-watt stations. It will be found, however, that even those f-m stations operating on 1000 watts will give 100 percent service day or night, 365 days in the year.

Thus f-m stations can produce an interference-free quality service which even 50 kw clear channel a-m stations frequently fail to produce. These facts all apply to primary service areas — those areas in which, presumably, the broadcaster makes his living. These are the reasons why broadcasters not occupying clear channels will consider seriously the establishment of f-m stations when such installations can again be made.

Field Strength Determinations

So far, consideration has been given to a distribution of f-m stations on the basis of population, without regard to primary service area. Much has been written regarding the "line of sight" characteristics of transmission on high frequencies and it is logical to reason that this limitation would make the comparison even more unfavorable for f-m. This reasoning may entirely fail to give the correct answer, however, for it is necessary to consider all of the factors which influence transmission distances and which limit service areas. The more important of these factors are power, antenna height, directivity, soil conductivity and nature of the topography of the area to be served, and the strength of man-made or natural interfering signals.

Consider the case of the standard broadcast station operating, for example, on 1000 kc with a power of 250 watts and an antenna 200 feet high. Such a station could be expected to produce an effective field intensity of about 75 millivolts per meter at one mile. The lowest signal strength that will give satisfactory broadcast reception is, of course, a function of the interference level at the receiver and will vary through wide limits. It has been general experience that a signal strength of 500 microvolts per meter gives a satisfactory signal-to-noise ratio in average rural locations for perhaps 90 percent of the time. This level is used by the FCC as the limit of good coverage.

If the figure of 500 microvolts per meter is used as the limit for satisfactory reception, and if we assume that the station is erected where average soil conditions exist, a non-directional antenna will provide a service area within a radius of about 39 miles, representing an area of 4,800 sq. miles. Since there are only a very limited number of broadcast channels available, a station of this type could not economically be given exclusive use of a channel and it would be necessary to assign other stations to the same channel. In so doing it is necessary to take into account both nighttime and daytime conditions.

Now, nighttime signals from a standard broadcast station may produce strong interferences with other stations at great distances. A station which produces a useful daytime signal at only 50 miles may seriously limit the service area of another station 2000 miles away at night.

Interference Factors

In view of these facts, interference limits have been adopted by the FCC in an effort to make the best possible use of the limited number of channels which are available. In the example which just has been examined, the station would fall in the local Class III B group and nighttime protection would extend only to the 4,000 microvolt-per-meter contour. The radius for the 4,000 microvolt-per-meter contour is only about 11.5 miles, so that the nighttime service area has been reduced from 4800 square miles to only 414 square miles. The range has therefore been reduced until the nighttime service area is less than one-tenth of the daytime service area.

Let us consider the case of a 250 watt f-m transmitter operating with an antenna also 200 ft. high and having unity gain, and operating on a carrier of 46 Mc. Again, the useful range of such a station is partially limited by the prevailing noise level. As a result of the inherently low static level on 46

TABLE V—PROPOSED ALLOCATION OF F-M STATIONS IN METROPOLITAN AREAS OF MORE THAN ONE MILLION PERSONS

Area	Population Served	Number of Stations (3, plus 1 for each 200,000 persons)
New York	10,991,000	26*
Chicago	4,532,000	25
Los Angeles	3,135,000	19
Philadelphia	2,962,000	18
Boston	2,692,000	16
Detroit	2,566,000	16
Pittsburgh	2,082,000	13
San Francisco	1,725,000	11
St. Louis	1,496,000	10
Cleveland	1,199,000	9
Baltimore	1,197,000	9
Washington, D. C.	1,179,000	9

* Maximum number of channels assumed in this analysis.

Mc and due to the advantages of f-m reception, a signal of 50 microvolts per meter has been found to give good service. On this basis adequate signal strength will be laid down for a radius of 24 miles, thereby serving an area of 1,800 miles either day or night, substantially independent of static level. The service area of the f-m station is thus more than four times that of the standard broadcast station at night. In the daytime, the f-m station would serve an area a little less than one-half of that of the standard broadcast stations.

In terms of completely dependable 100 percent coverage, this comparison is by no means unfavorable to the f-m station. Perhaps the most important consideration here is that the range of the f-m station can be extended by increasing the power, increasing the antenna gain, or by taking advantage of available tall buildings to obtain greater antenna height. This extension of local coverage can be obtained with negligible increase in the "nuisance range" of the station. Such extension or range for the standard broadcast station cannot be obtained without greatly increasing the sky-wave signal and consequent interference caused at great distances.

Soil conditions and frequency have a profound effect on the coverage of standard broadcast stations. For example a low-power regional station located in the central plains area of the United States and operating on a low frequency channel may have greater coverage than a 50-kw station in the New England area.

The Question of Fidelity

Much has been said about the fidelity of transmissions. There are some who say that the public is not interested in this fidelity. There are others whose thinking has been so superficial that they claim that improvement in broadcast receivers and speakers can make the a-m service the equivalent to the f-m service from a fidelity standpoint.

To those who question the public's interest in the higher fidelity of the f-m service, it can be said that enough practical f-m field experience is available to prove that higher fidelity does have definite public interest, and that it is liked and appreciated, and is a logical natural advance in radio progress.

To those who believe that the a-m service can be made to compare with the f-m service from a quality standpoint, it is pointed out that unless FCC changes the present a-m broadcasting structure, this can never be accomplished. Broadcasting stations now operate on channels spaced 10 kc apart. Radio receiver manufacturers must design their receivers with enough selectivity to separate one station from another. The best of receiver circuits do not dare be broad enough to accept the inter-station interference which exists half way between channels. This means that the fidelity of a-m broadcast receivers is defined and limited to something less than 5000 cycles. Improvements in speakers or circuits or any part of the system cannot overcome this limitation. It can only be overcome by spacing broadcasting stations further apart than 10 kc.

An engineering evaluation of proper spacing would indicate that stations ought to be at least 20 kc apart. Whether this can be done with the present broadcasting structure is extremely problematical. It is not believed that it can be done unless the number of broadcast stations assigned to the present a-m broadcast band is considerably reduced.

Primary Coverage with "Super Power"

At this point we might want to raise our sights to that level where f-m broadcasting can take over the requirements of primary coverage for broadcasting entirely. This could mean that only super-power stations would be licensed in the broadcast band. Let us say nothing less than 50 kw, and these on clear channels only. This would provide rural service throughout the United States which might not be generally available everywhere from a-m and f-m stations. The f-m service would provide a primary service in every locality in which it is established.

There are some who will say that f-m is an expensive service, that the receivers are complicated and that they are not available in small table models of a size and price comparable to a-m sets. The answer is clear. In the last five years of the radio receiver industry, nearly all receivers sold, whether they were $9.95 models or sets selling for hundreds of dollars, were superheterodynes. The initial comment made by the people in the industry 15 years ago, when superheterodynes were first proposed, was that they were complicated and expensive and could not be manufactured cheaply. There can be no question but what f-m receivers will follow this same pattern. Whether we like it or not, the laws of economics cannot be circumvented.

The question will then be asked, how can you produce high fidelity in a $9.95 f-m receiver? The answer to this one is that probably

(*Continued on page* 262)

TABLE VI—CLASSIFICATION OF BROADCAST STATIONS

Class	Station Classification FCC Designation	Power in kw	Field strength (μ per meter) for which protection is assured: Day	Night
Dominant Clear Channel	IA	50	100	Not duplicated
Dominant Duplicated	IB	10–50	100	500
Secondary	II	¼ to 50	2500	Not operated
Regional	IIIA	1 to 5	500	2500
Regional	IIIB	½ to 1 night 1 to 5 day	500	4000
Local	IV	0.1 to 0.25	500	4000

Post-War F-M

(*Continued from page* 99)

it cannot be done but the set will sound at least as good as the $9.95 a-m set, in all probability better, and it will have the noise-reducing feature of f-m which a-m sets do not have, and, so far as we know today, cannot have.

Finally, there is an important listener consideration which is that if people find satisfaction in listening to a-m broadcasting on $9.95 receivers, they will also have satisfaction in listening to f-m on $9.95 receivers, even though the tone quality is not greatly better.

The reasoning given above has, again, been based on pre-war ideas and practices; it has failed to take into account the impact of the war on the design and manufacture of f-m receivers.

Much work has been done to improve the sensitivity, the selectivity, and stability of f-m receivers and new and improved limiters have been evolved. Certainly the knowledge which has been gained through war research will be directly useful in engineering and manufacturing post-war civilian radio equipment.

The author wishes to acknowledge and express his appreciation for the material prepared for this article by Mr. J. W. Sharp and Mr. W. E. Phillips of the Zenith Engineering Department.

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ELECTRONIC BUGLE

Bugle calls are sent out over the ship's public address system to reach all parts of a new light crusier. Official U. S. Navy photograph