Narrow-Band FM Doubles Number

20 KC channel of effecting

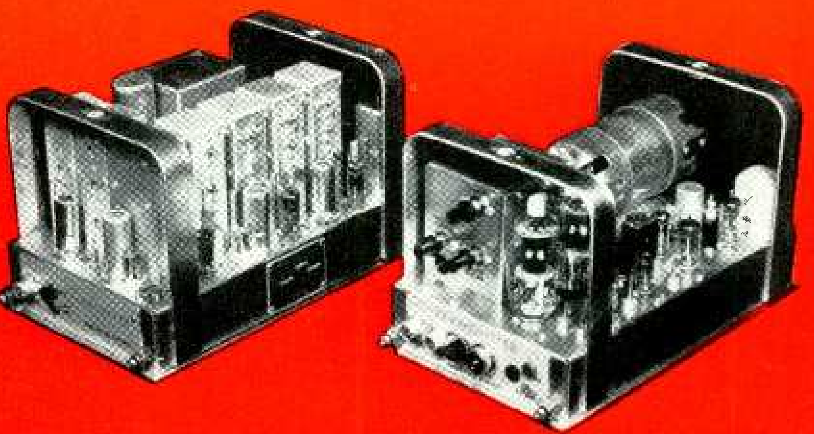

Fig. 1. Mobile transmitter (right) and receiver (left) for mobile narrow band FM

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FOR the past several years it has been apparent that the increased demands for radio communication facilities by currently authorized users and new services would inevitably require a great number of additional channels in the VHF region. It was equally apparent that more selective equipment would be necessary to make these additional channels fully practicable. To fulfill these needs, much basic research and development was carried on in the laboratories of the General Electric Company, at Electronics Park, to establish what could be done quantitatively with available technics at reasonable costs.

The ultimate result of this work was the production of two companion designs of radio communication equipments. A "Wide-Band" system utilizing a swing for 100% modulation of 15 KC, designed initially for additions to existing radio communication systems in order to provide the best possible performance utilizing the full 40 KC channel widths presently assigned, and a "Narrow-Band" system utilizing a swing for 100% modulation of 6 KC having performance equivalent to the "Wide-Band" but providing interference - free communication when operating on channels spaced 20 KC apart, provided only that some reasonable restrictions are observed in assigning these channels.

Field Tests—The Proof

Field testing of these two types of systems started almost immediately after the first samples were completed in the laboratory, to prove once and for all, whether or not cutting the transmitter swing would degrade the performance to a point where the readability in the fringe area would be unacceptable as compared to the conventional 15 KC system. All of the conditions that are normally encountered in an operating system were explored: Quiet rural areas, rural areas where the ambient noise level was high, and city areas. These tests convinced all that the narrow-band systems are more than practical.

These trials brought to light many requirements which must be adhered to if consistent and truthful results are to be obtained. Proper modulation is of utmost importance. Overmodulation, received on receivers which have been designed for a steel walled selectivity curve, can produce unreliable results. To prove this, modulation of approximately ±17 KC was transmitted and two receivers, a "Wide-Band" and "Narrow-Band" version, were compared as the fringe area was approached. When well within the fringe area, the modulation from the narrow receiver became mushy and then the signal began to chop up and become unreadable. The reception on the wide-band receiver was still coming through so that the signal could be copied. The modulation was then cut to the proper level for the narrow receiver and again the signal was fully readable.

In the test cars, which were fitted with both narrow and wide-band equipment, various precautions were taken to insure that as many of the variable factors as possible were fixed. A coaxial antenna relay was installed to switch the antenna from one set of equipment to the other. On the original field tests it was found that speakers and their positions in the vehicle gave different tonal results which confused the listener during critical tests. To switch one speaker between the two receivers, controls were installed which operated the speaker relay and the antenna relay simultaneously so that the observers could switch from one set to the other with little or no interruption.

Another precaution that had to be taken, to insure the least amount of confusion to the observers, was to balance the audio response of the receivers under test so that the audio quality of one receiver, as compared to the other, would not enter into the results. The sensitivity and selectivity of the receivers had to be comparable to fairly represent what could be expected from production equipment.

Incidentally, Syracuse has as nearly a perfect geographical setup for field tests as can be desired. Electronics Park is situated a few miles north of Syracuse. Due north of the Park is 50 or 60 miles of very level land terminated by Lake Ontario and the Thousand Islands. To the South is the metropolitan area with its outlying district of steep hills and deep valleys which provide excellent tests for reflec-

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assignments demonstrate unquestioned feasibility of new methods spectrum economy in the Land Transportation Radio Services

PART ONE OF TWO PARTS

tions of the higher frequencies. East and West of the Park is fairly rolling terrain which provides enough attenuation so that a test for fringe area operation can be completed in a few hours without driving too many miles. Yet the hills are not sharp or steep enough to change conditions so rapidly that the conclusions cannot be properly interpreted.

Narrow-Band vs. Wide-Band

The first test was made to compare narrow-band and wide-band operation with reference to the distance from the transmitter and to the noise level. Here a 50-watt station delivered a signal which was modulated one minute at ±6 KC swing alternated with one minute at ±15 KC swing. The one minute period was divided into one-half minute voice and one-half minute 1000 cycle tone. At any time in the test that the observer wanted any one of the modulating conditions repeated in a different manner, such as voice transmissions for extended periods, he could break in with the mobile transmitter and give the station operator the needed instructions. The station antenna was mounted approximately 65 feet above the ground. The test frequency was 42.98 MC.

On a typical test the following results were obtained: Traveling east from the Park the signals on both receivers were essentially the same until the small town of Chittenango was reached, approximately 15 miles airline from the antenna. Chittenango lies in a deep valley and is completely in the shadows of the surrounding hills. The buildings are built close to the edge of the highway and the business district, which is approximately four blocks long, is very typical with its colorful neon signs, traffic lights, etc. This town became one of the favored test spots because of the high ambient noise and weak signal strengths encountered. There was a difference in signal to noise ratio between the two systems, but the difference was so little that if silent periods of a minute or two between transmissions were ordered, the narrow-band system could seldom be differentiated from the wide-band system.

Proceeding east the country is very gentle rolling terrain with villages at five or six-mile intervals. In each of these villages, tests were made and results obtained similar to those in Chittenango. By the time that the Village of Vernon was reached, approximately 32 miles airline from the Park, the reception of both the narrow and wide-band transmissions became very spotty. The conclusions drawn from the tests were that there is a difference in signal to noise ratio between the narrow and wide-band systems, but the difference is slight and no serious degradation of intelligibility is experienced.

This conclusion became obvious again on the return trip to the Park, when the route was chosen, which led directly into the heart of the City of Syracuse where extreme noise conditions are found. During this portion of the test, the signal level of the transmitter was dropped to the point where the background noise was definitely heard in the wide-band receiver. The increase in noise in the narrow-band receiver was then noted and found slightly greater, but only to the extent that it was greater and not great enough to impair the readability of the signal.

Interference Rejection

Next tests were made to compare the ability of the receivers to reject interference caused by a 40 KC adjacent station employing ±15 KC modulation. The 250-watt interfering station, 40 KC higher in frequency than the desired signal, was modulated by 1000-cycle tone and was keyed on and off while the car proceeded with the test.

With the interfering signal off the air, the test car was driven close to the antenna (approximately 75 feet). The desired signal strength was reduced until the receiver was

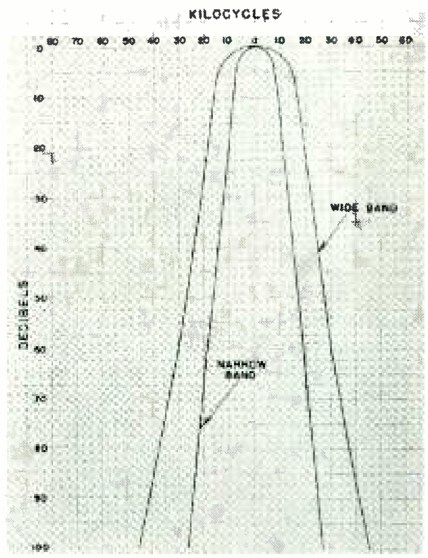

Fig. 2. Selectivity curves comparing narrow and standard (wide) band receiver performance

just quieting and the voice modulation is readable. The interfering signal was then put on the air. A weak 1000-cycle tone could be heard in the background but the desired signal modulated by voice overrode it with 100% readability on the narrow-band receiver, while on the wide-band receiver the 1000-cycle signal blocked out the desired signal and it was unreadable.

As the car moved away the 1000-cycle signal drops in and out of the background, due apparently to reflections and cancellations, until at a distance of approximately 1000 yards the tone entirely disappears from the background of the narrow-band receiver. This same type of action occurs on the wide-band receiver, but the distances were much greater and the interfering signals "hang" on longer.

The results of this test, especially in view of the intermodulation properties of the receivers, immediately show the possibility of using adjacent 40 KC channels in the same service area, using some of the previously unusable channels.

Finally a narrow-band run was made to show 20 KC channel selectivity and performance. Although the equipment was not designed to work adjacent 20 KC channels in the same service area, it was felt necessary to know the possibility of 20 KC adjacent channel operation when the stations were located in the immediate vicinity of each other and when they were geographically separated.

First Test Results

The first test was run with the desired signal of a 50-watt station modulated ±6 KC with tone or voice. An interfering signal from a 250-watt station, also modulated ±6 KC with tone, was located 20 KC higher in frequency. Transmitting antennas were separated just enough so that interaction between the transmitters did not occur.

With this ratio of powers of 5 to 1 (2.2 to 1 voltage ratio), the desired signal would "ride" through satisfactorily, although the signal was somewhat distorted because of the high-powered interfering signal. Since the antennas were relatively close together, except for minor reflections which cause the two signals to reach the vehicle antenna by different path lengths, the ratio of signal level remained fairly constant as the car moved away. Some improvement in quality was noted as distance increased because the selectivity is more effective on weaker signals. This test, although interesting to observe, does not represent a practical case, since systems in the 25-50 MC bands are seldom, if ever, located together.

The second part of the test gave a better picture of the limits of signal strength that can be tolerated from an interfering signal 20 KC off. After the car reached a point approximately 12-14 miles away, the desired signal dropped to the noise level, and the 250-watt equipment, 20 KC higher in frequency, was modulated ±6 KC. Measurements of the ratio of interfering to desired signal strength averaged about 18 to 1. On the return trip the interfering signal, which could just be detected in the background, remains fairly constant except again for the reflections. When the car was approximately 1000 to 1500 yards from the antennas, the interfering signal was so strong that the receiver blocked and there was complete silence.

Thus, if the systems were physically separated far enough so only skip signals appear on adjacent channels, 20 KC channel assignments could be made practical. This was tested out shortly thereafter in South America where many communication systems were working only 7 to 10 miles reliably because of the heavy barrage of signals from the United States. Running a receiver between channels and listening for the signals which he was hearing on the other receivers, indicated that the selectivity was great enough to reject signals 20 KC removed.

A pipe line company was using a pair of General Electric 250-watt transmitters operating on 39 MC to cover a 150-mile hop between Porto La Couz, Venezuela, located on a 1500-foot mountain with a 135-foot tower for the antenna, and Guasimito which utilized a directional antenna on a 400-foot tower on an elevation of approximately 500 feet. The stations on 39.020 and 38.980 were literally pouring in on the conventional equipment and so the system, although being used to good advantage, was anything but satisfactory. A narrow-band receiver at each end so reduced the interference that stations on 39.020 and 38.980 did not open the squelch even when it was set on the edge.

Design Factors

On all of the field tests described above, the equipment used in comparing wide-band and narrow-band performance was identical except for the critical features of receiver selectivity and transmitter swing. Both types have been in production now for more than a year with extremely satisfactory results in many operating systems which have verified the tests made in the developmental period.

Factors which pertain to the outstanding features of this equipment are in particular: Receiver spurious response attenuation, receiver selectivity, receiver intermodulation, spurious response attenuation, transmitter spurious, and harmonic radiation, and phase modulation limiting.

Spurious response attenuation is a measure of the ability to discriminate between a desired signal to which it is resonant and an undesired signal at another frequency to which it is simultaneously responsive. The main spurious response of superheterodyne receiver, the image, can only be attenuated by having adequate selectivity in the receiver circuits preceding the first IF amplifier. Other spurious responses likewise are attenuated by the selectivity of the r-f stages of the receiver unless they are very close to the desired frequency. In the GE receivers, Types ER-6-A and ER-7A, (Fig. —), five high Q tuned pre-selection circuits preceding the first converter grid result in an image attenuation of more than 100 db. The five tuned circuits are: A double-tuned antenna coil, and a triple-tuned r-f transformer following the r-f amplifier tube.

Since spurious responses are caused by mixing the undesired signal with the harmonics of the local oscillators, thus generating frequencies within the pass bands of the intermediate frequency amplifiers, many spurious can be inherently eliminated by reducing the number of harmonics generated in the local oscillators. So a triplex, or third overtone type of crystal, is employed for the first oscillator in order to obtain the high frequency required without frequency multiplication. This eliminates many spurious that are present in the older receiver designs which employ lower frequency crystals and frequency multipliers.

The selectivity of the first or high intermediate frequency amplifier, and, to a lesser extent, the selectivity of the second i-f, also affect the spurious responses by reducing the pass band of the amplifiers. The first i-f operates at 6 MC and has six, high Q tuned circuits contained in the two triple-tuned, first i-f transformers. Spurious responses of the narrow-band receiver are attenuated at least 90 db and on the wide-band receiver they are at least 85 db down.

Selectivity

For all practical purposes in the 25-50 MC band, no greater selectivity is necessary than has been obtained in these designs. The selectivity curves of both the wide-band receivers are shown in Fig. 2. This performance is obtained by three, carefully designed triple-tuned, second i-f transformers which operate at 455 KC in the narrow-band design, and 750 KC in the wide-band design. The transformers each contain three horizontal, parallel coils so that all tuning controls are easily accessible from above the chassis.

Part Two will appear in the October issue.

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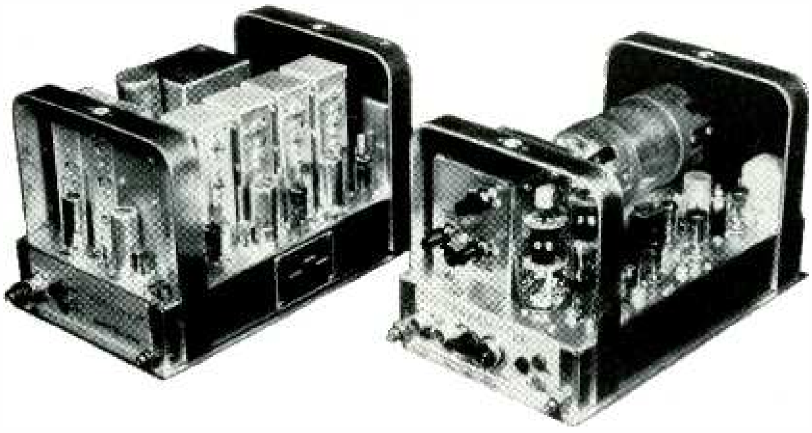

Mobile transmitter unit (right) and receiver unit (left) for mobile narrow band FM

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PART TWO

OF TWO PARTS

Receiver intermodulation spurious attenuation is defined as the measured amount of the receiver's ability to receive a desired signal to which it is resonant in the presence of two interfering signals so separated from the desired signal and from each other that the *nth* order mixing of the two undesired signals can occur in the non-linear elements of the receiver producing a third signal whose frequency is equal to that of the desired signal.

To illustrate with a specific example, suppose the case that is most likely to give trouble is considered. Suppose it is necessary to operate at some frequency F in the presence of two strong signals at F + 40 KC and F + 80 KC. The two undesired strong signals can mix in the first stages of the receiver producing modulation components, one of which falls directly on the frequency of the desired signal.

The intermodulation characteristic of the narrow-band receiver, Type ER-6-A (Fig. 3), shows the signal strength required for the undesired signals in order to obtain 20 db quieting. Here two curves are shown, one entitled, "40 KC Separation" for the case where the strong undesired signals differ from the desired signal by 40 KC for the adjacent signal and 80 KC for the alternate signal, and the second curve entitled, "80 KC Separation" where the adjacent signal is 80 KC away and the alternate signal is 160 KC away.

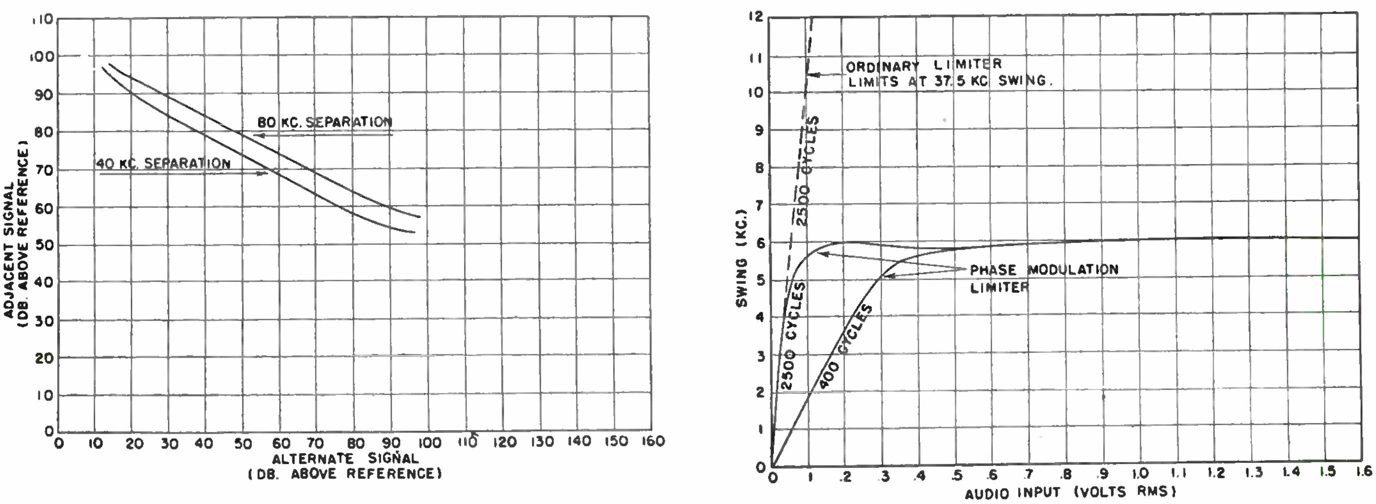
Spurious and Harmonic Radiation

Phase modulation transmitters, consisting of an oscillator, a phase modulator, a number of multipliers, and a power amplifier, will radiate an extensive spectrum of frequencies containing many harmonics of the crystal frequency.

In designing the new equipment, spurious effects were reduced by two design improvements: Better modulation characteristics — far exceeding the RMA requirements—were obtained with a lower multiplication factor, and the double-tuned circuits between stages were improved and tuned circuits were added.

The new wide-band transmitter, Type ET-6-B, has a multiplication factor of 24, and its spectrum (Fig. 4) was improved in that the highest spurious in the 25-50 MC band is now 76 db below the carrier as compared to 50 db on previous equipment. The second harmonic is

Fig. 3: (left) Intermodulation characteristics of receiver type ER-6-A. (right) Limiter characteristics of phase modulator stage



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66 db down compared to 46 db before.

The narrow-band transmitter, Type ET-6-A, has a multiplication factor of 12, thus giving a further improvement. The highest spurious in the 25-50 MC band (Fig. 4) is 88 db down, and the spurious adjacent to the carrier are now at least 95 db below the carrier. Also note that the narrow-band and wide-band transmitters have spurious and harmonics above 50 MC that are identical. These are a function of the final stages alone and in this respect the transmitters are the same.

> FCC STRESSES NEED FOR NARROW-BAND CHANNELS
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> **The proposed FCC Rules and Regulation of May 6, 1949 did not retain the 20 KC channel assignment plan for the 44-50 MC band contained in the June 30, 1948 proposal. The need of such assignments, however, is strongly emphasized in the following quoted statement:**
>
> "In acting upon that proposal herein, it is to be noted, we have considered the arguments addressed to the subject of frequency spacing and have established the assignments in the 44-50 MC band on a 40 KC interval, rather than on 20 KC as proposed originally. However, we wish to emphasize that the ultimate ultimation of this band, which is urgently required to take care of the anticipated overflow from the 152-162 MC band, will necessitate the development of technics and equipments which will operate on a closer spacing than 40 KC"

Phase Modulation Limiting

The limiting of the swing of a phase modulation transmitter poses one problem not encountered in transmitters having amplitude or frequency modulation in that with phase modulation the swing is proportional to the audio modulating frequency. Thus a phase modulation limiter must be capable of limiting the various components of the audio input in inverse proportion to its frequency. A simple mathematical analysis shows that this is equivalent to limiting the slope of the audio wave.

To accomplish this, the phase modulation limiter employed in these transmitters simply changes the audio input wave into a wave having an amplitude proportional to the slope of the original wave before it is limited in the usual manner. This change is accomplished by a simple pre-emphasis circuit. After limiting the wave is returned to its original form by de-emphasis so that, below limiting, the input wave is unchanged except for an insignificant phase shift between components. With such a limiter as this, it is not possible to swing the frequency outside of the assigned channel and yet satisfactory intelligibility is preserved under very heavy modulation.

Fig. 3 shows the modulation limiter characteristics and compares the phase modulation limiter with an ordinary amplitude limiter employed in a phase modulation transmitter. For the phase modulation limiter, both 400 cycles and 2500 cycles are limited to the same swing while for amplitude limiting the 400-cycle note may be limited to 6 KC while the 2500 note will reach 37.5 KC swing.

A swing of 6 KC has been used in this narrow-band equipment in order to limit the modulation components outside the 20 KC channel to the same percent that 15 KC allows outside of a 40 KC channel. The classical analysis using Bessel functions show that 6 KC is the correct value to use for this requirement instead of 7.5 KC. As previously explained, 6 KC has been used throughout the development and field tests.

Fig. 4: (left) Wideband transmitter ET-6-B emission spectrum with 32 MC carrier. (right) Transmitter ET-6-A narrow band spectrum