Mobile

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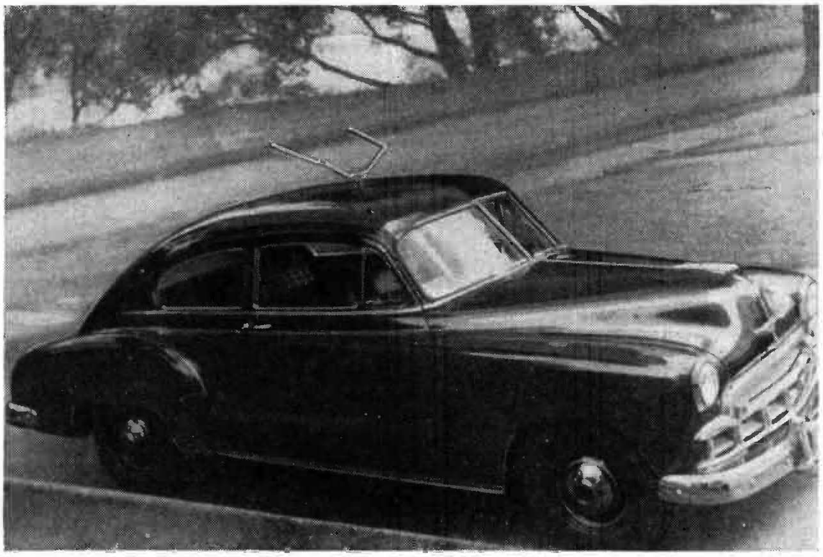

FIG. 1.—Automobile used in making tests is shown with ram's horn antenna in position

COMMERCIAL RECEIVER REQUIREMENTS

F-M AUTOMOBILE RADIO is already practical in some areas of the country having easy topography and good program service.

A national market of sizeable proportions will develop as f-m stations in other areas increase their daytime service.

Commercial receivers designed for mobile application will have to be quite different from those now used in fixed locations. This forward-looking article tells what some of the special requirements will be

AUTOMOBILE RADIO RECEPTION is not always a dependable source of entertainment due to constantly-shifting levels of signal and interference as the receiving automobile travels. Especially in open country at night, both cochannel and adjacent-channel interference alter their intensities with each mile, and fading of the desired signal may render it impossible to keep a station coming through during an entire program.

As is well known, there is less difficulty with atmospheric noise and cochannel interference with f-m, but different problems of commensurate importance become apparent in the course of tests. Enough data has been gathered, however, to indicate that f-m broadcast reception in moving automobiles is definitely practical.

Test Equipment

The automobile used in the tests (Fig. 1) was equipped with resistor spark-plugs, a distributor suppressor, and a generator capacitor. A wide-range amplifier (30 cps to 10 kc), employing push-pull 6AQ5's with 125 volts on the plates, yielded almost 4 watts. This was sufficient to over-ride the ambient noise-level of the car at 50 mph with the windows closed, although it appears that a reserve of audio power is desirable.

A 10-inch speaker was mounted in the firewall, using the hood for a baffle, as shown in Fig. 2. This makes an almost perfect speaker enclosure and provides good bass response.

The receiver used in most of the tests was Fidelotuner with an extra r-f stage and a modified limiter, having an approximate threshold sensitivity of 2.5 microvolts (50 ohms) over some two-thirds of the band.

Major Problem

The major problem manifested itself as rapid fluctuations of the audio recovery and as fluctuation noise, which occurred only when the car was in motion but seemed to have no particular relation to the roughness of the road nor to the speed of the car. Periodicity seemed to be related to the wavelength of the signal. This condition even occurred in areas of direct illumination by the transmitting antenna.

It was conjectured that out-of-phase reflections from various sources set up standing-wave patterns resulting in reinforcements and cancellations of the signal. Drops in signal strength were unnoted at first, as the average signal strength was quite high—much more than high enough to saturate the limiter when the car was not moving. Observations with an S meter verified this.

Curing Flutter

To assure saturation of the limiter while the car was in motion, an extra broad-band r-f stage was installed and the limiter was modified. Satisfactory performance was then experienced. Acceptable reception was obtained in many areas, and investigations were organized to establish what sensitivity was necessary under various conditions. It was concluded that the greatest possible sensitivity was necessary to assure the receiver's utility.

Rapid-fading proves troublesome in stationary long-distance reception. The same kind of fading often shows up in weak-field, long-distance mobile reception and is usually not accompanied by the standing-wave circumstances. The two are differentiated easily enough, as the rapid fading nearly always varies in frequency of fluctuation, probably because of a slip of phase in the paths of propagation as atmospheric refraction conditions change. When the extra path is caused by reflection from the wings of a moving airplane, the addition of the waves of changing phase is perfectly demonstrated. The trouble caused by multipath conditions can be alleviated by the wide-band treatment described in a later section.

It became apparent that amplifi-

F-M Broadcast Reception

Report on performance of various circuits and antennas for reception of frequency-modulation broadcasts in automobiles. Preliminary tests show need for increased sensitivities and improved limiting circuits in f-m broadcast receivers for moving vehicles

cation to saturate the limiter was not the whole answer to the near-field fluctuation trouble, as the speed of the ordinary limiter may not be great enough to hide serrated dips even in areas of high signal strength. These kinds of drops do not evidence themselves as vacillations of the audio recovery, but rather as fluctuation noise—sudden clicks and sputters. When the dips are not sharp, the result is a flutter of the audio.

The double cascade limiter, with its dual time constant and symmetrical limiting of both peaks, appears to be a necessity in this case. Increased numbers of cascades plus duo-diode shunt limiters can be used to advantage, but the 6BN6 gated-beam tube seems to provide good limiting without a time constant.

A transient condition of reception in cities, similar to serration noise, is caused by phase-interference of multiple reflections from hard-surfaced buildings and streets. Abrupt phase shifts cause an audio noise. This difficulty is treated as common channel interference. Though it is possible that common channel interference may produce p-m noise, most of the effect can be eliminated by wide-band detection techniques.

The second major problem also involves limiters and is the obvious one of ignition noise. (Industrial noise is less important.) Although internal-combustion engines treated with suitable suppressors cause little trouble in the majority of cases, a large percentage of cars and most trucks which pass cause tremendous static, often in spite of good signal strength and fair limiting. This is to be expected because of the proximity of the receiving antenna to the source of the noise. A partial solution of this problem will eventually come when laws are passed compelling all vehicles to be equipped with suitable suppressors, such as the resistor spark-plug, in order to eliminate tvi. In the meantime, improved limiters and antennas are prescribed.

Antennas

The design of a good antenna for mobile f-m reception is difficult. A

Table I—Typical Long-Distance Mobile F-M Reception Ranges

(Useful range limit estimated on basis of equivalent a-m noise performance)

Maximum range	*Receiving area length*	*Location*	*Station*	*Receiving antenna*	*Remarks*
105 mi	30 mi	Mount Pocono, Pa. Route 46	WHCU, Ithaca, N. Y.	Turnstile	Altitude of highway close to 2,000 feet
Up to 95	60	Skyline Drive in Virginia	All stations in Washington, most of Va. and Md. and some W. Va. stations	Ram's horn	Altitude of highway close to 4,000 feet
95	30	Routes 115 and 46 through Pocono Mts.	WQXR, New York, New York	Turnstile	
85	30		WCAU, Philadelphia, Pa		
90	No limit	Plymouth, Pa.	WSBA, York, Pa.	$\frac{1}{4}\lambda$ h–V	Received in Wyoming Valley over 1,500-foot mountains
75	Not ascertained	Dupont, Pa.	WENY, Elmira, N. Y. (5 kw ERP)	$\frac{1}{4}\lambda$ h-V	Perfect reception in mountains and good reception at foot of mountains (800-ft altitude)
70	No limit	Scranton, Pa.	WRAK, Williamsport, Pa.	$\frac{1}{4}\lambda$ h-V	
65	No limit	Scranton, Pa.	WKOK, Sunbury, Pa.	$\frac{1}{4}\lambda$ h-V	Good reception through most of variations in alt. and all towns
60	15	Wyoming, Pa.	WNBF, Binghamton, N. Y.	$\frac{1}{4}\lambda$ h-V	
50	3¼ mi areas	Kingston, Pa.	WFMZ, Allentown, Pa.	$\frac{1}{4}\lambda$ h-V	Reception in small areas from over 2,000-foot mountain range
50	Not ascertained	Binghamton, N. Y.	WQAN, Scranton, Pa.	$\frac{1}{4}\lambda$ h-V	
45	No limit	Scranton, Pa.	WPPA, Shenandoah, Pa.	$\frac{1}{4}\lambda$ h-V	
	2–50 yd areas	2 points inside Holland Tunnel in New York City	WQXR, New York, N. Y.		Reception possible in tunnel at points where change of slope occurs

ram's horn antenna was the first experimental antenna tried. The particular model shown in Fig. 1 has the disadvantages of extremely low gain (most pickup is concentrated skyward), a large component of vertical polarization, undesirable frequency sensitivity, and an irregular radiation pattern.

The properties of a vertically-polarized unipole were investigated, since it was thought that the loss of proper polarization might be compensated for if a good high-gain omnidirectional pattern could be acquired. Moreover, a large proportion of signals received while mobile are by reflection, and these often have much vertical polarization. However, patterns resulting were of small gain and just as irregular, due to the irregular ground-plane of the rooftop. A quarter-wave center-roof-mounted vertical whip, however, is useable for short ranges.

The gain of a horizontal antenna, ¼ wavelength above ground, was adopted as the minimum requirement. A whip type horizontal V was built using a foreshortened ¼ wavelength for a bazooka which symmetrized the pattern by balancing the potential of the two poles above ground. The gain and vertical directivity were vastly improved, and the horizontal directional characteristic obtained at center frequency was nearly perfect.

The antenna finally tested and more or less adopted as a permanent fixture is a turnstile, mounted ½ wavelength above the roof (maximum horizontal gain is obtained in this position). An extreme mechanical problem is introduced by the large dimensions of this type.

A 75-ohm coaxial cable passes through the center of the supporting mast. A combination bazooka-balancer and ¼-wave transformer matches the line to the parallel 75-ohm twinax leads which connect the dipoles. Good circularity and a low swr are obtained over the whole f-m band. The ½-wavelength mast raises the antenna above the ignition noise zone and a pickup with improved signal-to-noise ratio is obtained.

As desirable as antenna gain is, it must not be exalted at the expense of smoothness of the azimuthal radiation pattern. With all the variables to which the f-m signal strength is already subject, it is definitely undesirable to introduce a variation dependent on the car's maneuvering.

Present F-M Coverage

The research conducted was also intended to reveal how well typical highways are covered by f-m at the present time, which would indicate in part the practicability of commercial production of automobile f-m sets.

Highways in the East from upper New York state to Virginia are extremely well-covered by f-m stations. In fact, there are very few routes in these states that do not have large cities at least every 60 miles, and thus an f-m station always within receiving range.

The receiver used gave acceptable mountainless reception up to 40 miles from New York City with the ram's horn antenna, to 50 miles with the V antenna, and up to about 65 miles with the turnstile—when tuned to class B stations (20 kw at 500 ft). The useful distance of a set when immobile is, of course, much greater than when it is moving, because the motion of the automobile introduces the factor of fluctuating signal and noise.

It was found that the shadow problem on the highway is not so serious as feared or as academic predictions would lead one to anticipate. One can naturally expect very little reception when passing by a high mountain that lies between the route and the desired station. Also, when the road descends into a deep ravine, crosses a valley, or otherwise loses elevation rapidly, all but the nearest signals are lost until elevation is again established.

In wide valleys with steep sides there is usually good reception from stations perpendicularly behind the mountains, because reflection from the opposite side helps maintain signal strength. If the sides of the valley are gradually sloping, the fill-in may still be present, the major contribution being attributable to diffraction over a relatively sharp edge of the peak of the intercepting mountain.

It has been observed that excellent signal strength may be present from a station 40 miles behind a 2,000-foot mountain range in an area where the peak of the diffracting mountain can clearly be viewed.

Although these two kinds of fill may be present in a trough of sufficient width-to-height ratio, it is a different story in a narrower chasm. If a highway runs through a narrow trough with steep sides, there may often be no signal from any station unless the propagation is in line with the furrow. Short range reception is best for stations which use a sufficiently high tower to minimize close range shadows.

Good homogeneity even in streets of even hilly cities has been found, probably because of the vast possibilities of reflection fill-in by buildings. Tolerable reception on highways that change elevation abruptly is often afforded because the car's motion obscures the presence of dropouts which occur in only a small area.

Regarding the aid that hills give reception, the boost observed on the side nearest the transmitting terminal is carried all the way from near the bottom to the top and a considerable distance beyond the crown. If the hill is not too steep, the only apparent effect of the lower signal on the far side is a rise in receiver hiss-level. Nearly all the quirks of propagation and reception met can be predicted by present day theory[1] on uhf propagation.

Our comparisons of f-m and a-m practicability have shown that f-m fading is no more extensive, for the most part, than a-m, and that the signal returns more often. The useful range of f-m is commensurate with that of the majority of a-m stations.

Long distance reception occurs in low swr areas with a minimum number of dropouts, that have little relation to the absolute value of signal strength and which occur not necessarily because of line-of-sight conditions, short propagation route, nor because of large transmitted power, but occur because of the characteristics of the surrounding topography.

Reception of a purely diffracted wave is reliable, but an added wave caused by atmospheric refraction produces the weak signal oscillation mentioned previously. The omnidirectional antenna necessary for mobile reception is vulnerable to out-of-phase signals and cancellations of different reception paths, as well as other interference. No antenna rejection of interference is possible in the horizontal direction.

Receivers

The ideal receiver for installation in automobiles would be quite expensive. Some shortcuts might be necessary commercially. Great sensitivity is the major requirement. Other features could be used in a greater or lesser degree, depending on how idealistic one may be.

To obtain great sensitivity means a large amount of amplification—introducing the problems of regeneration, cross modulation, and undesired responses. The double or triple superheterodyne is a likely approach as it is easier to distribute a high degree of amplification in different frequencies, thus affording isolation; but the multisuperhet design must be worked out carefully to avoid spurious responses, such as those resulting from oscillator harmonics or oscillator beat frequencies.

Another approach to high gain is in the design of the selective circuits. A transmission-line type of tuned circuit, instead of the conventional lumped constants, will furnish a higher impedance and thus a higher gain, also with accompanying greater selectivity. The transmission-line type element should be as close as possible to a full quarter-wave, however.

The importance of selectivity in the front-end for minimizing spurious responses should not be undervalued. The tuned stage should be the earliest one possible and any broad-band coupling should follow it. If the first r-f stage is broadband, it will have to be carefully designed for linearity. The r-f stage added to the Fidelotuner was made broad-band for simplification and economy and it is, unfortunately, subject to overloads and heterodynes. The high sensitivity necessary in the mobile receiver renders it extremely vulnerable to cross-modulation.

Nominal sensitivity (50-ohm terminals) should be one microvolt and it is felt that a useful sensitivity in the tenths of microvolts can be achieved in production without extraordinary difficulty. The point should be made that supersensitivity is not of so much value unless it is accompanied by low-noise amplification in the r-f head. For a maximum range, the controlling noise of a receiver should be that due to the resistance of the antenna with a minimum added by the circuits and tubes of the r-f preamplification.[2]

When the receiver has enough amplification to assure saturation of the limiter, the vacillation of audio recovery previously described will not be exhibited, but in the fringe areas the trouble may still be evident in an undulation of the background noise level. This difficulty emphasizes the need for low-noise design with two triode r-f amplifiers. The cascode amplifier[3] is a good arrangement, and the use of the Tung-Sol 5687 twin triode would probably yield excellent performance in gain and noise factor, although the less expensive 12AT7 may certainly be utilized in less idealistic fabrication.

FIG. 2—Firewall speaker mounting using the hood as a baffle.

The commercial receiver would have to be quite rugged and capable of holding its alignment when subjected to road shock.

Tuning indicators are of no value when in motion. Automatic-frequency-control seems to be a must for mobile receivers.[4] It eliminates the side responses (which would occur if a conventional discriminator were used), acts as a valuable aid in tuning (the set is automatically brought into resonance when tuned near a station), obviates the necessity of crystal-controlled oscillators to eliminate drift, automatically reduces the distortion caused by adjacent-channel carriers[5], and maintains the i-f in the exact center of the discriminator characteristic, meaning maximum invulnerability to any ignition noise residue passed by the limiters. The only disadvantage is the possible loss of tuning during the fluctuation of a very weak signal, or the possible switchover to another channel.

Bandpass

It is desirable to use a somewhat wider i-f bandpass than usual. Most stations unfortunately maintain their modulation level high and speech transients slip through the compressor, resulting in the signal becoming distorted when passed through the conventional receiver —i-f—amplifier. It should be kept in mind that the bandwidth of an f-m signal deviated plus or minus 75 kc is quite a bit more than 150 kc[6], and that it is the phase unlinearity of the i-f, not the amplitude unlinearity, that causes distortion[7]. Residue overmodulation of short duration is much more apparent with f-m than with a-m. Allowance for this, plus some acknowledgement of i-f drift, would seem to indicate a bandpass of well over 200 kc as the preferred specification. A steeper bandpass can be obtained by using relatively low gain per stage, which would allow for an extra stage with another bandpass network.

Wide-band detection (3 to 6 mc) used to cancel out distortion and noise products of spikes caused by multipath reception and channel interference, as described in the references 8, 9, 10, has great value in the mobile receiver. At the very extreme limit of the propagation range the fluctuation is smoothed out, since the signal is weak, while the reception is distorted by cochannel out-of-phase waves arriving by a longer path, but with almost as much strength as the direct-path wave. Elimination of the distortion, by this means, may result in a receiver of a useful range extended to over 100 miles if careful attention is paid to the noise factor of the front-end so that the signal will not be lost in a background of noise.

Skywave propagation of f-m,

represented by reception in excess of 100 miles, is related to meteorological conditions for the most part and has very little to do with ionospheric propagation. It does not fade so much, nor is it so variable as a-m skywave.

Use of wide-band limiters and discriminator should also be considered as an aid to the adjacent-channel interference problem[5]. Channel interference has been observed in the New York City area with the receiver described having a selectivity not quite 60 db adjacent channel, considered sufficient by manufacturers at the present time.

Described in the references is a 6-mc wide-band discriminator which is conventional in utilizing tuned circuits, but is superior to the usual transformer type. Noise reduction capabilities are combined in the detector. It was conceived by Arguimbau and Granlund and is described in their latest article on Trans-Atlantic f-m[10]. The 6-mc bandwidth of limiters and discriminator is capable of ignoring distortion resulting from an interfering carrier with an amplitude of less than 5 percent of the desired carrier amplitude—½ db difference. A 3-mc discriminator is useful for a ratio of desired to interfering carrier up to 90.5 percent for 75-kc swing. Either is vastly superior to the rejection capabilities of the ordinary f-m system usually prescribed as requiring a 2-to-1 ratio of signal to interference.

In cases where this kind of wide-band detection is not warranted, it is felt that a wider discriminator than now utilized is still required. The best i-f of present-day techniques is still not good enough to ignore even a minimum of adjacent or alternate channel signal. When the peaks of the discriminator fall in the adjacent or alternate channel, the trouble is intensified and a large distortion product may result from merely an unmodulated carrier in this region. A discriminator with a bandwidth sufficiently wide so that its peaks are far out on the i-f skirt, at least farther than the alternate channel, seems to be the minimum requirement.

Though we have not yet had the opportunity to observe the mobile performance of a receiver with wide-band detection, we certainly expect it to perform with less noise, less distortion, and greater range, —to be reliable to 100 miles in conjunction with a good antenna. The combining of a-m facilities in the mobile receiver would be desired at the present time; however, with the circuit complexities already present in the receiver due to the involved requirements of mobile f-m, it would seem inadvisable to complicate matters further and increase expense. Our visualizing such an f-m receiver commercially available is for the day when all stations furnish full-time f-m programs.

Conclusions

From experimentation it has become evident that mobile f-m broadcast reception is feasible to further limits than had been expected. Shadow fill-in by various agents renders useful the quasi-optical type of propagation, but irregularities pose an extreme problem in limiting, since the signal intensity varies to extreme limits although fill in and other phenomena have kept it at a useful value. The line-of-sight restriction having been successfully dealt with, the remaining problem is that of distortion resulting from multi-path-wave interference in weak fields, which appears to be solvable with wide-band detection.

In this article we have not speculated as to the relative superiority of mobile f-m to a-m, or conversely; but in our investigation, there has been much evidence of a nature to cause a partiality toward f-m. Mobile reception of WQXR, a-m and f-m, illustrates the vast advantages of f-m, for the 10-kw a-m signals are consistently lost in a conglomeration of channel interference. (The programs of WQXR are ideal for a research of this nature.) We might add that the dead area of WQXR-FM's reception, which may occur between a distance of 65 to 80 miles from New York, is amply filled in by the retransmission of the programs through Allentown's WFMZ.

Table I lists some of the reception data obtained. It can be said that while the lower a-m frequencies have more effectual propagation properties, the f-m band has the more pertinent value of lower noise characteristics. As the solution to the problems of mobile broadcast reception, f-m holds great promise, although all of its theoretical advantages are not yet completely utilized.

Contrary to predictions, f-m is not lost in areas where line-of-sight is impossible, even amongst the tall clusters of shadow-throwing skyscrapers on Manhattan. Also, there are no ionospheric skip effects, a minimum of erratic skywave, no serious co-channel problems, and thunder storms and other atmospheric noise have no influence whatsoever on mobile f-m reception. Also f-m is capable of penetrating most of the roadside type of barriers to a-m. Passing over a steel cantilever bridge or under a steel reinforced viaduct has almost no effect, whereas almost complete shielding of a-m signals would result.

Looking on the dark side, it appears that some time will pass before all the advantages of mobile f-m can be incorporated in a commercially available receiver of reasonable cost. The receiver improvements suggested all involve expense and difficulty of mass production. We do look to f-m however as the ultimate answer to perfected mobile broadcast reception in the future, even though the problems are of great extent. Further investigation into this application is emphatically recommended.

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