Mobile radio communication — 3

Range, interference and a comparison of a.m. and f.m. systems

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The following factors govern the range of effective communication between two stations in the v.h.f. and u.h.f. mobile services.

Frequency. The frequency affects the propagation loss between aerials, transmission-line losses, receiver noise factor, ambient noise and interference, the effect of movement and of mistuning. An increase in operating frequency increases the losses, the noise factor and the effects of movement and mistuning but decreases noise and interference.

Modulation. The type of modulation has an effect on the signal/noise ratio at the input to the receiver for the required communication quality. Theoretical studies of the relationship between the commonly used modulation types, a.m. and f.m., show the latter to have a good margin of superiority over the former for all but very low signal/noise ratios. Field trials have not entirely confirmed such a clearcut advantage, probably due to the different behaviour of the two types of modulated signals when they fluctuate at low average levels. This discussion is limited to amplitude modulation and frequency modulation, using speech or sinewave modulating signals.

Depth of modulation. For a sinewave signal, it is easy to define a 100% modulation level in an a.m. system or to set an agreed maximum deviation in an f.m. system. Modulation depth for speech, with its high and indeterminate peak/mean ratio, is not so easy to set but, by experiment and experience, it has been found that peaks can be clipped or compressed to within 6 dB of the mean without excessive distortion or loss of naturalness in the voice. A.g.c. circuits can be used to keep the mean level of speech from all operators constant to within a few decibels at the transmitter modulator stage. Excessive distortion in the audio circuits of transmitters and receivers degrades intelligibility and, hence, the communication range.

Effective radiated power. Systems models assume, in most cases, that half-wavelength dipoles are used as aerials. It is possible to concentrate more power in a given direction by using a directional aerial or, when omnidirectional propagation is essential, by stacking aerials to reduce the vertical beamwidth of the aerial. Such gains over a dipole must be taken into account when calculating the effective radiated power. Although r.f. losses in aerial elements are low, feeder, filter and changeover relays reduce the effective radiated power (e.r.p). Typical values in the mobile services are 25 W for high-power mobile and base stations, 5 W for low-power sets and 0.5 W for portables.

Low-power a.m. mobile unit (GEC-Marconi)

Effective transmitting-aerial height. This parameter is a difficult one to settle in any given location because it depends to a large extent on the path profile between the transmitting and receiving aerials as well as the height above local ground level. CCIR recommend that this height be taken as that above the average height of the ground along the path towards the receiver between 3 and 15 km from the transmitting aerial.

Propagation loss. CCIR give curves for field strengths for a radiated power of 1 kW and various aerial heights and paths, and from these the propagation loss can be calculated. These curves are drawn for 50% of locations and varying time percentages. Corrections are given for path roughness and for different percentages of locations. Height/gain corrections are also discussed by CCIR. These curves are averages and should not be relied on for high accuracies, especially when ground constants differ from the average values they assume.

Effective receiving aerial height. CCIR recommend that this be taken as the actual height above local ground.

Receiving-aerial gain. As with the transmitting aerial, the receiving aerial can be more directional than a dipole. If this directivity is in the vertical plane, it may also result in higher noise pickup. The usual quarter-wavelength whip for 'low' band v.h.f. mobiles has a small loss compared with a half-wavelength dipole, but aerials with gain relative to a dipole may be used for the higher frequencies.

Receiver sensitivity. CCIR recommended a minimum ratio of 15 dB as output signal/noise ratio, measured by means of a volume-unit (v.u.) meter, for a speech signal set to give an average modulation depth (amplitude modulation) of 6 dB below peak at the source transmitter. The signal/noise ratio for 100% modulation is thus 21 dB. For a.m. receivers this is the i.f. signal/noise ratio required at the detector. For frequency modulation, the required i.f. signal/noise ratio depends on the relative bandwidths of the i.f. and a.f. sections and, for low ratios, on the peak deviation also when, as is necessary, so great an allowance has to be made for frequency inaccuracies due to temperature changes and mistuning that the deviation does not fill the whole channel. For 25 kHz channels the average crystal filter in the i.f. stages has a bandwidth of about ±8 kHz and the peak deviation is ±5 kHz, with an audio bandwidth of about 2800 Hz. For 12.5 kHz channels, the figures are ±3.75 kHz, ±2.5 kHz and about 2400 Hz, respectively. No correction for unused bandwidth is necessary above an output signal/noise ratio of about 20 dB for these figures (a.m. and f.m.). The input signal/noise ratio is determined by the level of the wanted signal field around the aerial, the aerial gain, the losses between the aerial and the receiver, the noise factor of the receiver and the ambient noise and interference picked up by the aerial within the passband and spurious response bands of the receiver. Good mobile receivers of recent design have noise factors of about 2.5 (4 dB) and losses between aerial and set as low as 1-2 dB, usually rising with frequency.

Table 3. Typical ranges in mobile radio systems

Band	Receiver noise figure, dB	Mobile aerial gain, dB	Range in kilometres for ambient noise								
			low			medium			high		
			a.m.	f.m.	f.m. with flutter	a.m.	f.m.	f.m. with flutter	a.m.	f.m.	f.m. with flutter
Low v.h.f.	5	—	37	55	45	33	46	39	**20**	30.5	**25**
	12	—	36	52	43	32	45	38	19.5	30	25
Mid v.h.f.	5	—	38	53	34	**31.5**	44	**26.5**	23	34	19.5
	12	—	34	49	29.5	30	42	25.5	22.5	33	19
High v.h.f.	5	—	39	60	34	33	47	27.5	24	35	19.5
	12	—	32	46	27	30	42	24.5	23.5	34.5	19
	5	3	45	68	37	**37**	54	**31.5**	27	39	22.5
	12	3	36	53	31	33	48	28	28	38	22
u.h.f.	5	—	26	41.5	29	24	38	28	17.5	29	20
	12	—	19	32	21.5	18	30.5	20.5	16	28	18.5
	5	6	33	53	**38**	32	49.5	35	24	38	26.5
	12	6	26	42	29	25	39.5	28.5	22	35	25

Note: Flutter allowances are —4dB for v.h.f. and —8dB for u.h.f.

Ambient noise varies widely and has not been quantified recently for all conditions of service of mobile radio units. Generally, it reduces with increasing frequency and is almost negligible at u.h.f. There may be several paths between transmitting and receiving aerials and losses and phase angles in each path may change as the mobile changes position and therefore the resultant signal to the receiver input also varies. Such changes are large in urban areas where no direct line-of-sight path exists. The effect of large obstructions is not allowed for in CCIR data but smaller irregularities are covered by alteration of a terrain factor. Losses caused by large obstructions can be estimated using a parameter related to their height in wavelengths above an unobstructed datum. In a.m. sets, the output signal/noise ratio follows closely the fluctuations in input signal level but, in f.m. sets, there is a threshold below which the output signal/noise ratio deteriorates rapidly, more rapidly as the deviation ratio* increases. The average output signal/noise ratio therefore falls below that for a notional average in the absence of fluctuation at these low levels, and degradations of some 8dB for 25 kHz u.h.f. channels and 4 dB for 12.5 kHz v.h.f. channels may be caused by this effect.

Effect of tuning inaccuracies. A.m. systems are more tolerant to detuning than f.m. systems in which the result is harmonic distortion rather than the amplitude distortion of the a.m. systems. Noise also increases more rapidly with detuning in f.m. systems because of the resulting asymmetry of the noise sidebands with respect to the centre frequency of the i.f. and discriminator circuits.

Using the CCIR data and assigning typical figures to the various parameters, typical ranges when using the four main frequency bands are given in *Table 3*. Ranges with and without the flutter allowance discussed above are shown and the most likely conditions for urban systems are shown in bold type. Results are given for a.m. in the u.h.f. band although this type of modulation is not used in that band.

The beneficial effect of aerials with gain at the mobile for the higher bands is evident. The small effect of a substantial degradation in noise figure in mobile low-band receivers can also be seen. If the flutter allowances are not applied, the ranges for f.m. are considerably greater than for a.m. but the flutter allowance brings them more towards equality, in line with field results.

Interference problems

All present-day mobile radio transmitters, using crystals as frequency-determining elements, are constrained by the availability of crystals and the need to avoid large power gains at the output frequency to use multiplying stages to obtain the final frequency from a lower crystal frequency. A wide range of harmonics of that crystal frequency are generated and all but the wanted one have to be filtered out before the signal reaches the aerial. The limit specified in the UK is 2.5μW (11.2mV across 50 ohms) which is about 70dB below the wanted output level in a high power set. Even this level of unwanted harmonics, if fed to a resonant aerial, could cause trouble to, or open the mute of, a receiver at a distance of up to about 3km.

In other types of transmitter using synthesizer drive, spurious emissions and noise can be derived from the side chains or frequency-correcting and stabilising circuits. Noise or signals on supply lines may also modulate the wanted output and good filtering is again necessary. Other unwanted signals can be produced in the output stages of transmitters, spaced at multiples of the spacings between the various signals present. Such spurious signals are especially likely in multiple transmitter installations and can severely restrict the choice of operating frequency for new additions.

As mixing is a feature of all receivers used at present in mobile radio services, the existence of spurious responses is unavoidable. Other unwanted outputs can be produced in a receiver which is overloaded or has insufficient selectivity. Receivers can generate interfering signals at harmonics of the crystal frequency and also at the i.f. Spurious responses can be reduced in number by using the highest practicable injection frequency for the first and only mixer — using more than one mixer adds to their number. The required spurious response ratio with respect to the wanted signal is about 70dB and this can be attained with relatively inexpensive and efficient r.f. tuned circuits for r.f. to i.f. ratios up to about 25. There is therefore a case for a higher i.f. than the conventional 10.7MHz for the u.h.f. band or for the use of double superhets with a much higher first i.f.

Reductions in the overload spurious responses, intermodulation, cross modulation and blocking, are difficult to achieve as they depend on the linearity of the r.f. amplifier and mixer stages unless extremely selective circuits, such as crystal filters, are fitted in the r.f. section. Co-channel signals also cause a great deal of interference and are more likely to cause difficulties in data systems than in those employing speech when they can, to some extent, be ignored. In a.m. receivers, a protection ratio of about 17dB for interfering a.m. signals and 8 to 17dB for f.m.

signals may be necessary for good reception while in f.m. receivers the ratios may be about 10dB and 8dB respectively.

Noise can be generated in transmitters, where it appears as sidebands accompanying the carrier. Noise generated in the crystal stage or subsequent phase modulator in f.m. sets is usually preponderant because of the high following power gain but other sources may be the power lines or the audio circuits which can pick up hum or converter noise. External devices, such as the ignition system, regulator, horn, windscreen wiper and even brakes originate unwanted noise and can usually be made innocuous by suitable decoupling, screening or earthing. In duplex systems, any poor electrical contact between sizable metal parts will produce noise when the transmitter is in use and extensive bonding of all such parts is advisable. In receivers, noise originates mainly in the input stage and aerial, though some may again be fed into audio circuits from noisy supply lines or be picked up by direct radiation from the noisy devices listed above. External noise, not originating in the set or vehicle, is picked up by the aerial and varies widely with frequency and location. Some American measurements of the effects of noise and flutter, in terms of the increase in signal level necessary to restore a specified communication quality, are given in *Table 4*. The degradations tend to a minimum at 470MHz and above showing the reduction of ignition noise with frequency and the residual allowance for flutter.

Avoiding interference

When only a few stations are sparsely scattered over a given area the main precautions to be taken in choosing frequencies and setting up stations are the avoidance of spurious emission or response frequencies and the reduction of noise. In single frequency systems it may not be possible to operate transmitters and receivers from the same site when more than one channel is involved and they may have to be spaced apart by a few kilometres. Frequency selection becomes more and more difficult as the numbers of closely-sited stations increase because the numbers of third, fifth and higher odd-order intermodulation frequencies increase rapidly with the numbers of stations involved.

If one base station transmitter is shared by a number of small users the channel can be more fully used and fewer base stations are then needed in a given area. This has the obvious limitation that one channel is incapable of serving more than about 60 mobile units using normal procedures. In shared systems, each group of mobile units is selectively-called, individually or as a group, and time limitations are set for base station transmissions to ensure fair sharing of air time.

Table 4. Degradation of mobile signals by noise and flutter

Signal increase necessary to restore communication quality (dB above 0.7 μV).

Band	Grade	Mobile stationary in noisy area	Mobile moving in noisy area	Mobile moving in low noise
Low	4	25	18.5	11.5
Mid	4	21	15.5	11
High	4	17.5	13.5	10.6
U.h.f.	4	11	10.5	10
Low	5	18	15	8
Mid	5	13	11.5	7
High	5	10	9	6.5
U.h.f.	5	6.5	5.5	5.5

Notes: Grade 4 is for noticeable interference, Grade 5 is for annoying interference.

Where the source of an interfering signal is known, a direction aerial can be fitted as a base station with a null in that critical direction. Such minima are usually sharper than the maxima and so the sacrifice of coverage in the direction of the unwanted signal can be small. Conversely, the gain aerial can be used to override an unwanted signal at a mobile from a transmitter located outside the normal coverage area but this method should be used with caution to avoid increasing interference in the neighbouring area.

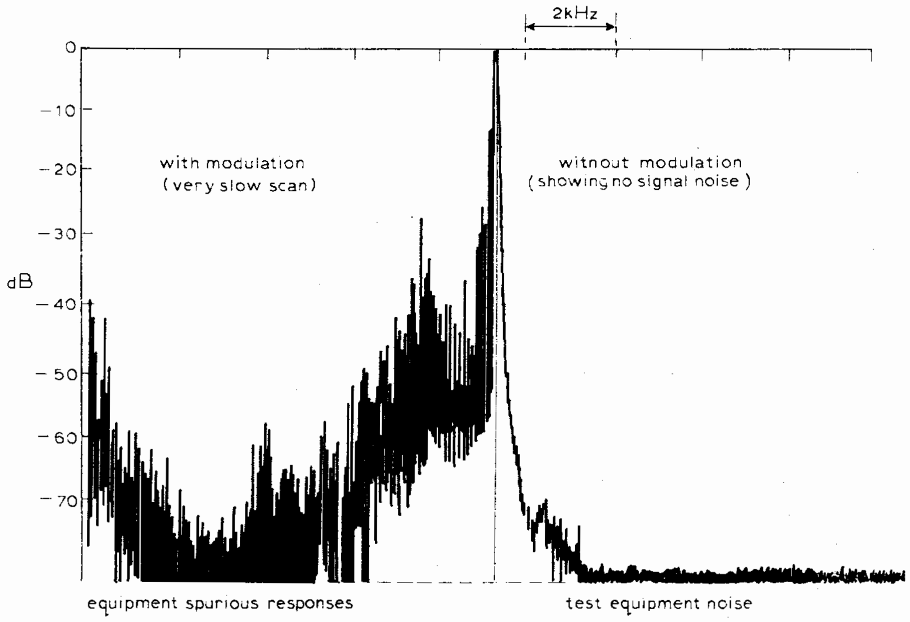
When sufficient frequency spacing exists between the wanted and the interfering signals, filters can be used to give additional selectivity. Bandpass filters, based on cavity resonators or similar devices offering very high working Q factors, will yield losses of about 30 dB at 2% off centre frequency with an insertion loss of about 1 dB. More complex filters, designed according to conventional techniques, can be built up from such elements for both bandpass and band-stop functions. In all cases, attention is required to the effect of temperature changes to avoid tuning drifts.

Comparison of modulation systems

Amplitude modulation has stood the test of time in the UK as a system of modulation which gives good practical results. The process of modulation and detection are readily visualized by servicemen and can be checked with an oscilloscope when desired, making for simple servicing. The use of peak limiters in transmitters has increased the mean level of speech modulation, giving longer ranges or improved signal/noise ratios. Some tailoring of the responses or microphones and audio amplifiers has cut out unnecessary bass, without entirely removing individuality from the operator's voice.

Frequency modulation is still used exclusively in some services and is coming into increasing use in the land-mobile services, owing partly to its exclusive adoption in the u.h.f. band. The usual modulation characteristic is neither pure frequency modulation nor pure phase modulation, but a hybrid whose proportions vary with the degree of limiting imposed in the transmitter audio circuits. In theory, the present 12.5 kHz channel widths are inadequate for faithful transmission of frequency modulation with the full permitted deviation of ±2.5 kHz, but the distortion in properly tuned sets resulting from any loss in sidebands has been found, in practice, to be small. Frequency modulation has a considerably wider spread of significant sidebands than amplitude modulation when modulated by a sinewave but, for speech modulation, set to the same peak, the sideband levels are lower for both types of modulation and distortion adds to both, so that the difference between the two is less marked, as shown in Figs. 6 and 7.

Fig. 6. Typical integrated sideband plot for an a.m. transmitter.



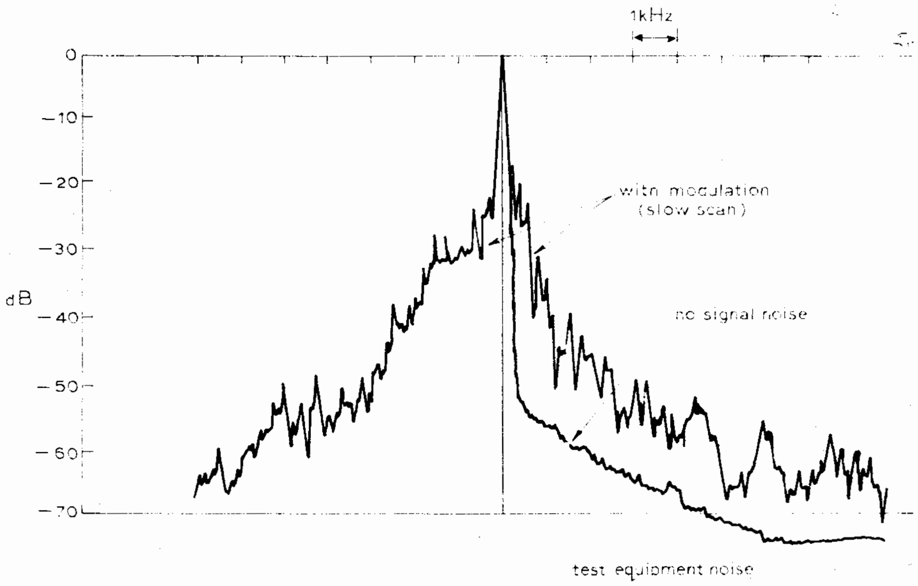


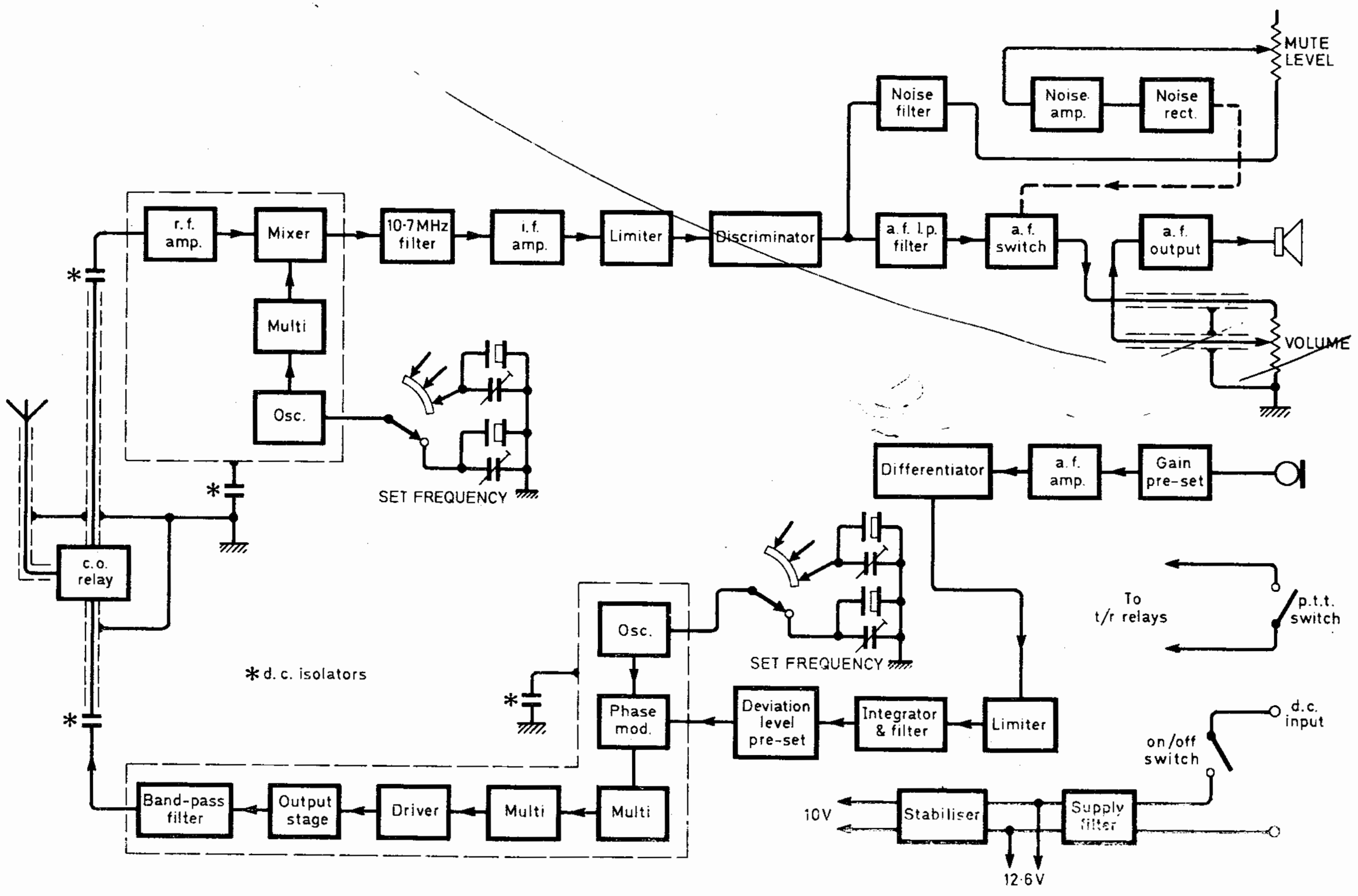
Fig. 7. Typical integrated sideband plot for an f.m. transmitter.

In f.m. receivers, an improvement is obtained in output signal/noise ratio above a certain threshold input signal level when compared with an equivalent a.m. receiver but, in practice, flutter and man-made noise mask this effect in mobile service. In point-to-point links, the superior signal/noise ratio in f.m. systems, operating at the higher and more constant signal levels and in the wider channels generally available, makes frequency modulation the usual choice. Fig. 8 shows a typical low-power f.m. mobile unit.

Noise limiters have been developed effective in reducing the nuisance value of impulsive noise in mobiles. In f.m. sets, the width of the i.f. passband limits the height of impulses passed to the audio amplifier after demodulation, but, as the i.f. bandwidth must include some allowance for drift in frequency, these impluse peaks can exceed the peak of the wanted modulation envelope, whereas, for a.m. sets, the peak limiter can be set to clip down to 50% modulation or less without distortion of speech. F.m. limiting is therefore not as effective as a.m. limiting, and suffers more from mistuning. So far, attempts to design an f.m. limiter on the same basis as the a.m. type have not yet yielded sufficient improvement to merit their inclusion in standard mobiles.

F.m. transmitters make better use of an available r.f. output device than an a.m. transmitter. In the last-mentioned, allowance must be made for the upward swing of the modulating voltage and the increased power dissipation under modulated conditions, whereas the f.m. output stage works permanently under steady carrier conditions. The difference in the low-power transmitters used in the mobile radio services is not very significant however, being less than 2.5 dB in most cases. Power conversion efficiency is also slightly better for f.m. transmitters in this power range, the need for more multipliers or modulators off-setting the absence of the high-level modulator stage. Care is necessary in the design of the supply circuits to the modulated stages in an a.m. transmitter, to ensure that parasitic oscillations cannot occur at any point in the modulation cycle owing to parametric effects in the collector capacitances.

Fig. 8. Block diagram of typical low-power f.m. mobile transceiver.



Single sideband (s.s.b.) operation has been largely ignored in the UK for mobile radio in the v.h.f. and u.h.f. bands, although its use has grown very rapidly in similar bands used by radio amateurs. Reports of trials in the USA in the 1960s were not encouraging and, in particular, revealed poor performance in s.s.b. receivers in the presence of even modest levels of impulsive noise. More recently, it has become apparent that one of the possible advantages of single sideband, that of narrower bandwidth, is not as real as might be supposed, because of the limited rejection of the unwanted sideband achieved in practical transmitters, especially when modulated by speech. Rejections of 40-50 dB are not adequate to free the adjacent channel for use in the same location, and so the number of available channels would not increase in proportion to the nominal reduction in occupied bandwidth. Nevertheless, channel famine may have grown to such an extent that s.s.b. will have to be reconsidered.

In recent years double-sideband suppressed-carrier (d.s.b.s.c.) and double-sideband diminished-carrier (d.s.b.d.c.) systems have been investigated in depth by the University of Swansea on behalf of the UK Home Office in pursuit of a system which would allow area coverage in narrower channels than the present 25 kHz ones, and which would increase the range of the power-conversion efficiency of portable sets. Theoretical and bench studies showed that the original idea of using d.s.b.s.c. was not very practicable, because of difficulties in reinserting the carrier, especially when two signals of comparable strength were being received, and in providing effective a.g.c. It was found that a diminished carrier, set about 16 dB below the equivalent a.m. carrier, would greatly reduce these problems without losing the benefits of beat reduction and transmitter d.c.-to-r.f. efficiency coupled to a degree of secrecy, achieved in the d.s.b.s.c. system.

Double side-band diminished-carrier was preferred to s.s.b., despite its apparent increase in occupied bandwidth, because it did not suffer to the same degree from impulsive noise, being a balanced system, or from a.g.c. problems in receivers, and it can be introduced into an a.m. system with fewer changeover difficulties. Receivers are phase-locked to transmitters, reducing the overall frequency drift to that of the base transmitter, which can be made very stable at little expense. The required channel width can be reduced to about 25/3, or 8.33 kHz. It is expected that d.s.b.d.c. systems will accept data signals readily, but full confirmation of this and other aspects await the results of a large-scale field trial now in progress.

Whereas this system may be suitable for the police and fire service, with their special problems of wide-area coverage with centralised control, the advantages do not seem to outweigh the disadvantages of initial higher costs and integration difficulties for established commercial systems using amplitude modulation or frequency modulation. In particular, the cautious claim that the channel width could be reduced to 8.3 kHz would not be very attractive in the v.h.f. bands, where channel widths are already 12.5 kHz and the next division in the same tradition as previous splits would be to 6.25 kHz. Such a channel width might be usable by a.m. d.s.b. systems, using phase-locking techniques and the referencing of mobile transmitters to the base station frequency to remove all differential drift, but the chances of a competitive f.m. system seem to be bleak, although the same was once said of the 12.5 kHz system now in general and successful use.

At present, there are no practical alternative systems on offer in which direct speech modulation is replaced by some form of speech coding. It is possible that some such arrangement can be devised which will still further compress the bandwidth required for intelligible speech or which will multiplex many conversations into one channel of present width, allowing present frequency allocations to remain untouched.

The successive reductions in bandwidths over the years have resulted in a worsening in the quality of communication in individual systems, and this has generated a certain amount of dissatisfaction in users taking over new equipment, operating in narrower channels, after having experienced using wider channels. The overall problem, however, is still one of accommodating the large number of users in a limited radio spectrum and so, as in many other fields, quality of communication has to be sacrificed to some degree for quantity.

Testing and test equipment

Normal routine testing in the field is usually carried out using simple, specialized meters to check important voltages and currents, discriminator operation, when relevant r.f. output and similar parameters. In these days of integrated circuits, first-line servicing can be carried out by interchanging plug-in boards and so a full set of test equipment is needed only at the base workshop. Such equipment must, however, be of a high standard if full scale tests are to yield results related to the performance of the set rather than to the test gear itself.

When the number of sets to be serviced is high, automatic test equipment is sometimes used. Special jigs are necessary to connect the equipment to the sets unless, as is becoming a feature in some sets, a special connector is provided externally for this purpose.

Acceptance testing is carried out by the licensing authority on prototype units, representative of the subsequent production run. These tests are very exhaustive and are carried out over a range of temperature and supply voltage and demand test gear of a very high standard, especially in respect of adjacent channel noise and frequency stability.

**deviation ratio = ratio between half the i.f. bandwidth and the a.f. bandwidth.*