S.S.B. on Medium Waves?

Can we get more broadcasting channels into the available frequency band?

by G. Wareham

The European medium-wave broadcasting band has been getting into a mess in the years since the Copenhagen Plan of 1948. More than half the present-day transmitters are not authorized by the Plan. Some transmitters use excessively high power, with the result that ionospheric modulation (the "Luxembourg Effect") hampers the reception of other stations in line with them. In addition, there is now a widespread source of local interference in the form of whistles caused by harmonics of line timebase oscillators in television sets.

Voices have been raised from time to time in favour of adopting single-sideband broadcasting as a means of doubling the available channels. Others are inclined to write off the medium waves for broadcasting purposes and concentrate on v.h.f./f.m. with its advantages of freedom from interference and noise, and potential high quality.

What future, if any, has medium-wave broadcasting? The technical problems — overcrowding and excessive powers — are manifest, and the engineer naturally searches for engineering answers. But the problem involves economics and politics as well. So before looking at some specifically technical proposals it may be worth while examining the situation in a more general way.

Need for m.w. broadcasting?

The argument against m.w. broadcasting is straightforward: v.h.f./f.m. is technically better. Yet there are some good reasons for continuing with medium waves:

1. Exclusive m.w. transmissions. So long as people want to listen to programmes which are put out only on medium waves there will be a demand for m.w. receivers. In the U.K., for instance, there is an audience for Radio Luxembourg.

2. Capital wastage. Much money is tied up in m.w. transmitters and receivers. The cost of abandoning m.w. broadcasting must include the writing off of all this capital.

3. National emergency. V.h.f. has limited range. It is conceivable that in a national emergency, such as very widespread flooding, the local v.h.f. transmitters might be put out of action. The authorities would then need medium waves for broadcasting messages to isolated people.

4. Picnic situation. Near ground level a v.h.f. receiving aerial is not very effective and elsewhere may be in a shadow. This restricts the use of portable v.h.f. sets. "Picnic situation" describes one typical example of such adverse conditions, but it should be remembered that similar considerations may apply to the use of v.h.f. portables in the home and in cars.

These factors are perhaps sufficient in themselves to clinch the case for keeping on domestic broadcasting on medium waves, but there is now an additional, political consideration. This is the widespread use of m.w. for international broadcasting. This use may not have been uppermost in the minds of the Copenhagen planners but a great deal of broadcasting across frontiers does go on, and it would be unrealistic to expect either crusading governments or commercial operators to abandon it. The worst offenders against the Copenhagen Plan fall into these categories.

Strategies for change

For these reasons it seems inevitable that m.w. broadcasting will continue. So it is helpful to take a closer look at the nature of the present problem in Europe.

The key fact is that the range of m.w. transmitters varies greatly between day and night. In daytime, with no ionospheric reflection, reception is purely by ground-wave, with a very limited range. In order to achieve complete ground-wave coverage of a large region by day a number of spaced transmitters may be required. By night, on the other hand, there is ionospheric reflection, and the sky-wave range of a transmitter is perhaps twenty times its daytime ground-wave range.

In theory, therefore, a relatively small number of night-time transmitters could cover a large region such as Europe. But in practice the number of transmitters is not reduced after dark. They all go on working, filling the air with signals which interfere with reception at great distances, especially when they are on the wrong wavelength.

In Europe it is usual to attempt "area coverage"; i.e., to enable all the residents in an area to receive the programmes put out by the broadcasting authorities in that area. (An alternative policy, practised in the U.S., is to graduate the quality of coverage in accordance with the local density of population, providing the best reception in the most populous localities.) It has been estimated[1] [2] that, on an area-coverage basis, there is enough bandwidth, at present-day legitimate channel spacings, to enable four domestic programmes to be reliably received by ground wave during daylight hours anywhere in Europe. By night, however, the situation changes drastically. The effective area becomes, not some small local region, but a large chunk of Europe. There is room for only one local programme in each area, but nine foreign programmes can now be received in that area. This is a small number in relation to the total number of channels, and explains the cacophony which is to be heard every night in the real Europe, where transmitters are not operated to an optimum plan.

From this analysis various possibilities emerge. We may be pushed towards an American situation, with m.w. broadcasting mainly on a local basis, with severe shrinkage of service areas after dark. Or perhaps m.w. will come to be used for a few international broadcasts, everybody else having given up and gone over entirely to v.h.f. for local stuff. Most likely, however, things will go on much as now, with gradually deteriorating reception.

It is here that the possibility of more channels by using single-sideband transmission and reception becomes relevant. The only positive action possible is to carve up the available bandwidth into enough portions to satisfy the customers, for the time being, but bearing in mind the tendency for transmissions to expand and overfill the available bandwidth. Single-sideband offers the greatest increase in the number of channels, yet to adopt it at once, using the closest possible channel spacing, would be to take a giant stride to a position where, if the situation again deteriorates, no further accommodation is possible.

Broadcasting authorities, being no fools, are well aware of this, and prefer to approach chaos by small, slow steps. The principle likely to be applied at European Broadcasting Union meetings in the immediate future is: make the smallest changes consistent with avoiding an intolerable state of affairs. It is unlikely that this will involve the adoption of s.s.b. even in the medium term. All the same, the longest journey begins with one small step, so it is prudent to assume that we shall come to s.s.b. in the end, which brings us back to engineering. Engineers have been investigating the problems and possibilities, some of which are described below.

Transmission systems

A number of possible modulation systems exist. Each has its advantages and disadvantages.

Pure s.s.b. This is the most efficient system from the transmission point of view. It uses the minimum bandwidth and there is no "wasted" carrier power. The problems lie at the receiver. Envelope detection (e.g. ordinary diode detection) cannot be used. This makes pure s.s.b. incompatible with existing a.m. (i.e., double-sideband plus carrier) receivers. The pure s.s.b. receiver must contain an oscillator (more than one in a superhet) stable to within a few hertz of the incoming signal's "missing" carrier, since the audio is recovered by "carrier reinsertion". This process amounts to beating all the incoming sideband frequencies with a local carrier nominally identical in frequency with the original one. Any frequency error destroys the harmonic relationships of a complex audio signal. Thus, if the error is 10Hz, original audio frequencies of 300 and 600Hz are detected as 310 and 610Hz, which are no longer harmonically related. For natural quality the error should be less than 5Hz. This implies a local oscillator stability to within 5 parts per million at 1MHz. Only a good crystal oscillator can provide this.

S.S.B. + C. If the full carrier and one sideband are transmitted, an envelope detector can be used. The price, at the transmitter, is "wasted" carrier power, and at the receiver whistles from adjacent carriers, and harmonic distortion. The distortion reaches a theoretical 23% at 100% modulation but is much reduced at normal modulation depths, where it becomes comparable with the distortion of practical diode detectors with a.m. signals.

If only a reduced carrier is transmitted an envelope detector cannot be used, but exalted-carrier or synchrodyne detection is still possible.

C.S.S.B. Various systems of "compatible single sideband" modulation are known[3,4]. They are essentially amplitude-modulation systems in which the carrier is not constant in frequency but is phase-modulated by the audio signal in such a way that the sideband power lies to one side of the nominal carrier frequency instead of both sides as in a.m. The result is a spectrum which is superficially like an a.m. spectrum, but with what looks like an ordinary a.m. envelope. An envelope detector can therefore be used.

In practical systems harmonic distortion is incurred. This is because the bandwidth needed for distortionless reception is greater than the bandwidth of an equivalent s.s.b. transmission. When the c.s.s.b. bandwidth is filtered down to a comparable amount, the detector produces a distorted output. In practice the distortion is not severe in comparison to what listeners habitually put up with in existing a.m. receivers.

The c.s.s.b. systems require extra circuitry at the transmitter (Fig. 1) and if maladjusted may cause out-of-channel emission. While compatible with normal amplitude modulation, c.s.s.b. is not compatible with pure s.s.b., since there is no constant carrier to reinsert in c.s.s.b. A further problem is that although the c.s.s.b. spectrum may be constrained to occupy the same bandwidth as an s.s.b. signal the distribution of energy in the two spectra is different. In c.s.s.b. there is more energy at frequencies farther from the nominal carrier. This means that adjacent-channel interference may be worse with c.s.s.b.

Vestigial sideband a.m. Most of the distortion which occurs when an s.s.b. + c. signal is envelope-detected involves the lower modulation frequencies, since these are strongest in most programme material. If the part of the "unwanted" sideband closest to the carrier is transmitted, the lower-frequency modulation is received as ordinary a.m. and detector distortion is reduced. "Vestigial sideband" also eases reception by exalted carrier and synchrodyne techniques. Disadvantages are the greater transmission bandwidth and transmitter complexity.

Common-base frequency allocation. Many of the problems of receiver tuning would disappear if all carrier frequencies were multiples of some common "base frequency". Thus, in a system with 5kHz channel separation, all carriers would be multiples of 5kHz.

If a stable 5kHz signal were then available at the receiver the local oscillations required for frequency-changing and demodulation could be derived from the 5kHz by frequency multiplication. The whistles found in superhets would also be reduced, since many would occur at 5kHz or its multiples and be easy to reject with a fixed filter.

The receiver tuning may be discontinuous, moving in 5kHz jumps, each step coinciding with a broadcast channel. Mistuning would then be impossible (except by tuning to the wrong channel altogether). Some receivers for base-frequency systems are described below. They rely on obtaining the base frequency from some separate source such as a crystal oscillator. However, there seems no reason in principle why the base frequency should not be transmitted as a pilot tone. Since it would coincide with the carrier in the adjacent channel no new whistle problems would be created.

If the base frequency were not 5kHz but an exact submultiple of the local television line frequency all timebase harmonics would coincide with the carriers of m.w. stations and would be inaudible or give rise to fixed-frequency whistles identical with inter-carrier whistles and easily filterable.

A further possibility is to derive the base frequency from the local television signal, by means of an auxiliary receiver as suggested by Netzband (see below).

Reception systems

It is universally recognized that the feasibility of s.s.b. broadcasting will depend on keeping down the cost of the receiver. Techniques which are perfectly acceptable in a communications receiver may be too expensive to be transferred to the domestic market, where the yardstick of cost is the price of a present-day "pocket portable". People will not pay much for marginally better performance, as is shown by the slow progress of v.h.f. receiver sales in the U.K.

Certain requirements are common to various types of s.s.b. system, and these will be considered before particular receiving systems.

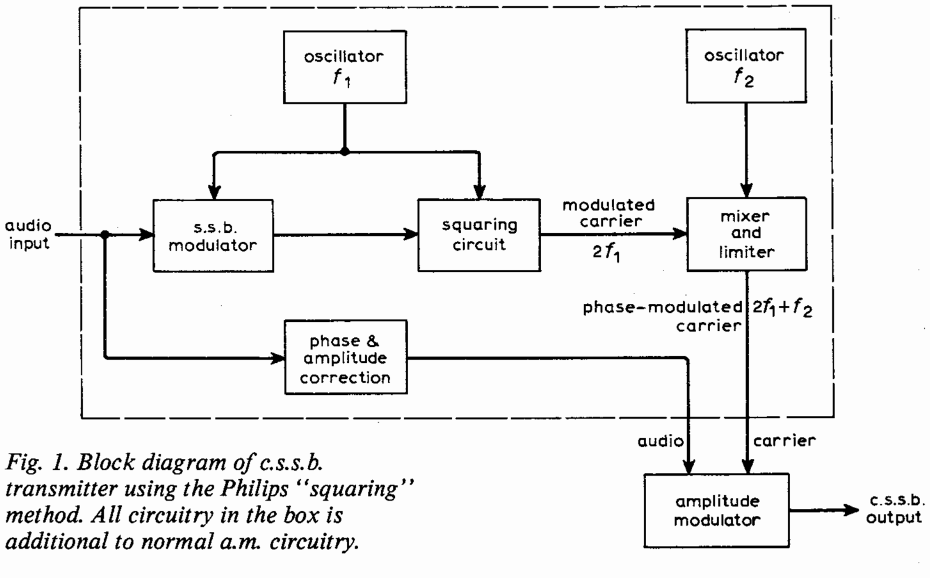

Fig. 1. Block diagram of c.s.s.b. transmitter using the Philips "squaring" method. All circuitry in the box is additional to normal a.m. circuitry.

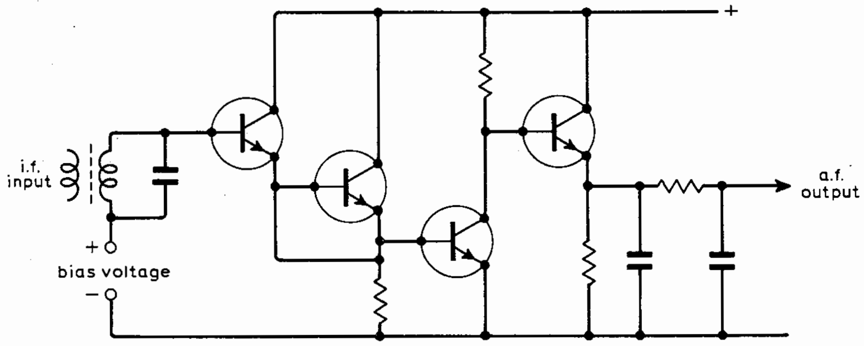

Fig. 2. Low distortion detector (used in TAD100 integrated circuit).

I.F. filtering and whistle suppression

Closer channel spacing implies the use of sharper i.f. filters. It is unlikely that, in the confines of a pocket portable, adequate filtering can be obtained from *LC* circuits. The alternatives are quartz-crystal filters, mechanical filters, and ceramic-resonator filters. Quartz filters are too expensive; mechanical filters are vulnerable to shock; so ceramic resonators seem the best bet. If closer channel spacing and transmitted carrier are adopted some form of intercarrier whistle filter becomes desirable. A possible solution is an *m*-derived active fillter with its rejection slot at the whistle frequency. The active part of the circuitry is already in existence in i.c. form and the frequency-determining components could perhaps be cheap carbon-film resistors and polystyrene capacitors.

Receivers for s.s.b. + c.

A conventional superhet may be used for s.s.b. + c., provided that its i.f. response is narrow enough. Local oscillator drift may then be a problem if the channel spacing is small. At 5kHz spacing, for example, the permissible mistuning error is about 1kHz. This is already greater than the initial tuning error to be expected when unskilled users operate the receiver, so there is no margin for oscillator drift. An associated problem is that most receivers are not equipped with a fine enough tuning control.

If it can be assumed that an unskilled operator can be enabled to reduce the initial tuning error to nearly zero — for example by fine-tuning until an inter-carrier whistle disappears — then a permissible drift of 1kHz requires a local oscillator stability of around 1 part in 1000. This must be maintained for a reasonable listening period (say one hour) and in the face of a fading battery voltage and the temperature changes to which portable receivers are subject. Quite a formidable problem for the designer.

A second requirement for s.s.b. + c. is reduced distortion in the detector and audio stages. As mentioned above, there is an inevitable distortion of 23% at 100% modulation, even with a perfect detector. Ordinary diode detectors are very far from perfect, and the inevitable class B amplifier which follows them does not make matters any better. Some improvements to these parts of a receiver are therefore desirable, and fortunately the means are already to hand. The use of integrated circuits in a.m. receivers has led to the development of a transistor analogue of the old "infinite impedance detector" (Fig. 2). This does not have the unfavourable a.c./d.c. load ratio of the ordinary diode and distortion is much reduced. Similarly there is no reason, apart from a relatively small increase in cost, why low-distortion integrated amplifiers should not be used.

Reinforced carrier

If the level of the s.s.b. + c. carrier could be increased relative to the sideband level distortion could be reduced. The classical solution, exalted carrier reception (Fig. 3(a)), achieves this by means of a very sharp carrier-extraction filter. While a sharp enough filter can be made, using a quartz resonator, it leaves the receiver wide open to the effects of mistuning and local oscillator drift. Exalted carrier reception is only useful, therefore, when backed up with some form of frequency-stabilization.

An alternative is the synchrodyne detector (Fig. 3(b)). Here the carrier is used to lock an oscillator, whose high-amplitude output is applied to a switching-type demodulator with low distortion. The sidebands are largely suppressed by the oscillator, which also gives an effective gain, since the sync level need be only about 20% of the oscillation amplitude at the point of injection. The effective bandwidth of a synchronized oscillator can be made arbitrarily small, but this is of no interest in the present case because of the danger of first oscillator drift and because it gives rise to a loud tuning-in whistle. However, it is also possible to make the locking bandwidth quite large. If it is larger than the i.f. bandwidth, then to a first approximation the tuning is flat and the oscillator locks to the strongest signal in the i.f. passband, which is the carrier.

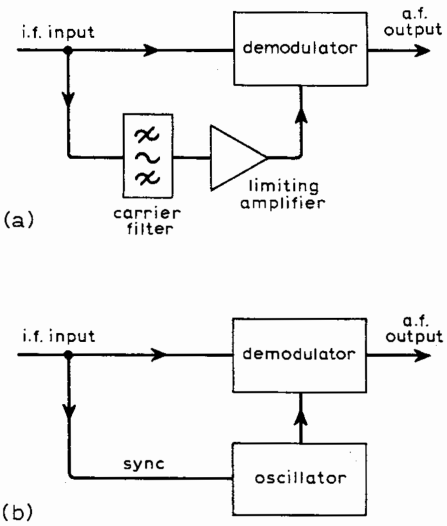

Fig. 3.(a) Exalted carrier detector; (b) synchrodyne detector.

In this way the problem of local oscillator drift is circumvented. But there are other difficulties. The system is vulnerable to selective fading. If the carrier fades relative to the sidebands then the oscillator may lock temporarily to the sidebands, giving bad distortion. There may also be difficulties with a.g.c. The d.c. output of practical balanced demodulators (which is proportional to the carrier) is rather small, so an amplified a.g.c. system may be needed. In addition, the d.c. output varies with the relative phase of incoming carrier to local oscillation, falling to zero when this reaches 90 degrees.

Phase-locked receiver

As noted above, the exalted-carrier technique fails, in the simplest form, because local oscillator drift takes the carrier outside the passband of the sharp i.f. carrier filter. This problem can be dealt with by adding a frequency correction system to keep local oscillator drift within limits. An attractive (and "integratable") way of arranging this makes use of a phase-sensitive detector operating at the i.f. One such system was embodied in a receiver developed at Philips Research Laboratories[5] and shown in Fig. 4.

The phase-sensitive detector receives two signals — a pure, constant-amplitude filtered and limited carrier and the raw i.f. signal which contains the carrier and sideband. The raw signal is given a 90-degree phase shift by a network assumed to be insensitive to frequency changes. The filtered carrier has nominal zero phase shift, but the phase-frequency characteristic of the carrier filter is such that the phase departs rapidly from zero as the frequency goes off-centre, changing positively in one direction of frequency shift and negatively in the other. The effect of such deviations is to give corresponding positive or negative d.c. outputs from the phase detector, and these, after smoothing to remove modulation, are applied as a.f.c. to the first oscillator.

The designers say that, in a practical receiver, the catching range of the phase-lock system was 2kHz and the holding range 4kHz. The carrier was found and held even when noise was great. Tuning was said to be "even easier than with normal a.m. receivers".

This is encouraging, but it is worth pointing out that phase-locked receivers do have a drawback. If the carrier fades selectively, the system may lock to the sideband, or even to an adjacent carrier.

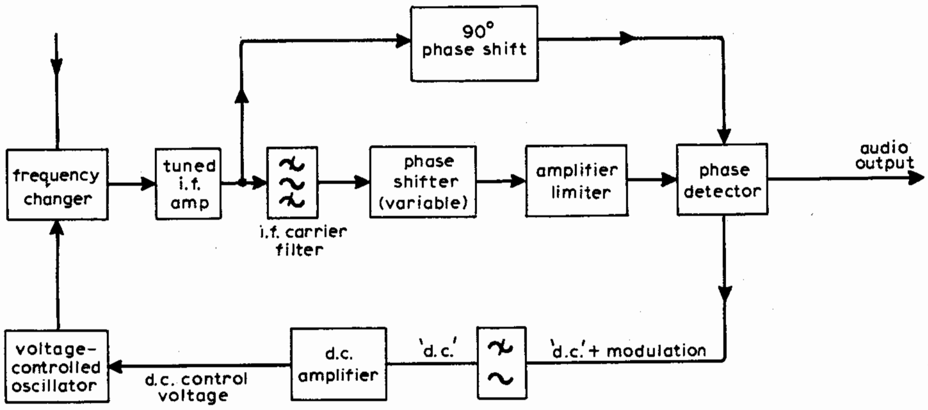

Fig. 4. Phase locked s.s.b. + c. receiver.

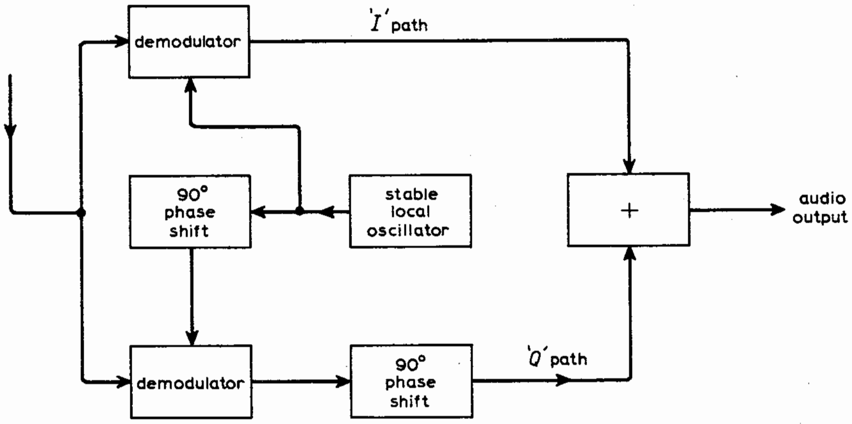

Fig. 5. Direct-conversion s.s.b. receiver.

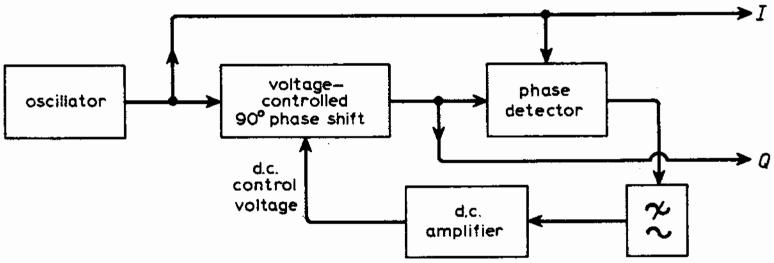

Fig. 6. Automatic quadrature phase splitter.

These disturbances to reception may last for an appreciable time, since the effective bandwidth is very small, being a function of the low-pass filter, which has a cut-off frequency of perhaps 2Hz. Immunity to the worst effects of selective fading (harmonic distortion) is often claimed for s.s.b., but it can only be fully realized in a receiver with its own built-in stable frequency source.

Pure s.s.b. receivers

The simplest method of detecting an s.s.b. signal is to beat it against a local oscillation whose frequency corresponds to the missing carrier. Unfortunately this method is capable of detecting either sideband, so any signals in the unwanted sideband appear as noise and interference. The system is wide open to interference from one of the adjacent channels.

To overcome this, a system has been devised [6] (Fig. 5) in which signals from the unwanted sideband are phased out after detection. Detected signals from the unwanted sideband which emerge from the 'I' and 'Q' (in-phase and quadrature) paths reinforce one another when added, but those due to the unwanted sideband cancel. If the transmission in the two paths is the same (equal gains), and the phase shifts are exactly 90 degrees, cancellation is perfect. In theory no r.f. selectivity is required since signals from all other channels emerge as higher frequencies than the wanted audio band and can be rejected by a low pass filter in the audio circuit. In practice, the demodulator responds to harmonics of the local oscillator so some r.f tuning is required.

Apart from the stability of the local oscillator, the main problem is the design of the 90° audio phase shifter. This must give a constant phase shift over several octaves. It must also have a flat frequency response. These requirements cannot be met, and practical direct conversion receivers make use of differential audio phasing networks which give a 45° advance in one leg and a 45° lag in the other. Even so, suppression of unwanted signals may only be around 30dB.

Maintenance of the required 90° shift at the oscillator frequency over a whole tuning band may be difficult. The problem can be solved neatly, at a price by the automatic quadrature circuit in Fig. 6.

Superhet for pure s.s.b.

This consists of a conventional front end followed by a narrow i.f. filter, accepting one sideband only, and finally a "product detector" (switching demodulator) driven by a b.f.o. or carrier reinsertion oscillator operating on the skirt of the i.f. passband. Although manually tuned superhets are used by amateurs they are hardly a practical proposition for domestic s.s.b. reception. Even if the local oscillator could be made stable enough, far too much skill is required when tuning in.

The only hope for pure s.s.b. broadcasting, therefore, is to provide a stable frequency synthesizer giving just the right frequencies, so that mistuning is impossible. Crystal oscillators of the required stability exist, and so do the necessary dividers and multipliers in i.c. form, but they are too expensive for domestic use.

One technique which shows promise is the use of PAL delay lines to force a local oscillator to operate only on discrete frequencies, corresponding to the wanted carrier frequencies. The technique has been described recently in *Wireless World* (May 1972. p. 218) so will only be briefly outlined here. It makes use of the fact that the phase shift through a PAL delay line is exactly proportional to frequency and changes by 180° for every change of 15,625Hz (i.e., the line frequency). With the help of a phase detector this property can be used to provide a sort of "staircase" of discrete frequency-control voltages for a voltage-controlled oscillator. Each step in the staircase corresponds to a stable locking point, separated from its neighbours by 15,625Hz. Manipulating the v.c.o. tuning causes the frequency to change in 15,625Hz jumps.

Increments other than 15,625Hz can be arranged by multiplying or dividing the frequency at some point. The PAL delay line operates at 3-6MHz. A v.c.o. on 1-2MHz, multiplied by three before phase comparison, would give steps of 5,208.3Hz, which is a suitable channel spacing for s.s.b. broadcasting. Interference from TV line frequency harmonics would be eliminated by allocating broadcast carriers on a system with a base frequency which is a submultiple of the local TV line frequency.

Receivers for base-frequency channels

Netzband's base-frequency receiver. This interesting proposal[7] is for a pure s.s.b. receiver. The circuit (Fig. 7) has a conventional superhet front end and suitably selective i.f. stages. But the output of the i.f. section is passed to a second frequency-changer driven by the first oscillator. This transposes the i.f. signals back to their original radio frequencies. The object is to cancel the effects of first

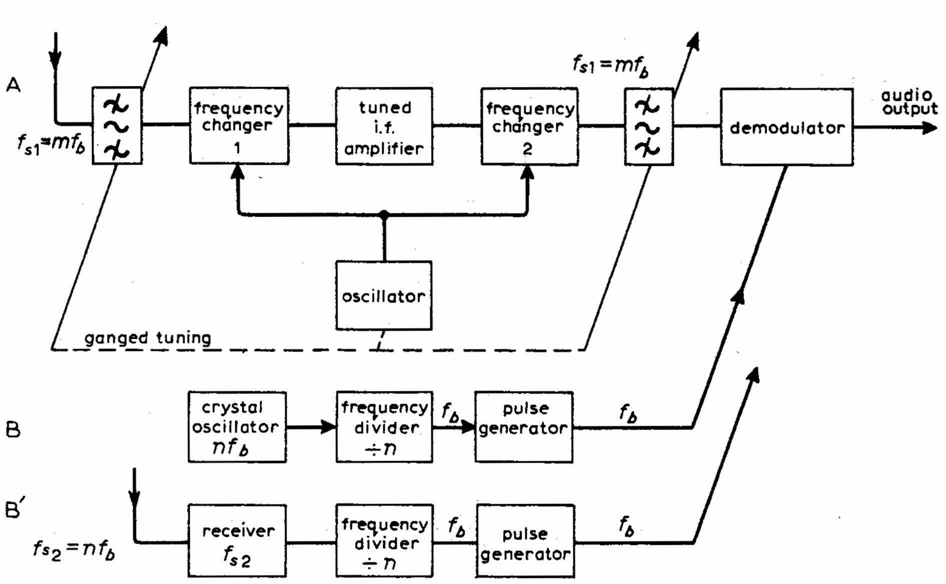

Fig. 7. Netzband's base-frequency receiver.

oscillator drift. What emerges from the second frequency changer (after simple filtering) is therefore the original signal, now freed from all other signals. This isolated wanted signal is now demodulated by a multi-frequency demodulator capable of detecting any signal whose carrier is a multiple of the base frequency. The demodulator is driven by 0.3μs pulses repeated at the base frequency. Its output contains only the wanted audio plus some low-amplitude beats at the base frequency which are rejected by a low-pass audio filter.

Netzband proposes two methods of generating the base frequency. One, shown as chain B, uses a crystal oscillator and frequency divider. The other (chain B^1) has an auxiliary receiver tuned to a "standard frequency transmission".

Eden's independent sideband receiver. This is a proposal[1] for transmissions with carrier and two independent sidebands, but is readily modified for s.s.b. + c. The receiver (Fig. 8) is a double conversion superhet with a synchronous demodulator. Frequency stabilization is applied to the carrier reinsertion oscillator which drives the demodulator. From this oscillator are derived, by means of a simple frequency synthesizer, the two frequencies required by the second frequency-changer. One selects the upper sideband and one the lower.

The first oscillator is synchronized by direct injection of base-frequency pulses, which, in turn, are derived by frequency division of the carrier-reinsertion frequency. In this way all required frequencies are derived from one stabilized oscillator.

The final circuits constitute a direct-conversion receiver operating at the final i.f. Its purpose is to provide additional discrimination against the unwanted sideband, which cannot be entirely eliminated by a practical i.f. filter.

The proposal to synchronize the first oscillator by injecting narrow pulses at the base frequency is unusual and raises the question whether the waveform of the local oscillator will not contain unwanted harmonics of f_b which will beat with unwanted signals and bring them within the i.f. passband. In a study of synchronized oscillators van Slooten[8] says that a pulsed synchronizing range of 2-3% is obtainable without serious distortion. This is more than enough for the present purpose.

Hardware

Most of the elements required for making an s.s.b. broadcast receiver already exist, though not necessarily in the best form, or at the right price. Notes on a few of the more interesting ones are given below.

Crystal oscillators. Packaged r.f. oscillators of good frequency stability (1 in 10^6) and small size are in use in professional communications receivers. A recent development, which has the merit of being aimed at a mass market for a portable use, is the crystal controlled electric wrist-watch. This will use a lowish-frequency crystal which might be adaptable to base-frequency generation.

Th Motorola 32NT crystal oscillates at 32,768Hz (which gives 0.5Hz when divided by 16 bistables). The aging characteristic is given as 5 p.p.m. per year, the temperature drift has a turnover point at 28°C and gives a change of ± 15 p.p.m. for a temperature change of ± 5°C. Resistance to shock and vibration is said to be good. The frequency can be "pulled" over a range of about 100Hz by means of a small trimming capacitance. Suitable m.o.s. frequency dividers have been designed, and their power consumption is very low. All elements are small. (A picture in "New Products" of this issue shows the crystal and a divider i.e. beside a watch case.)

Ceramic resonators. Selectivity is crucial to s.s.b. broadcasting. In a recent study[2], Eden has shown that the expected increases in coverage from use of closer channel spacings cannot be realized in practice with the usual amounts of selectivity. Increase in adjacent channel interference breaking through the tuning circuits more than wipes out the advantage of the increased number of channels.

The cheapest forms of sharp i.f. filter at present available use ceramic resonators. These are mass-produced elements with the same equivalent circuit as a quartz

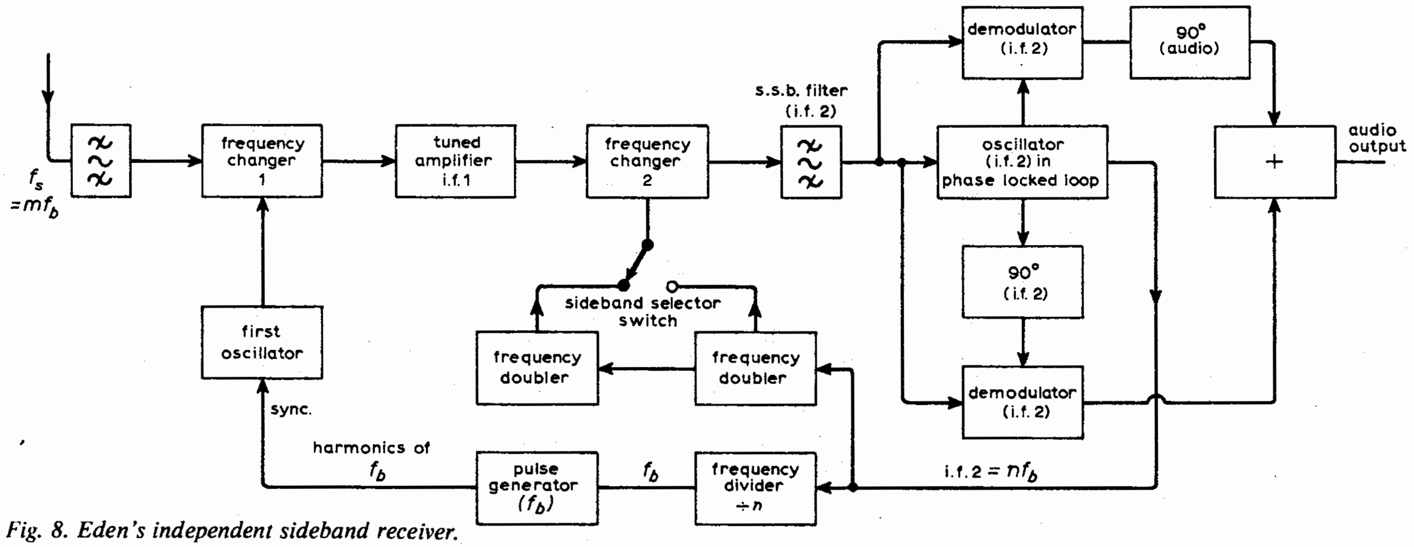

Fig. 8. Eden's independent sideband receiver.

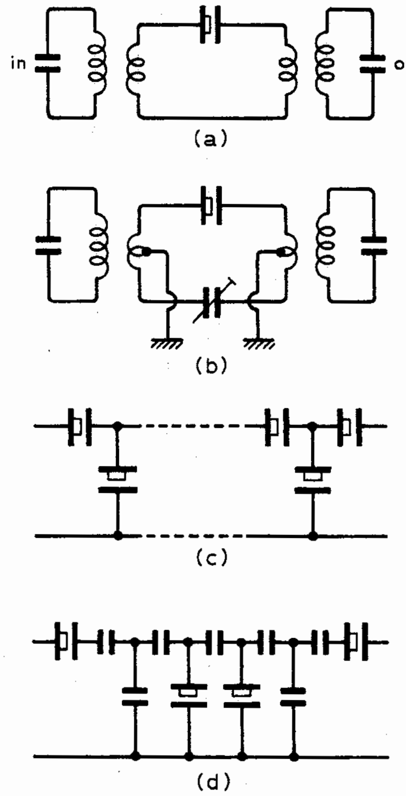

Fig. 9. Ceramic-resonator i.f. filters.

resonator but with different element values (lower inductance, higher capacitances). They are already in use in domestic receivers as the coupling elements between *LC* tuned circuits (Fig. 9). Circuit (a) gives an asymmetrical response and (b) a symmetrical one. Much better response shapes can be obtained by using a number of resonators. In communications receivers the usual form is the ladder filter (c). This can be made to give a good performance in a small space. As an example, the Vernitron TL-4D8A has 17 resonators, a centre frequency of 455kHz, 6dB bandwidth 4kHz, is − 60dB at not more than ± 4kHz, and measures about 1½in by 0.3in diameter. Unfortunately it is expensive (over £15 retail). One reason for the cost is that these filters are made from carefully selected and matched elements. An alternative approach (Fig. 9(d)) uses resonators which are nominally identical, and sets the response by adding networks of fixed capacitors to modify the natural resonances. Ordinary 5% tolerance polystyrene capacitors in standard E12 values can be used, and a kit of parts for the filter illustrated can be bought for about £2 retail. The response shape with presently-available resonators is not ideal, nevertheless the filter is a great improvement on *LC* circuits and many are in use by amateurs for s.s.b. reception.

Integrated circuits. All the circuitry for an s.s.b. receiver is already available, at a price, in integrated form. The Plessey SL600 series of i.cs was indeed designed for the job (apart from frequency synthesis, which can be done using computer type i.cs). The SL621C is a good example. Its purpose is to derive an a.g.c. control signal from the audio output of a pure s.s.b. receiver. This entails "remembering" the peak audio output, ignoring noise pulses, and compensating for slow (20dB/sec) fading.

Integrated forms of phase-locked loop are at an advanced stage of development (e.g., Signetics NE561B, etc.). The usual format is a voltage-tuned relaxation oscillator whose phase is compared with that of an external reference signal (e.g., the carrier in an s.s.b. + c. signal) and a d.c. control voltage derived to lock the v.c.o. to the reference frequency. In this way a noise-free high amplitude carrier for reinsertion can be derived. The elements of such a phase-locked loop are shown in Fig. 10. In effect, the phase detector samples the reference wave as this passes through zero. The detector output is then zero. Any incipient frequency error causes the sample to be advanced or delayed, giving a d.c. output whose polarity depends on the sense of the phase error. This is amplified and applied to the v.c.o. to correct the error. The effective bandwidth can be made small by giving the low-pass filter a cut-off frequency of, say, 1Hz. The v.c.o. and reference, under normal locked conditions, are in quadrature; it follows that a phase-locked loop can also be used as a 90° phase shifter at a fixed frequency.

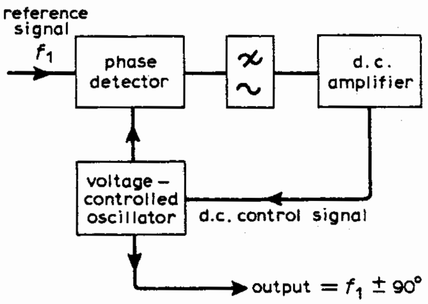

Fig. 10. Phase-locked loop.

Conclusion

Until a satisfactory cheap receiver for some form of s.s.b. broadcasting is evolved no move to s.s.b. broadcasting can be contemplated. All the elements exist, and receivers can be made, but not yet at the right price, even on optimistic assumptions about cost savings through quantity production.

If a move to s.s.b. ever does take place then it is likely that some form of modulation compatible with existing a.m. receivers will be adopted. Essential improvements to new receivers will be adequate selectivity, frequency stability, and tunability in the hands of the unskilled.

In the long run, it may be possible to move to pure s.s.b., which is the one system with all the advantages: maximum bandwidth economy, maximum transmitter efficiency, maximum protection from distortion during selective fading, and minimum detector distortion. But, as Lord Keynes was fond of remarking, in the long run we are dead.

References

1. Eden, H., "Perspectives of replanning LF/MF broadcasting" *E.B.U. Review*, No. 106A, Dec., 1967.
2. Eden, H., "Sound broadcasting coverage and frequency planning in the LF/MF bands". *Telecommunications Journal*, Vol. 39, No. VI, June, 1972.
3. Kahn, L.R., "Compatible single-sideband", *Proc. Inst. Radio. Engrs*, 1961, Vol. 49, No. 10.
4. van Kessel, T. J., "Compatible single-sideband modulation", *Philips Technical Review*, 1963/4, Vol. 71A.
5. Stumpers, F. L. H. M., van Hurck, N., and Voorman, J. O., "A receiver for AM and for single sideband AM with a partially suppressed carrier", *E.B.U. Review*, No. 108A, April 1968.
6. Noorgard, "Practical single-sideband reception", *Q.S.T.*, July 1948.
7. Netzband, R., "A novel arrangement for the reception of single sideband and double sideband transmissions in AM sound broadcasting", *E.B.U. Review*, No. 114A, April 1969.
8. van Slooten, J., "On synchronization of LC oscillators", (Philips) Electronic Application Bulletin, June/July 1951, No. 6/7.

S.S.B. Receiver for M.W.

Since the above article by G. Wareham was written a further review of possible single-sideband receiving techniques for broadcasting has come out. "Receiver innovations for future domestic broadcasting" is the title of a paper by J. F. Craine and R. C. V. Macario, presented at an I.E.R.E. conference on Radio Receivers and Associated Systems held at the University College of Swansea (4th-6th July). The paper contains several additional references on this general subject and also mentions a particular s.s.b. receiver for medium waves developed at the College by the authors.[1] Coming in the category of "receivers for base-frequency channels" mentioned by Mr. Wareham, the Swansea design uses many of the principles described by Eden but has other interesting technical features. The local oscillator is phase locked to a pulse train by a sample-and-hold phase-locked loop, and the quadrature detector waveforms are obtained from the same logic circuit that produces the reference pulse train. When the receiver is tuned the output changes abruptly from station to station instead of gradually as in conventional sets.

Reference

1. Craine, J. F. and Macario, R. C. V. "A crystal controlled phase-lock method for the reception of amplitude-modulation and single-sideband broadcasting", *E.B.U. Review*, No. 131-A, February 1972.