Synchronous Detection in Radio Reception -1

*by Pat Hawker**, G3VA

Increasing use is being made of various forms of synchronous, or coherent, detection in radio communication, broadcasting and instrumentation. For a decade now, product detectors have been fitted in general purpose communications receivers; synchronous detectors form an essential part of stereo and colour television decoders; there is considerable interest among radio amateurs in 'direct-conversion' receivers as an alternative to the superhet; the availability of complete phase-locked loop detectors in integrated circuit form — these are all examples of this trend.

Again, the advantages of synchronous demodulation when applied to vestigial sideband television signals have led to the development of special synchronous detectors for high-quality re-broadcast receivers. For the future, it seems feasible that the phase-locked loop and related techniques will open the way for much wider use of double-sideband suppressed-carrier transmissions for mobile communications, s.s.b. broadcasting or relatively narrow-band v.h.f. /a.m. broadcasting. The potential of such systems as the 'bi-aural', synchronous, exalted-carrier detector – which will be described in Part 2 – is already being stressed in some quarters. This list could readily be expanded, but in listing what is technically possible, there is the danger of underestimating the inflexibility of broadcasting systems and standards, resulting from the massive investment by the public in existing systems. No matter how many advantages may be claimed for synchronous detection, it would be misleading to suggest that the days of the simple diode envelope detector or, even more, the well-established superhet receiver are now numbered. Nevertheless, the time is ripe to review – in non-mathematical terms – some aspects of this growing interest in synchronous detection and to outline how this may influence receivers for broadcasting and amateur radio communications.

One of the most attractive features of a phase-locked loop synchronous detector is its flexibility: it can be designed to cope with a.m., s.s.b., d.s.b.s.c., f.m., n.b.f.m., c.w. and r.t.t.y. (radioteleprinting). In addition, it has long been recognized that synchronous detection provides much improved signal/noise performance at the very low input levels where the diode envelope detector is notoriously inefficient — Fig. 1. At low s/n ratios the envelope detector distorts or may even lose the intelligence signals. The synchronous detector preserves the s/n ratio and thus makes possible the use of very effective post-detector signal processing, allowing recovery by integration of certain types of signals even when these are buried deep in the noise.

For the broadcasters the attraction of synchronous detection is the flexibility it would give receivers, opening the way to the use of different modes. On the other hand, work[1] by the B.B.C. Research Department, carried out on behalf of the B.B.C. and I.B.A., emphasized the practical problems involved in attempting to adopt synchronous detection in, say, simple portable broadcast receivers. This showed that the marginal benefits on a.m. would hardly compensate the listener for the extra cost and increased power consumption. Yet clearly some form of synchronous detection will be essential if the ordinary listener is ever to be offered such spectrum-saving modes as s.s.b. or relatively narrowband v.h.f. /f.m.

The performance of the diode detector can be improved on weak signals by exalted carrier techniques, which can be regarded as a form of synchronous detection. In this system a locally generated carrier is added to the incoming signal to ensure that the diode detector works at its most efficient level.

Synchronous detection is essentially a linear frequency conversion process. The r.f. or i.f. signal is heterodyned by the original carrier frequency and then passed through a low-pass filter to remove the r.f. components, so that the modulation products are converted back to their original frequencies. To improve dynamic range and to limit the number of unwanted products, it is an advantage if the heterodyne or product detector is balanced.

When the incoming signal at r.f. is applied to the synchronous detector, without first being converted to an intermediate frequency, the arrangement is frequently called 'direct-conversion' – Fig. 2.

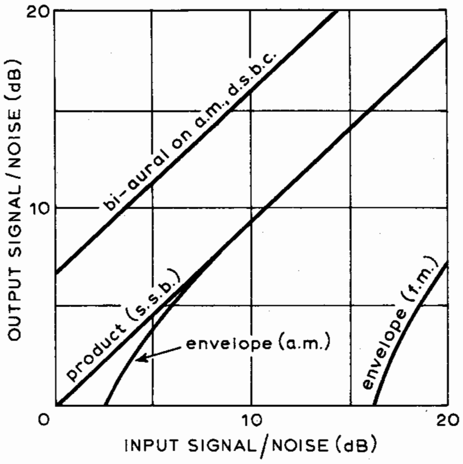

Fig. 1. Effect of demodulators on signal/noise ratios (after Haviland).

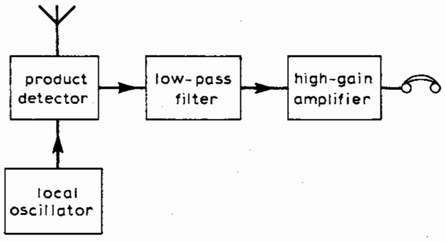

Fig. 2. Basic form of direct-conversion receiver.

A carrier is needed for both envelope and product detection; this carrier can be radiated along with the sidebands, as in a.m., or locally generated and inserted in the receiver for suppressed carrier systems. Any difference in frequency between the inserted carrier and the original carrier results in a frequency shift in the intelligence signal. Investigations have shown that for speech communication, the amount of shift that can be tolerated depends on the direction of the shift and the signal/noise ratio; but typically a shift of up to about 100 to 300 Hz will not seriously degrade speech intelligibility, particularly to an ear attuned to frequency-shifted speech.

Thus for s.s.b. speech it is common practice to use synchronous detection in the simple form of a product detector and

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free-running carrier insertion oscillator. For the reception of music, much closer agreement between the modulating and demodulating carriers is essential, around 2Hz or better. Even less tolerance is demanded by some specialized forms of s.s.b. transmission such as Lincompex speech or Piccolo telegraphy.

If s.s.b. is ever to be widely used for broadcasting* a conventional product detector of the type used in communications receivers is out of the question. One of the more complex forms of synchronous detection with simple-to-operate means of locking the re-inserted carrier – virtually in phase-coherence to the original modulating carrier – must be used; or alternatively some related form of a.f.c. provided. Provision of a.f.c. on systems with the carrier suppressed to a very low level clearly presents difficulties but a recent suggestion by Villard[2] shows that phase-locked loop and/or zero-crossing techniques might be used, at least for communications applications.

For synchronous demodulation of a.m. or double-sideband suppressed-carrier transmissions there are two main approaches. A modern communications receiver fitted with a good s.s.b. crystal or mechanical filter can resolve d.s.b. by filtering out one sideband and the carrier if present and then seeing the signal as s.s.b. at the conventional product detector. This, however, results in the loss of the potential advantages which arise from coherent demodulation of two sidebands, including greater resistance to narrow-band interfering signals. Haviland[3] has emphasized that if one is to make a true assessment of the "figure of merit" of different modulation systems it is essential to take fully into account the form of demodulation used in the receiver and its performance under conditions of random interference.

To take advantage of the presence of two sidebands, we need to insert a fully phase-coherent carrier, that is to say the locally generated carrier must be within a few degrees of phase of the modulating carrier. As noted earlier with a.m. we obtain similar benefits by using such a carrier to provide enhanced-carrier demodulation. A local tunable or crystal-controlled oscillator cannot be maintained to this degree of accuracy unless some form of synchronizing control is included.

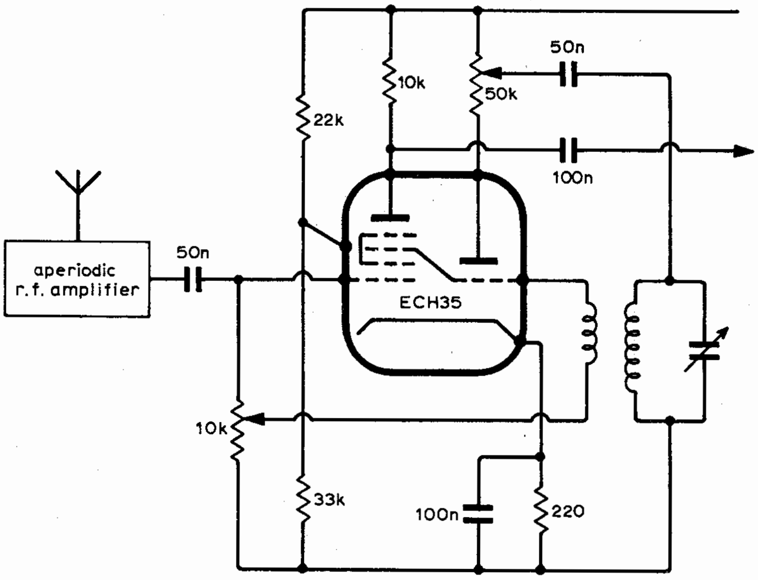

Fig. 3. Synchrodyne mixer detector described by Tucker in 1947.

In its simplest form, synchronization may take the form of forcing a phase lock on a free-running oscillator by applying a portion of the incoming carrier to the oscillator, if one is available. (Even with suppressed-carrier systems a weak carrier may be available by careful filtering.) This approach formed the basis of the Tucker "synchrodyne" direct-conversion receivers.[4]

These designs showed that in practice effective phase coherence could usually be achieved by feeding a little of the incoming signal to the oscillator over which it assumes control. This technique had been known for many years, but Tucker showed that it could form a satisfactory basis for broadcast receivers of varying complexity, demodulating the incoming r.f. signal directly to a.f. without intermediate frequency amplification. (Almost all the techniques which in recent years have been applied to direct conversion amateur receivers were foreshadowed either in the original Tucker articles or in the correspondence to which they gave rise.)

The synchrodyne receiver thus consisted of an optional signal-frequency amplifier, a frequency-changer stage (product detector plus synchronized local oscillator), a post-detector audio filter which effectively governed the selectivity of the receiver, followed by a high-gain audio amplifier. It represented a form of "straight" (t.r.f.) receiver but, because of its linear form of demodulation, permitted the selectivity to be governed by the audio filter without the problems of cross-modulation and blocking which arise when attempting to do this with a conventional t.r.f. receiver.

In his articles, Tucker presented receivers using various forms of synchronous demodulators: a simple triode-hexode frequency-changer demodulator (Fig. 3); a double-balanced ring-type

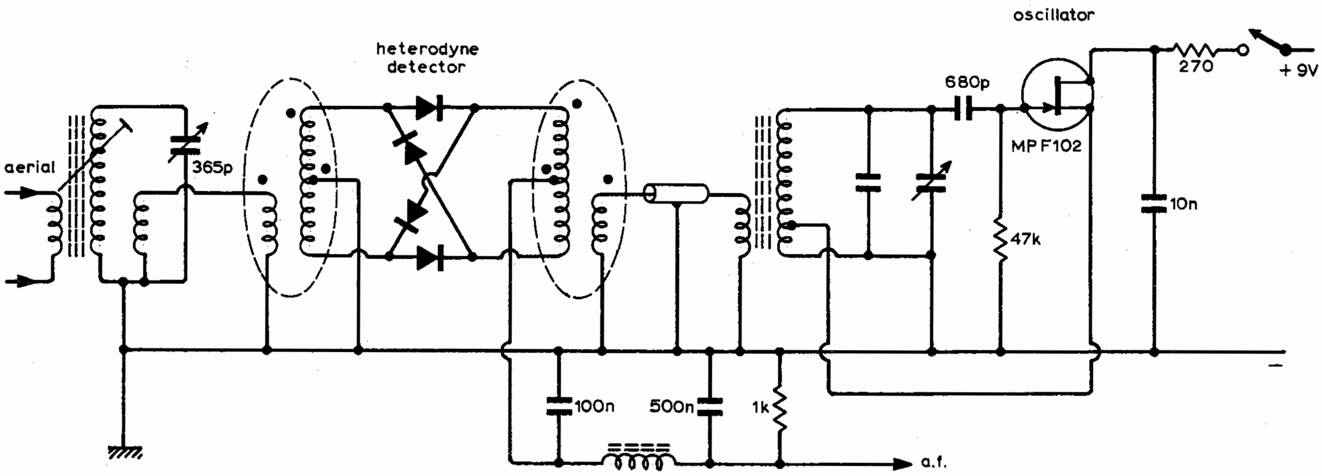

Fig. 4. Double-balanced ring demodulator with f.e.t. local oscillator in the Hayward and Bingham 3.5MHz direct-conversion receiver.

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*See, for example, G. Wareham's article pp358-63 August issue.

demodulator; and single-balanced Cowan-type four-diode demodulator. At least one of these receivers was demonstrated at one of the early post-war London Radio Shows, and a number were built by home constructors; I vividly recall dabbling with one. However some constructors experienced difficulty in ensuring that the local oscillator synchronized effectively; another common criticism was the heterodyne whistles generated during tuning. As far as I have been able to discover, no commercial models were produced.

Among the correspondence generated at the time was the suggestion by Apthrope[5] that it should be possible to lock the oscillator by using a frequency twice that of the carrier. Such a signal can be derived by full-wave rectification of a proportion of the incoming signal. This technique has recently been revived, as an alternative to the phase-locked loop, by Macario[6] in his investigation of synchronous demodulation for h.f. and v.h.f./d.s.b.s.c. applications.

The synchrodyne era also produced another suggestion: that one sideband could be phased-out by the use of quadrature two-phase techniques. This system was later used by Costas (see below) and is being applied by a number of amateurs for high-performance direct-conversion receivers. Undoubtedly, the synchrodyne was yet another example of techniques a little ahead of the technology; widespread use was to await the development of semiconductor devices.

The development was also influenced by the coming of amateur s.s.b. and the greater use of phasing techniques for s.s.b. generators and add-on demodulator units. Villard[7] pointed to the use of balanced product detectors to allow much more effective use to be made of post-detector audio filtering, and his ideas formed the basis of the first simple direct-conversion receiver presented by White[8] specifically for amateur reception of c.w. and s.s.b. signals. Phasing-type single sideband demodulators never achieved wide use, largely owing to the development of effective mechanical and crystal s.s.b. filters, but a number were described, including several by General Electric (U.S.A.) engineers such as the Signal Slicer[9].

But the most powerful advocate of synchronous systems and direct-conversion receivers during the 1950s was undoubtedly J. P. Costas, also of General Electric. In the issue of December 1956 of *Proc. I.R.E.,* devoted almost entirely to s.s.b., he struck an "odd-man-out" attitude in showing that the main arguments in favour of s.s.b. were based on conventional demodulation, and would not apply if receivers fully utilized synchronous demodulation[10]. He outlined, as Tucker had done, the advantages of direct conversion and gave some details of an experimental high-performance (and clearly very complex) synchronous receiver — the AN/FRR-48 (XW-1). This complexity was largely because of the use of a frequency synthesizer of that period; it also used two-phase synchronous demodulation, phase-locking the local oscillator by the use of an a.f. phase discriminator.

Costas pointed out that the direct-conversion receiver eliminates the basic superhet problem of image response as well as providing the opportunity to use economical post-detector filtering to achieve extreme selectivity and be readily switchable. Despite a later blast at s.s.b.[11], Costas' advocacy of d.s.b.s.c. and direct-conversion phase-locked receivers had little immediate effect on professional communications. Even today s.s.b. is often credited with the higher communications efficiency and more economical use of the

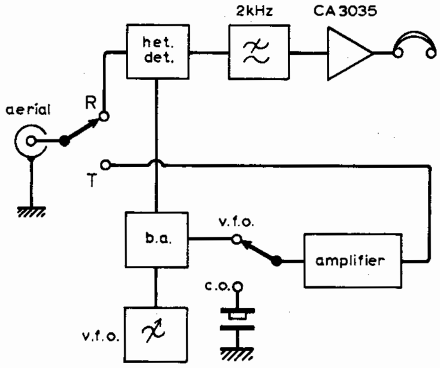

Fig. 5. Simple transceiver using the same oscillator for synchronous detection and for the transmitter v.f.o.

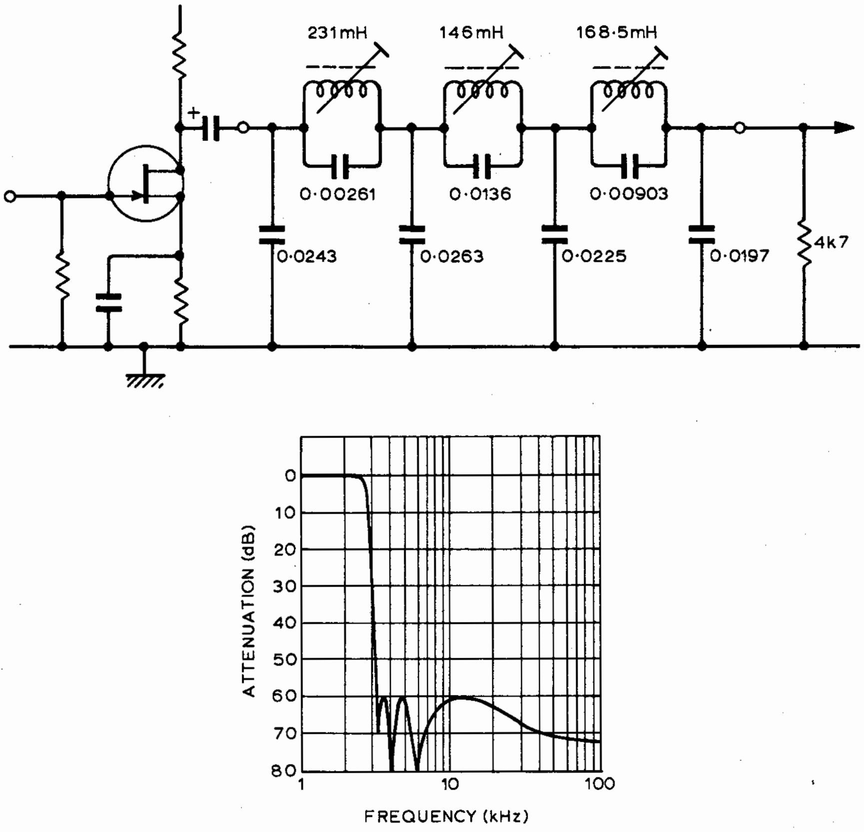

Fig. 6. Dual-gate mosfet heterodyne detector in the Ten Tec transceiver.

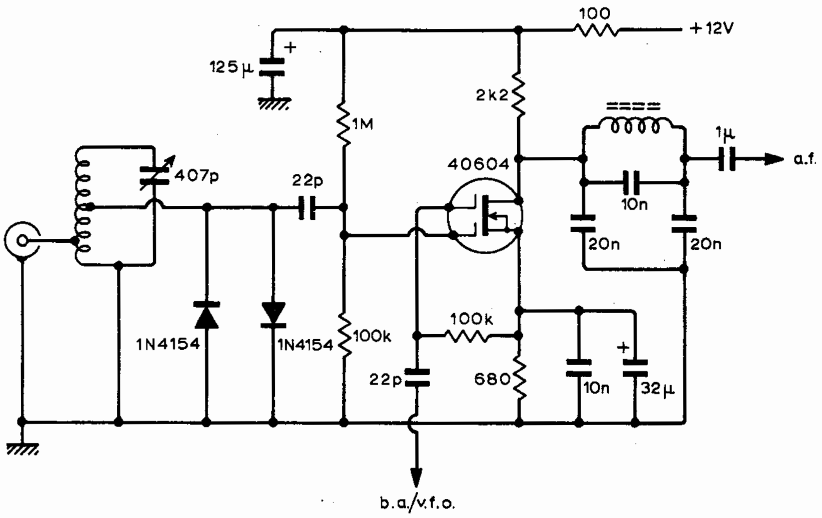

Fig. 7. High performance audio filter designed by P. G. Martin for use in direct-conversion receiver.

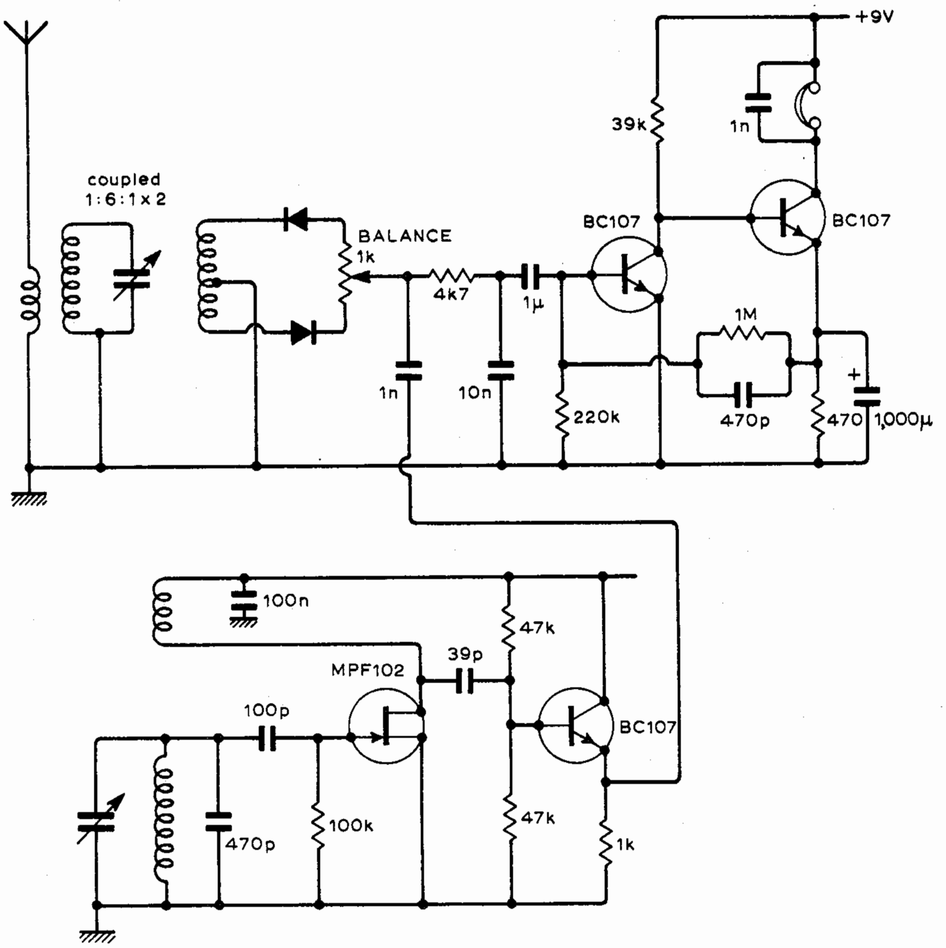

Fig. 8. How simple can you get? A direct-conversion receiver for 3.5MHz designed by K. Spaargaren.

spectrum — both claims are open to debate.

But meanwhile the simple direct-conversion receiver, which makes no attempt to achieve phase coherence, began to attract the interest of home-construction-minded amateurs concerned at the soaring prices of communications receivers suitable for s.s.b. reception. K. Spaargaren (PA0KSB) led the way by describing[12] a simple all-semiconductor receiver for 3.5MHz using five bipolar transistors and single-balanced demodulator. This design was reprinted in the U.K. and attracted considerable interest. The following year, two American amateurs Hayward and Bingham presented a design[13] using four hot-carrier diodes as a double balanced ring demodulator with f.e.t. local oscillator, Fig. 4. Meanwhile Charles Bryant (GW3SB) had pointed out[14] that, for amateur operation, the direct-conversion receiver could form a useful basis for simple transceivers because, unlike the superhet, the local oscillator was virtually at signal frequency and could be used as the transmitter v.f.o. This approach has been used by a number of amateurs for home-built portable transceivers and also forms the basis of a low-cost transceiver marketed by the American company 'Ten Tec': see Figs. 5 and 6.

Many amateurs have already found that a simple direct-conversion receiver can provide performance fully comparable to that of a medium-cost superhet, particularly where balanced heterodyne detectors are used and where the local oscillator has good stability and a low tuning rate. Selectivity of a good direct-conversion receiver is governed by the design of the post-detector low-pass filter: Fig. 7 shows an s.s.b. filter designed by P. G. Martin, G3PDM[15] with a slope factor (6 to 60dB) of 1.18, cut-off frequency 3kHz, and ultimate attenuation 75dB.

Theoretically there is no requirement for high-selectivity tuned circuits or r.f. amplification in front of the mixer provided it is of a low-noise type such as those using hot-carrier Schottky diodes. In practice it may be advisable to incorporate a reasonable degree of signal-frequency selectivity and a low-gain amplifier stage to prevent overloading the detector by strong local broadcasts or other signals and also to eliminate spurious responses that can result from harmonics of the local oscillator. Provided the detector is truly linear this is virtually the only form of spurious response, representing a marked advantage over simple superhets. Many designs, both with semiconductor devices and valves, have appeared in the past few years in the amateur press. Although such designs are usually presented as suitable only for s.s.b. and c.w. reception, some a.m. capability is usually achieved with stable oscillators, allowing the detector to work in the enhanced carrier mode.

Altogether these developments have underlined the usefulness in this specialized application of synchronous direct-conversion receivers, even when these are of extreme simplicity. Part 2 discusses how performance can be improved by the use of two-phase quadrature techniques and indicates how synchronous detection can now be extended to normal broadcast reception by phase-locked loop demodulators, and outlines the operation and advantages of bi-aural synchronous detection.

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13. Hayward and Bingham, "Direct conversion — a neglected technique" *QST,* November 1968
14. Pat Hawker, "Technical Topics", *R.S.G.B. Bulletin,* July 1967.
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(to be concluded)

Sixty Years Ago

September 1912. In this month's issue of *The Marconigraph* Dr. W. H. Eccles contributed a short article "as a kind of supplement" to an earlier article in which Dr. J. A. Fleming had suggested that the incidence or non-incidence of sunshine on an antenna affected the intensity of the signals received by the antenna. Dr. Eccles wrote "The proposition does not appear to receive support from any known physical fact. Of course the possibility that light, especially ultra-violet light, might affect the waves *emitted from* an antenna is well known . . . but this possibility has nothing in common with the impossibility of the illumination of an antenna to affect the signals received."

Sychronous Detection in Radio Reception — 2

Phase-locking and the "bi-aural" detector

by Pat Hawker, G3VA*

The main advantages of synchronous detection, as indicated in part 1 (September issue), are the modulation mode versatility it permits, its signal-to-noise ratio preserving qualities at low signal levels, and a good dynamic range when balanced forms are used. Further, the simplest applications of synchronous detection — product detectors for s.s.b. and direct-conversion receivers for s.s.b. and c.w. — do not require phase coherence. If full flexibility is to be achieved and synchronous detection used widely in receivers intended for the general public then something more is needed; some form of automatic control of the oscillator must be incorporated. History suggests that this needs to be done more elegantly than simply by triggering the local oscillator with a proportion of the incoming signal as proposed in the synchrodyne receivers. One must be able to lock the oscillator either directly to the incoming carrier or to control it from signals derived from the incoming sidebands.

First, it is worth having another look at direct conversion techniques. The very simple receivers outlined in part 1 can provide surprisingly good results with excellent selectivity, but they cannot achieve true "single-signal" reception as the audio image means that the receiver will respond to incoming signals on either side of the local oscillator frequency no matter how good the audio filter may be. Fortunately, this problem can be overcome, though at some cost in complexity, to the extent of some 30 to 45dB of rejection by the use of quadrature phasing techniques. A number of designs of what are termed two-phase direct conversion receivers have been published.

For example, Fig. 1 shows the block schematic of a 14-MHz receiver described by Taylor[1]; this provides true single-sideband reception by "phasing out" one set of sidebands in a manner akin to that used in phasing-type s.s.b. generators. In fact the designer used a standard Barker and Williamson phase-shift network in the audio combiner section. This technique is the same as that advocated for s.s.b. reception in such units as the Signal Slicer mentioned in part 1.

A basically similar approach was used by Spaargaren[2] in an experimental high-performance receiver for 3.5 MHz. In his receiver a cascode gain-controlled f.e.t. r.f. stage is followed by two balanced twin-diode detectors (Fig. 2) with the oscillator output phase shifted by 90° (Fig. 3) to provide phase quadrature injection. The a.f. outputs, after preliminary amplification, are similarly passed through active 90° phase difference networks (Fig. 4) and are then combined and passed through a five-section active low-pass filter to the main audio amplifier. He reported achieving 40dB of sideband suppression. Receivers of this type, while significantly more complex than the simplest direct-conversion receivers, are still basically simpler and cheaper to construct than a superhet receiver of comparable performance.

Further possibilities exist in this area. For example, the critical components in the phase shift networks could be eliminated by using digital i.c. techniques to provide the 90° phase shifts. A good deal of interest has been shown recently in digital phase shifting not only for possible simple s.s.b. demodulators for broadcasting[3] but also for s.s.b. generators, possibly based on the "third method" approach to s.s.b.

Phase-locked loop demodulators

The basic phase-locked loop synchronous demodulator, for example as used in the experimental receiver described by Costas in 1956 (Fig. 5), has been known for many years but until recently its use was confined to complex receivers such as those developed for space tracking. The incorporation of a phase-locked loop in a receiver means, among other advantages, that the receiver can utilize a noise bandwidth virtually equal to the intelligence bandwidth.

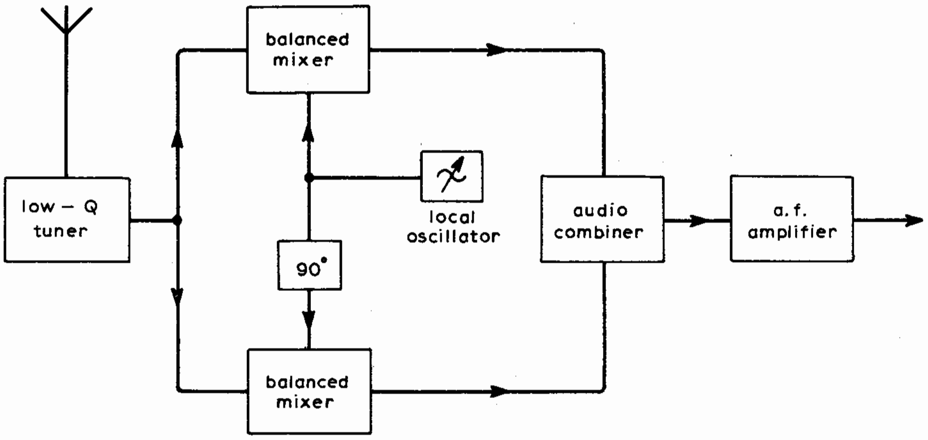

Fig. 1. Two-phase direct-conversion receiver providing "single-signal" reception for s.s.b. and c.w. signals.

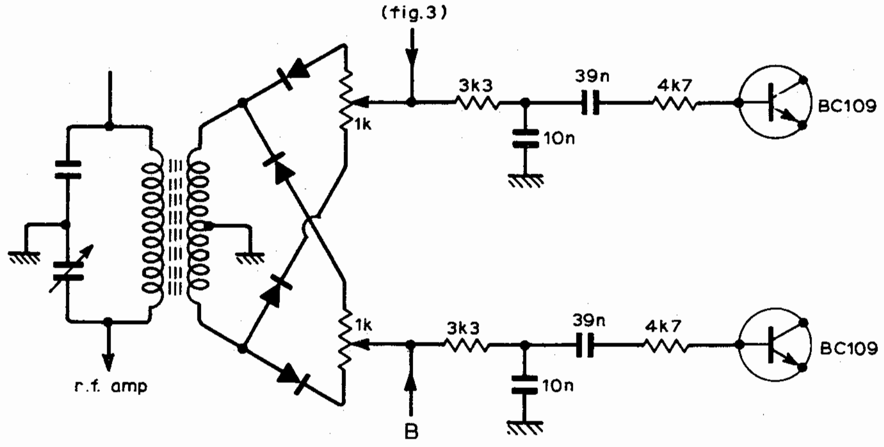

Fig. 2. Phasing-type balanced diode detectors for two-phase direct conversion receiver (Spaargaren).

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The position, however, has been dramatically changed by the present availability of integrated-circuit "signal conditioner and demodulator" devices[4] which provide a complete phase-locked loop demodulator in a single device — Fig. 6. Typically, such an i.c. contains a voltage-controlled oscillator, phase comparator, amplifier and low-pass filter. Some devices are intended only for f.m. demodulation, others include additional product detectors for other modes, including s.s.b. Such a device permits f.m. demodulation without any external tuned circuits — Fig. 8. The phase-locked loop can be externally tuned by a single adjustable element over a frequency range of 1Hz to more than 30 MHz. Within this range, a device such as the Signetics NE560B provides a tunable narrow-band filter with a selectivity comparable to that of three conventional tuned i.f. stages.

The phase-locked loop is an arrangement similar to that used in automatic frequency control circuits for many years but capable of maintaining the internal v.c.o. in phase coherence with the input signal. This means that the initial v.c.o. frequency need not be precisely tuned or unduly stable, as when within lock-in range it will automatically be drawn to the frequency of the input signal and held there.

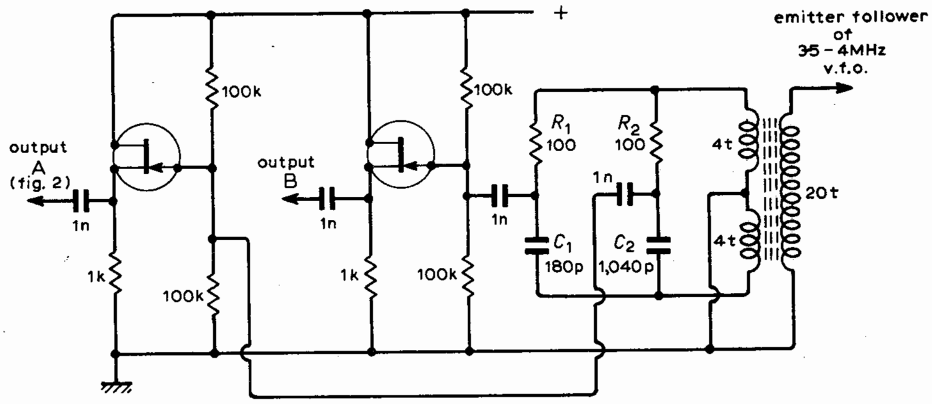


Fig. 3. Phase shifting networks used to obtain quadrature injection for the detectors of Fig. 2.

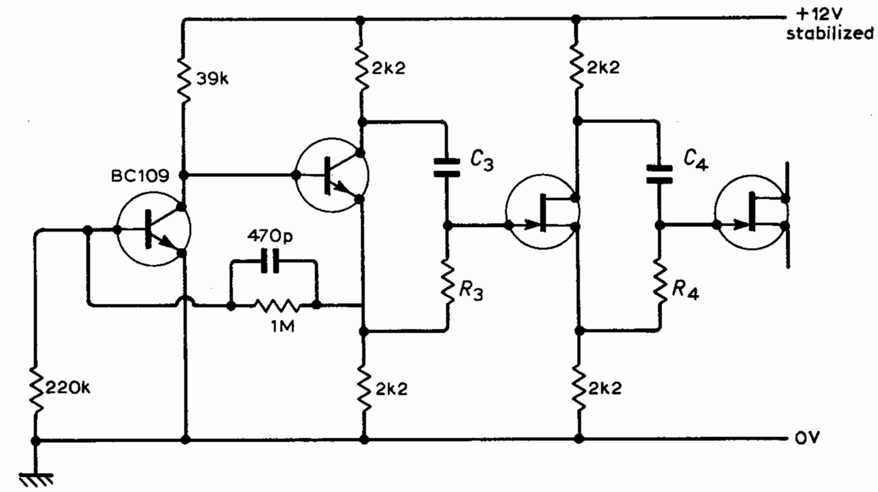


Fig 4. Principle of audio phase shifting networks. In one network C_3 is 4.7nF, R_3 220kΩ, C_4 4.7nF, R_4 18kΩ. In the other network C_3 is 1nF, R_3 800kΩ variable, C_4 1nF, R_4 20kΩ variable.

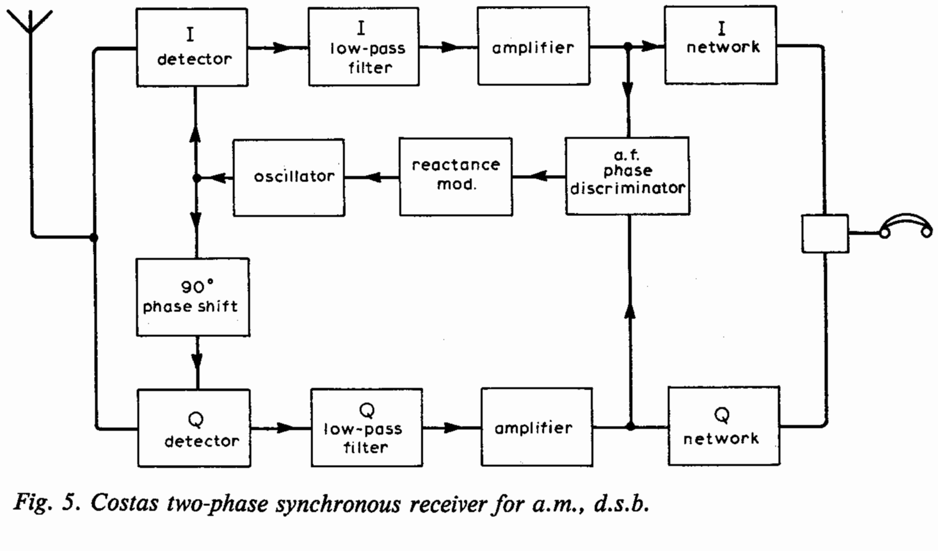


Fig. 5. Costas two-phase synchronous receiver for a.m., d.s.b.

For conventional f.m. or narrow-band f.m. the phase-locked loop provides a highly effective discriminator and eliminates the need for the usual ratio detector or quadrature f.m. detector on all signals above a low threshold value. W. N. Burridge has reported using an NE560B device as an f.m. detector for television sound and found it functioned extremely well on long-distance signals, receiving Crystal Palace in south Devon — see ref. 5. He has also used the NE561B as an a.m./f.m. demodulator on amateur 144MHz and 432MHz signals, using an i.f. of 1.6MHz.

Among the applications suggested[6] by Signetics for their NE560/NE561 devices are: i.f. strip and demodulator for f.m. receivers; television sound i.f. amplifier and demodulator; tuned a.m./m.w. receiver of the direct-conversion type (Fig. 9); "storecast" (s.c.a.) receivers and the like.

It must be admitted that the cost of these purpose-designed demodulators has so far remained high for amateur experimenters, but some lower-cost units are available for use as narrow-band f.m. demodulators at intermediate frequencies up to 500kHz.

Recently, K. Spaargaren has shown that it is possible to achieve comparable results using three of the relatively low-cost t.t.l. integrated circuits plus a few external components — Fig. 10 and ref. 7. By adjustment of C this system can be used at virtually any frequency up to about 30MHz. One section of an SN7400 is used as a voltage-controlled oscillator with the frequency determined roughly by C, and brought into accurate lock by the output of the phase detector connected via a BC109 transistor.

Bi-aural demodulator

The basic phase-locked loop detector can be extended still further by its use in conjunction with quadrature phasing techniques and dual audio channels to provide high performance on almost all possible broadcast modes. This system is generally termed a bi-aural synchronous exalted-carrier detector — Fig. 11.

In this detector two balanced mixer-modulators (usually at i.f. but again the system could be adapted for direct conversion) are driven in phase quadrature from the controlled local oscillator to provide in-phase (I) and quadrature (Q) product detectors. The d.c. and a.f. output from the Q detector is used to lock the local oscillator to the incoming signal. The d.c. output from Q can be used to operate a tuning meter, and when in lock the d.c. output of the I detector provides an indication of the incoming signal strength and so can be used to operate an S-meter

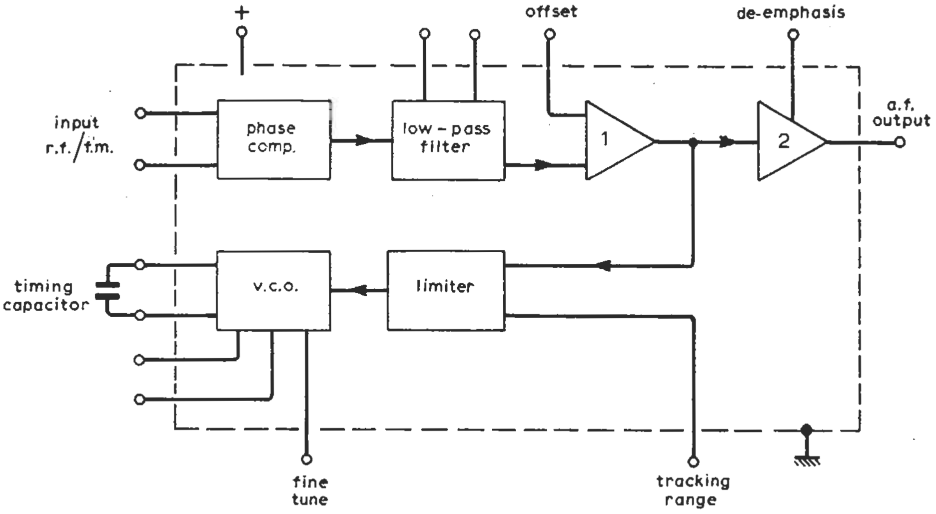


Fig. 6. Block outline of NE560B phase-locked loop demodulator integrated circuit.

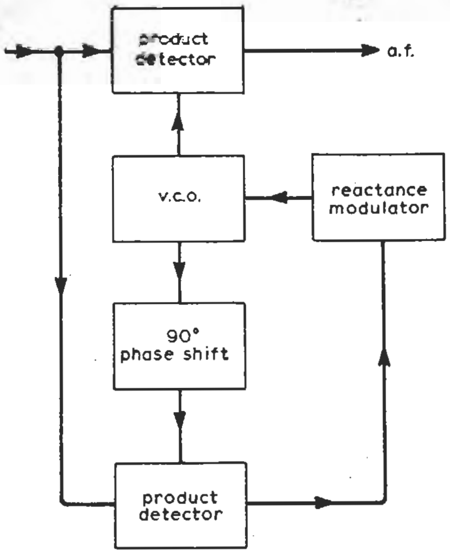


Fig. 7. Synchronous lock-loop demodulator.

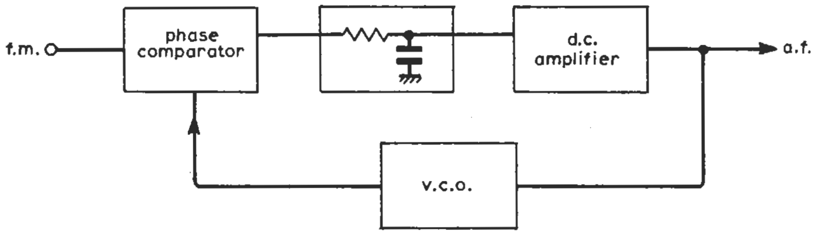


Fig. 8. Basic phase-locked loop f.m. demodulator.

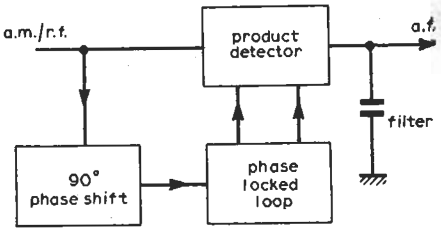


Fig. 9. Use of an NE561 i.c. as a simple direct-conversion receiver for medium-wave a.m. reception.

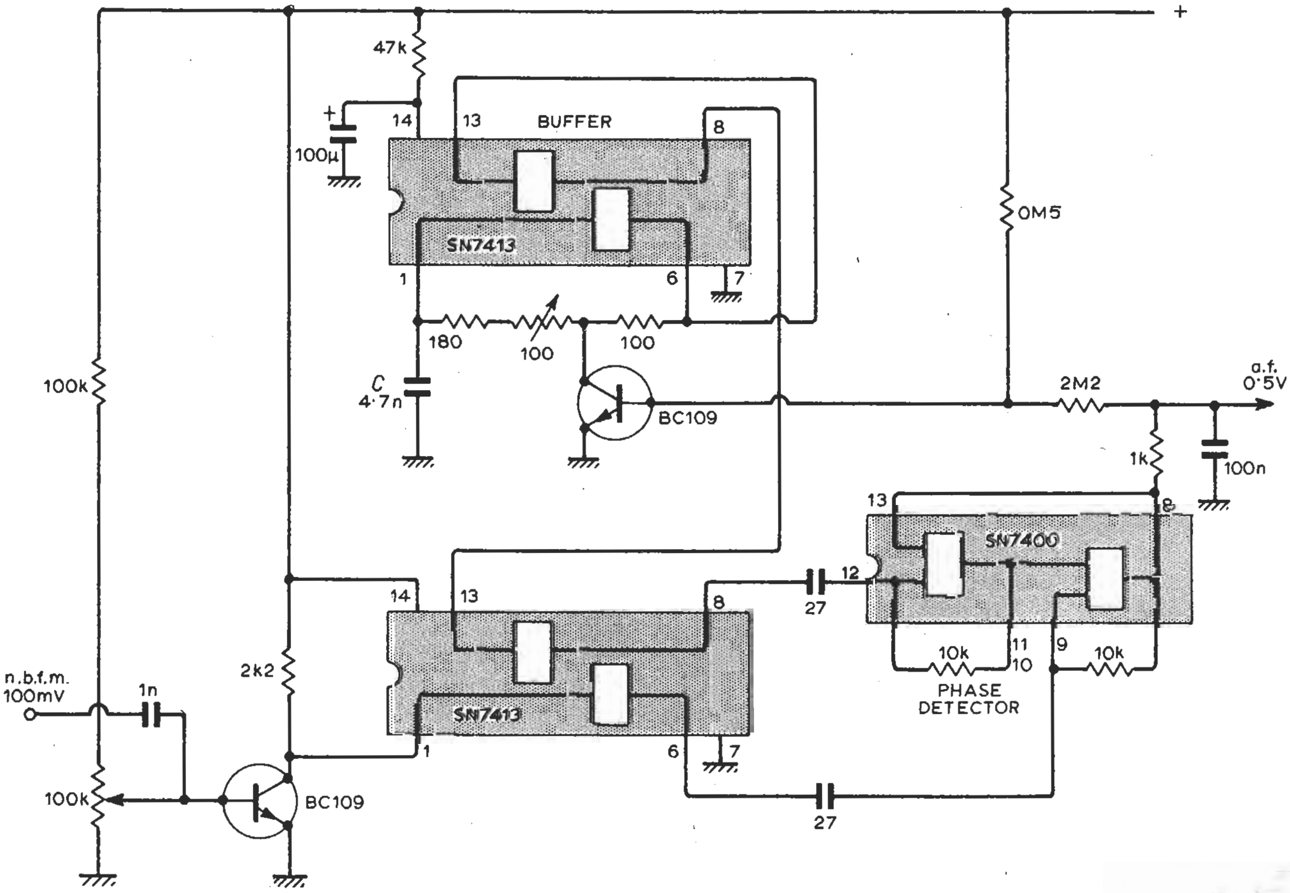
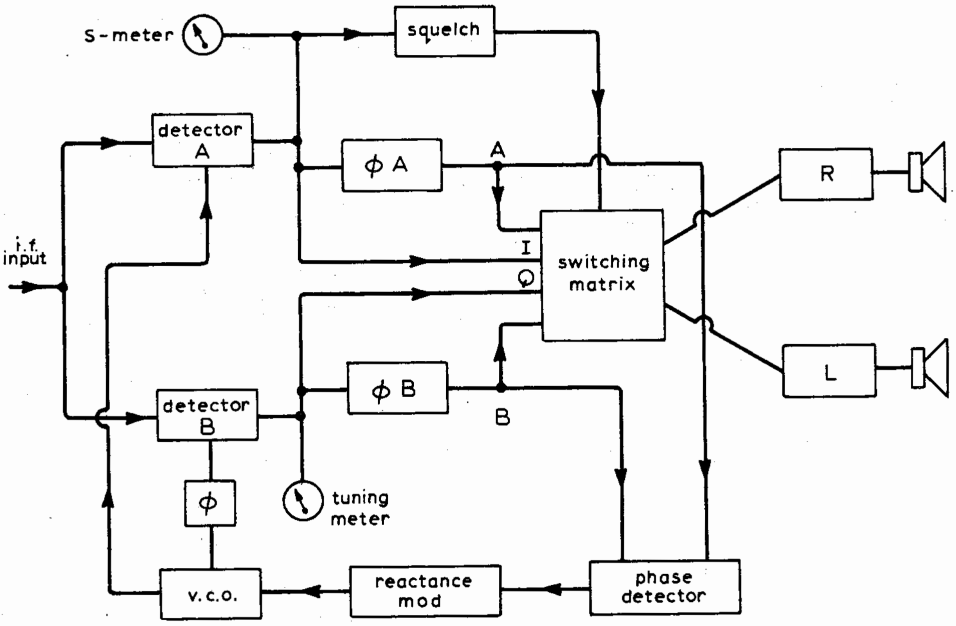


Fig. 10. Use of low-cost t.t.l. digital integrated circuits to form phase-locked loop n.b.f.m. demodulator. With value of C indicated, this is suitable for intermediate frequencies of around 470kHz (Spaargaren).



SWITCH MATRIX	AUDIO R	AUDIO L
1 a.m./d.s.b.	I	I
2 f.m.	Q	Q
3 reject u.s.b.	A+B	A+B
4 biaural	A+B	A−B
5 reject l.s.b.	A−B	A−B

Fig. 11. Flexible bi-aural synchronous exalted-carrier detector.

Relative effectiveness (in dB) for speech in the presence of random interference showing influence of the demodulator (after Haviland).

Mode	Envelope detector	Slope detector	Product detector	'Select' product	Locked loop	Bi-aural
d.s.b. (10kHz)	−3.2	—	−6.2	−3.2	−3.2	+2.8
n.b.f.m. (10kHz)	−20.4	−7.4	−10.4	−7.4	−7.4	−1.4
s.s.b. + C (5kHz)	−3.4	—	−0.4	−0.4	−3.4	−0.4
s.s.b. (5kHz)	—	—	+10	+10	+7	+10
d.s.b.s.c. (10kHz)	—	—	+7	+10	+10	+16

or a squelch arrangement to mute the receiver between stations to eliminate tuning heterodynes.

The I and Q outputs are passed through two phase shift networks (A and B) and then go to a switching matrix, arranged to give sum and difference components or direct outputs from the detectors. From this matrix, outputs are taken to two separate audio amplifiers and loudspeakers, as in stereo practice, although this is not a stereo system.

The detection system, as reported by C.C.I.R. Study Group 10, operates as follows. When receiving normal a.m., its a.f. component appears in the output of the I product detector, but no output appears at Q. In these circumstances, a.f. is fed to both L and R channels except with the matrix switched to position 2. The listener "hears" the source midway between the loudspeakers.

Should non-synchronized interference be present, it will appear in the outputs of both I and Q detectors and at the outputs of the A and B networks. With the switching matrix in position 1, the interference appears in both loudspeakers. But, depending on which sideband the interference is affecting, it will be rejected in either position 3 or 5 of the matrix.

In position 4, the wanted audio appears on both loudspeakers but the unwanted signals, provided they affect only one sideband, appear on only one loudspeaker. It appears to the listener displaced in position and he is able to ignore it. In this position, in practice, there may be interference on both sidebands, but the listener is still able to reject it as only the wanted audio will appear to be coming from the central area.

If the signals are fading, the relative strength of the wanted and unwanted signals changes. But in the case of selective fading of the wanted signal, this will result in an apparent moving of the source from the mid-point between the loudspeakers resulting from the simultaneous amplitude and phase changes; but it is claimed that the usual "garbling" produced by selective fading normally does not occur.

For reception of phase-modulated or narrow-band f.m. signals, performance will be similar apart from the fact that the a.f. output of the I detector is zero, with the output of the Q detector containing the wanted signal.

For the reception of s.s.b., an output will appear at both I and Q mixers with the unwanted sideband providing a null signal which can be rejected by switching either to position 3 or 5. It has been stated that with careful design of the phase-locked loop it is possible for the local oscillator to be locked by the incoming carrier even when this has been suppressed to the extent of 40dB. The system can still be used for greater degrees of carrier suppression as it then functions as an un-locked product detector, but becomes subject to tuning errors.

Study Group 10 has suggested that it is difficult to assess the improvement over a conventional detector of this system, at least on a theoretical basis, but tests have suggested that average, improvement in reception is around 10 to 20 dB and interference rejection may in some circumstances reach 30 to 40dB, the value depending on the accuracy of the phase shift networks. It is also believed that the "presence" of programme material is enhanced by the geometric effects arising from the two audio channels.

The value of this form of bi-aural demodulator is also indicated in the Table, drawn from reference 9. It should be stressed, however, that this form of improved synchronous detector is only one of a number of improved forms of detectors which are under investigation in the feasibility studies for s.s.b. broadcasting.

All the ideas discussed in these two articles utilize the various properties of synchronous detection, from relatively simple product detectors already widely used to the quite complex bi-aural system outlined above. In addition there are many other, often even more exotic, applications in communications and instrumentation which already use — or are likely in future to use—synchronous techniques.

Concluded. (Readers may have noticed that captions to Figs 6 and 7 in part 1 were transposed in error.)

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