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.

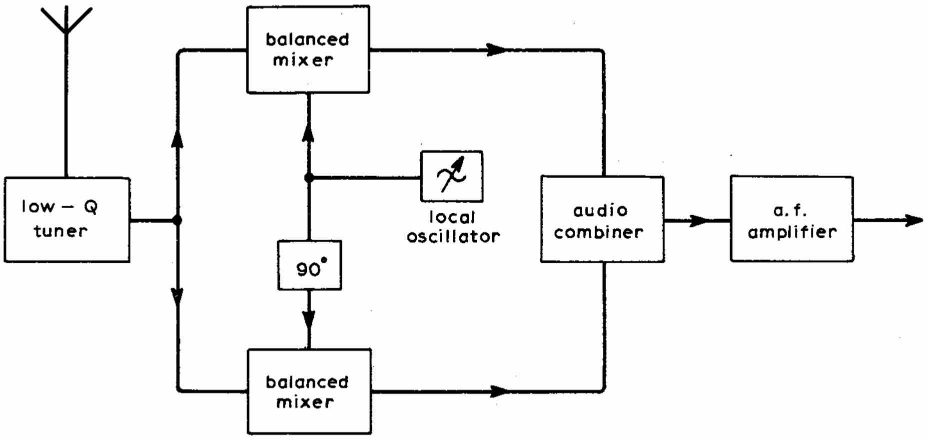

Fig. 1. Two-phase direct-conversion receiver providing "single-signal" reception for s.s.b. and c.w. signals.

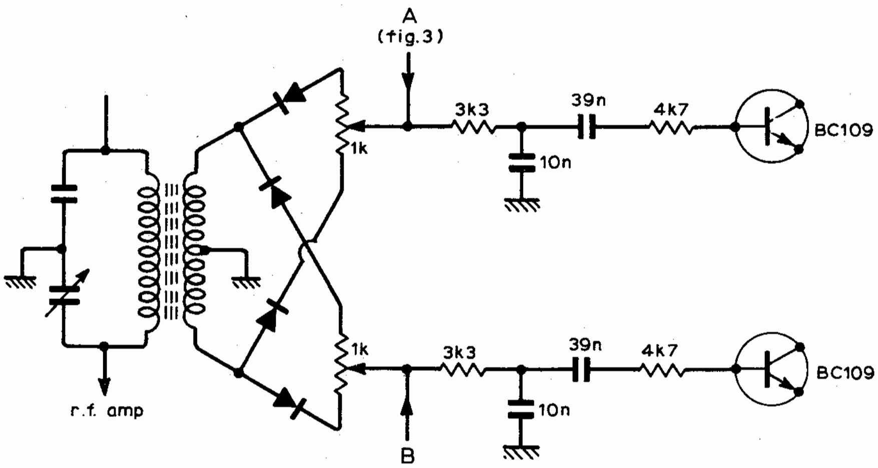

Fig. 2. Phasing-type balanced diode detectors for two-phase direct conversion receiver (Spaargaren).

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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.

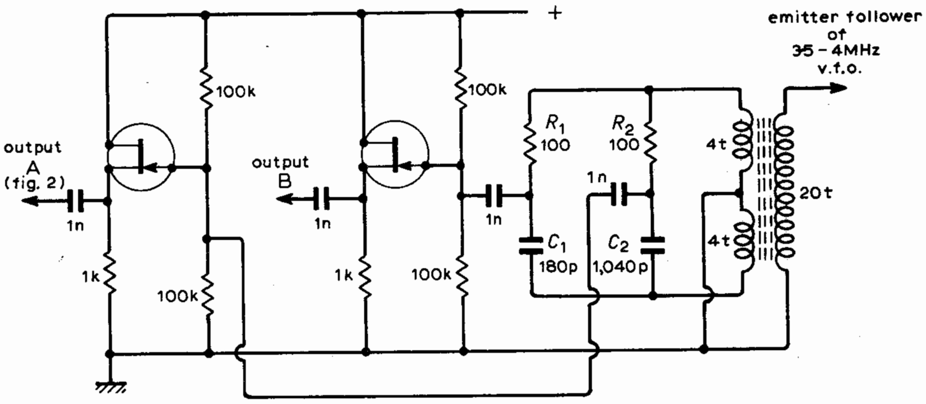


Fig. 3. Phase shifting networks used to obtain quadrature injection for the detectors of Fig. 2.

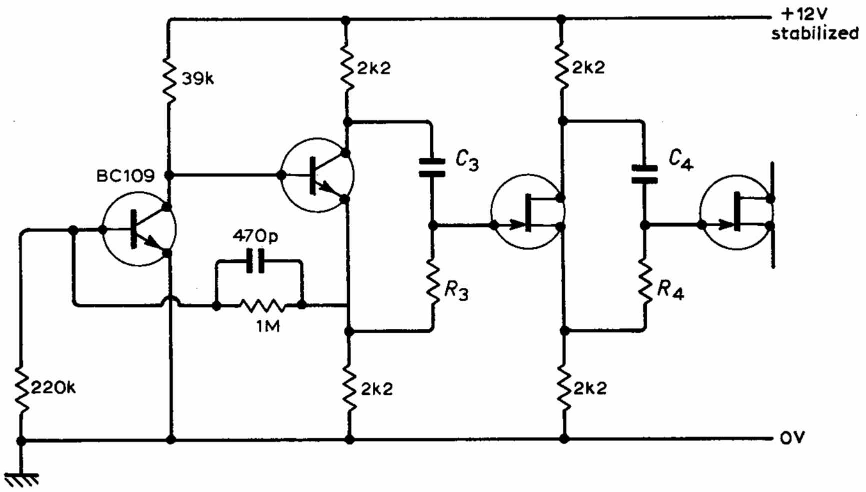


Fig 4. Principle of audio phase shifting networks. In one network C_3 is 4.7nF, R_3 220kΩ, C_4 4.7nF, R_4 18kΩ. In the other network C_3 is 1nF, R_3 800kΩ variable, C_4 1nF, R_4 20kΩ variable.

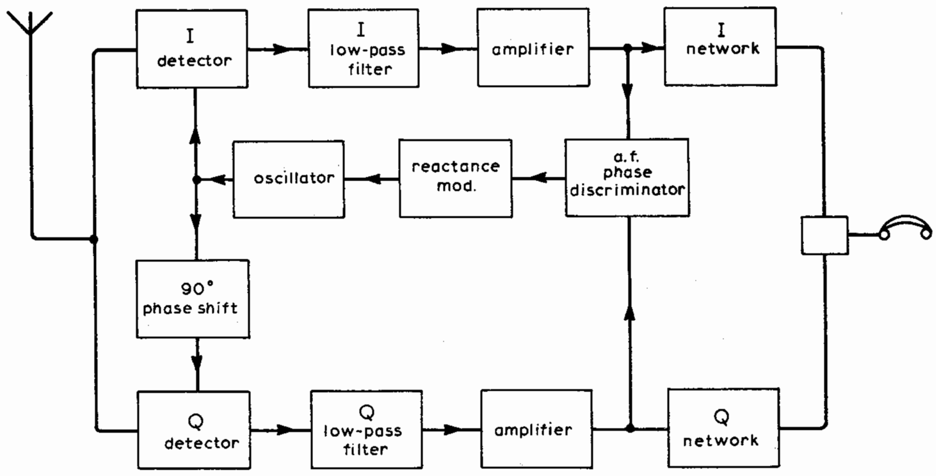


Fig. 5. Costas two-phase synchronous receiver for a.m., d.s.b.

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

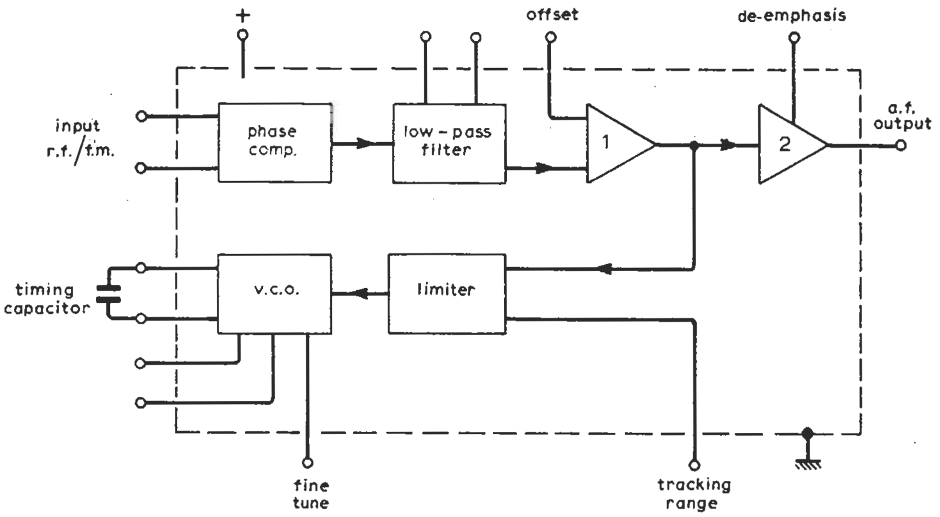


Fig. 6. Block outline of NE560B phase-locked loop demodulator integrated circuit.

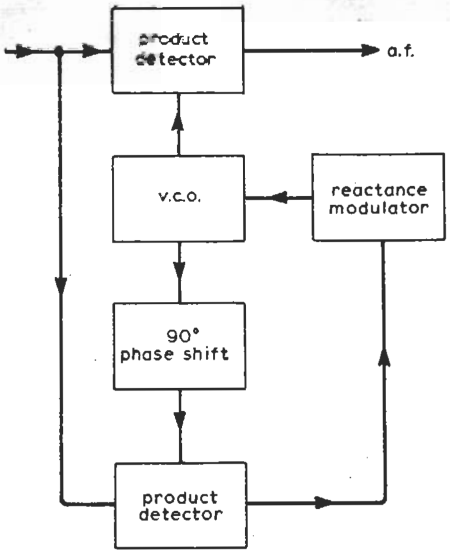


Fig. 7. Synchronous lock-loop demodulator.

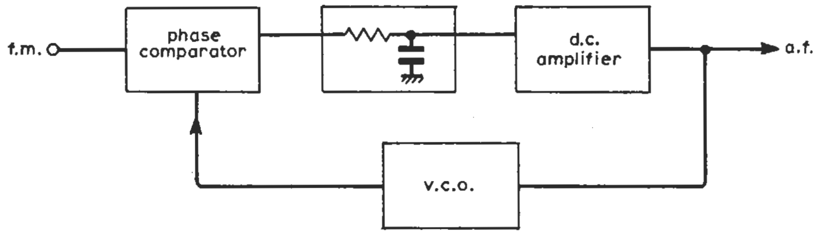


Fig. 8. Basic phase-locked loop f.m. demodulator.

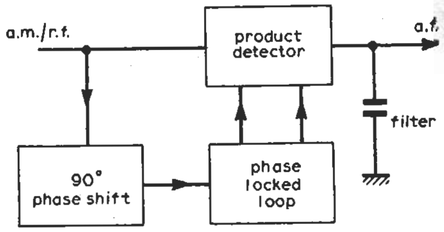


Fig. 9. Use of an NE561 i.c. as a simple direct-conversion receiver for medium-wave a.m. reception.

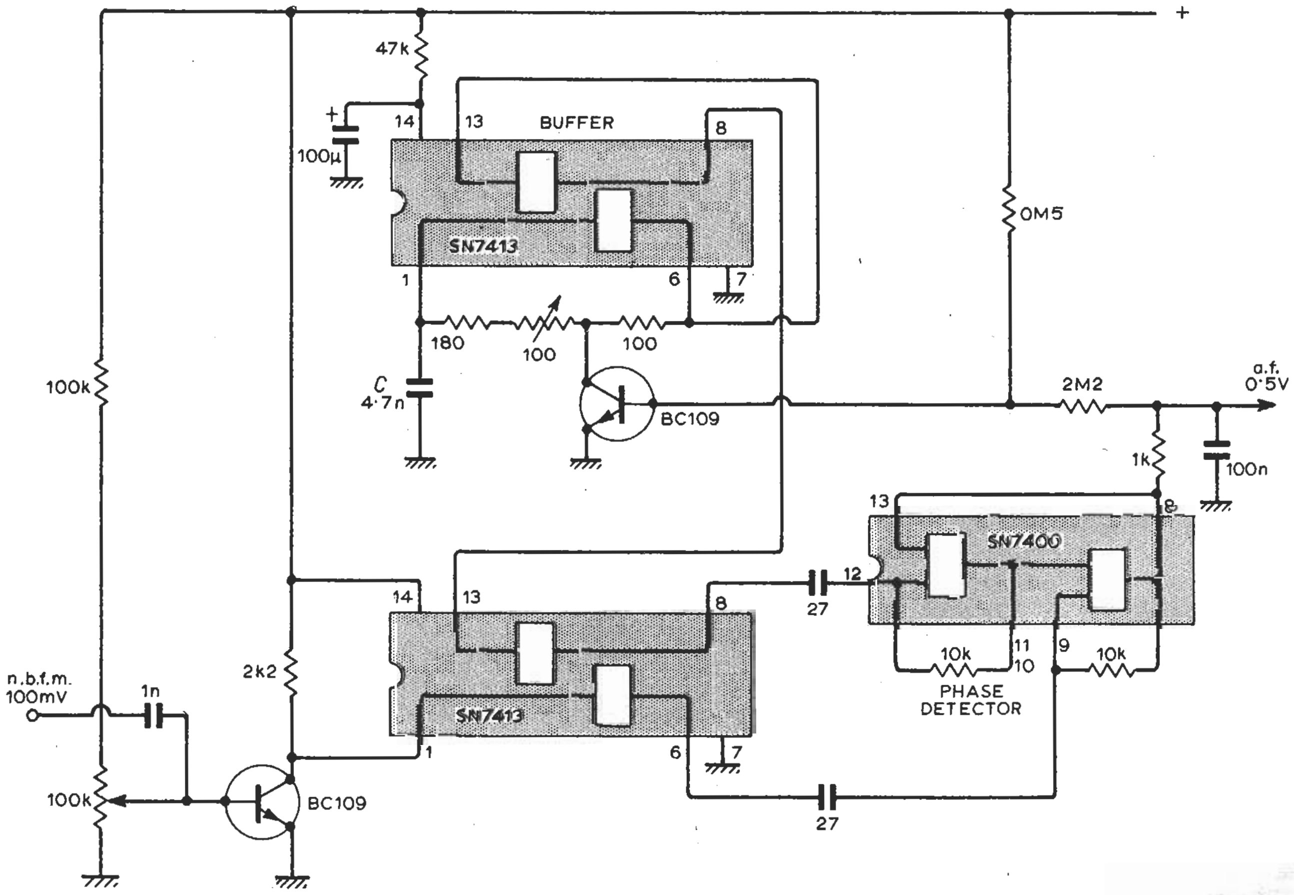
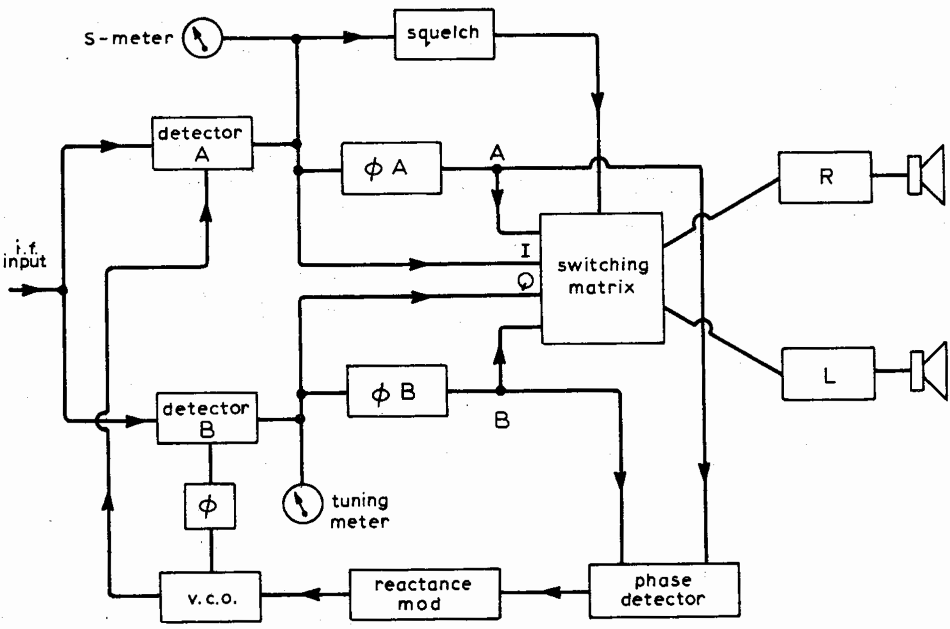


Fig. 10. Use of low-cost t.t.l. digital integrated circuits to form phase-locked loop n.b.f.m. demodulator. With value of C indicated, this is suitable for intermediate frequencies of around 470kHz (Spaargaren).



SWITCH MATRIX	AUDIO R	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.)

References

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