Synchronous Detection in Radio Reception -1

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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.

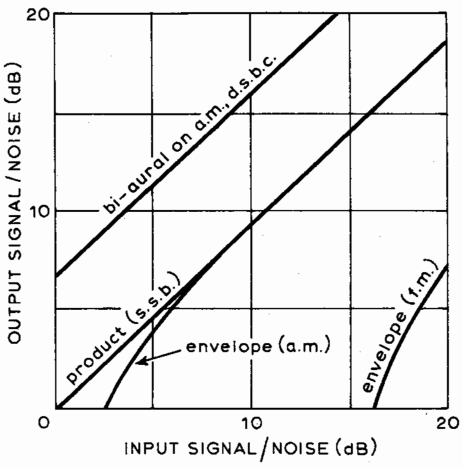

Fig. 1. Effect of demodulators on signal/noise ratios (after Haviland).

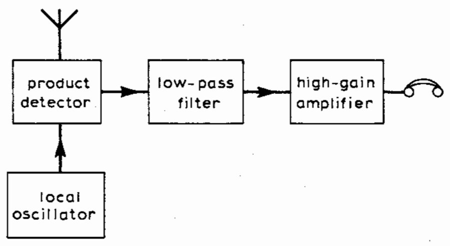

Fig. 2. Basic form of direct-conversion receiver.

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

* Independent Broadcasting Authority

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

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

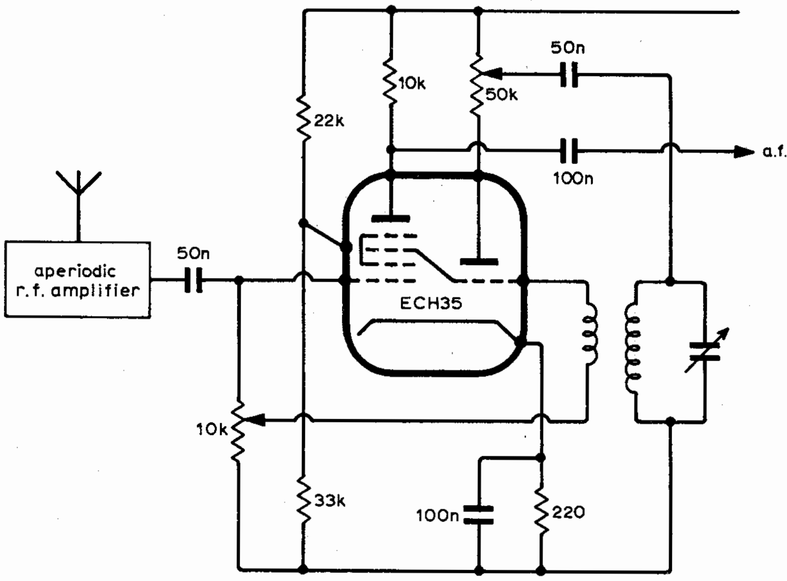

Fig. 3. Synchrodyne mixer detector described by Tucker in 1947.

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.

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

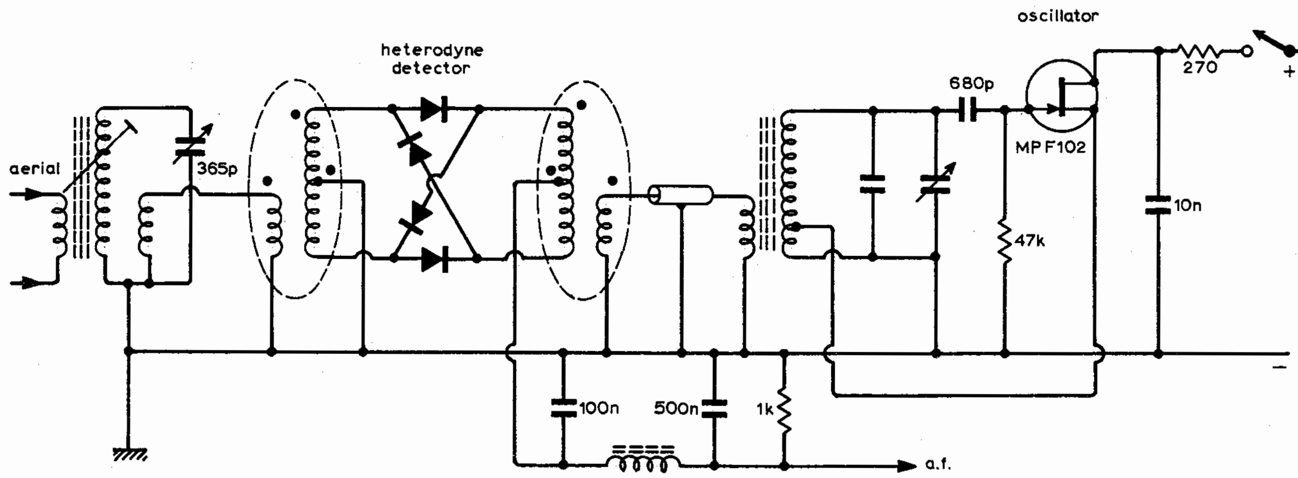

Fig. 4. Double-balanced ring demodulator with f.e.t. local oscillator in the Hayward and Bingham 3.5MHz direct-conversion receiver.

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

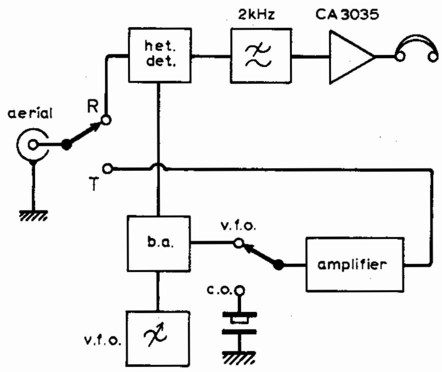

Fig. 5. Simple transceiver using the same oscillator for synchronous detection and for the transmitter v.f.o.

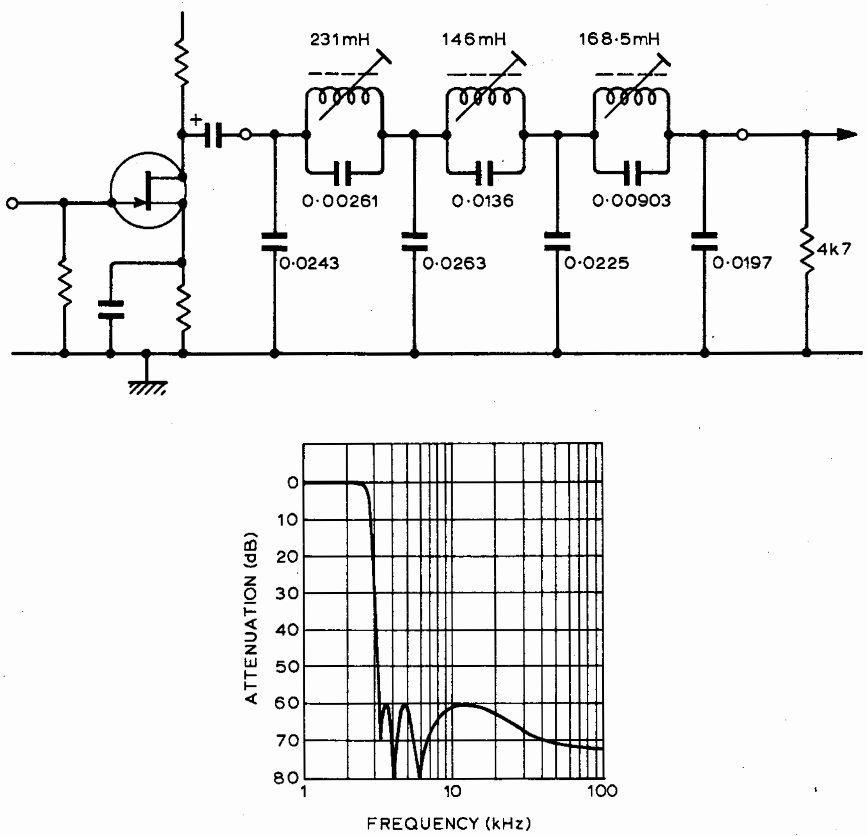

Fig. 6. Dual-gate mosfet heterodyne detector in the Ten Tec transceiver.

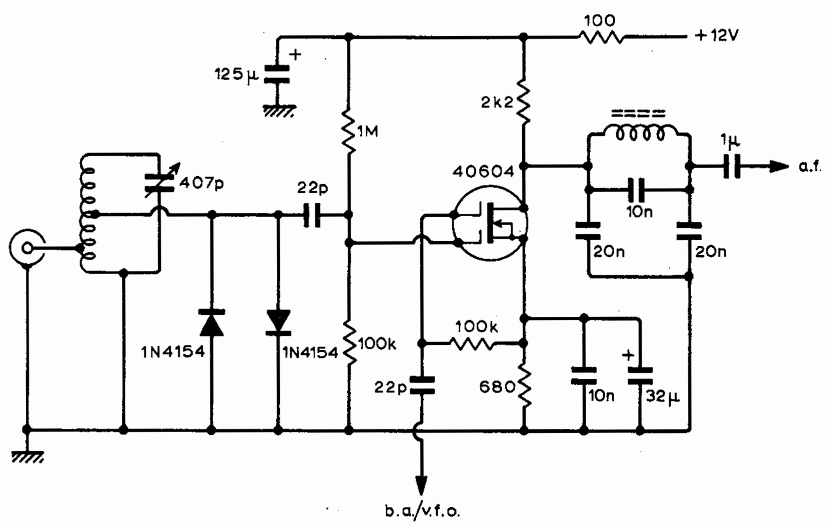

Fig. 7. High performance audio filter designed by P. G. Martin for use in direct-conversion receiver.

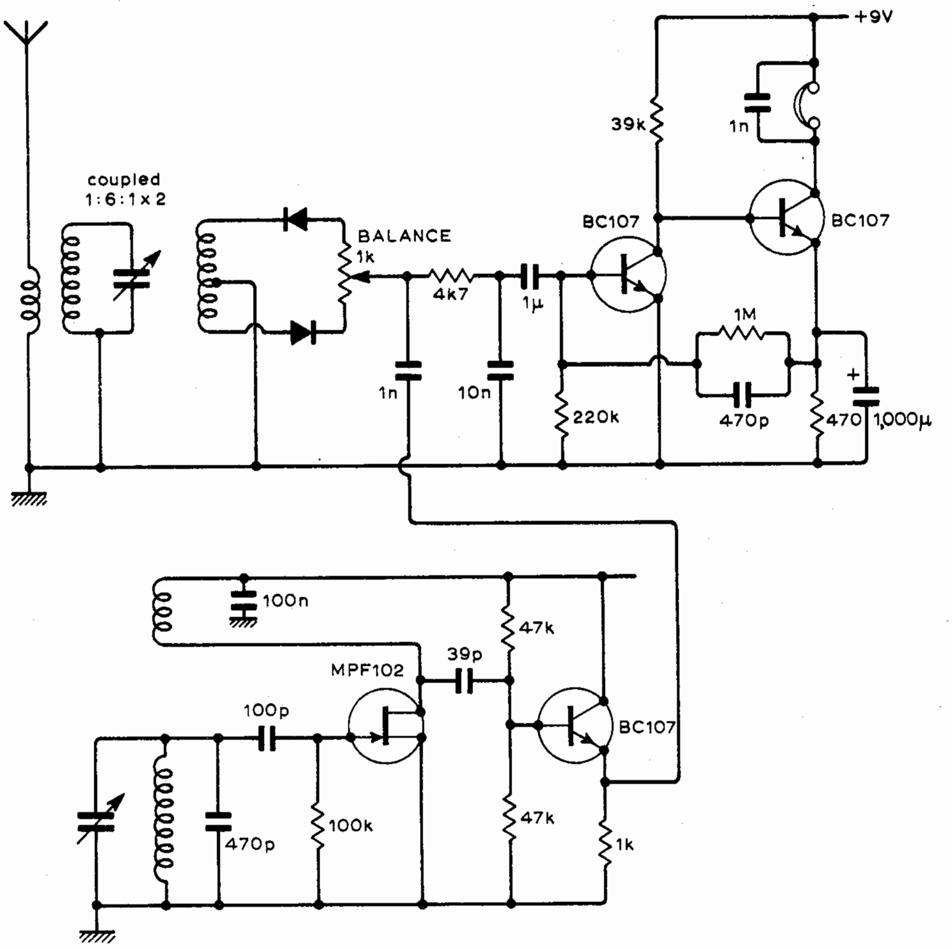

Fig. 8. How simple can you get? A direct-conversion receiver for 3.5MHz designed by K. Spaargaren.

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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(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."