New thoughts on demodulation

Edward Forster investigates the performance of Archie Pettigrew's award-winning amplitude-locked loop demodulation technique in both AM and FM receivers.

The amplitude-locked loop, or ALL, was not described as an automatic-gain system* but it clearly is a distinct form of one. Generally agc systems use gain-controlled amplifiers i.e. multipliers with a logarithmic or semi-log law to obtain large dynamic range. The dynamic range of an ALL with linear multiplier is described as 26dB.

Automatic gain control is rarely used to entirely suppress the amplitude modulation but this is only a matter of bandwidth. It is true that the ALL outputs the reciprocal of envelope amplitude together with a fully compressed envelope signal within its operating range. But how useful this is remains to be seen.

Demodulating AM

The ALL is used here to provide a constant envelope signal to the demodulator which is of the square law carrier recovery type[1] using a phase locked loop or pll. This might be unexceptional were it not for the claims made for this circuit. This is certainly not an advance in the art nor is it an optimum system. The ALL is said to provide special features which cannot be met by a limiter.

At threshold levels, I suggest that a soft limiter having a gain of 26dB put in place of the ALL would yield identical results. This is because at the end of its range the ALL also has a constant gain of 26dB and it would be impossible to distinguish between the two. At high carrier levels it also makes no difference which is used.

The subsequent pll shown in the circuit as the carrier recovery device is not an optimum type. This is a common mistake. It raises the question of what the point of the system is in the first place. The problem of AM full carrier reception in conditions of multipath interference and doppler shifts – such as found on the hf broadcasting bands – was successfully solved in the *Liniplex F1I2* receiver made by Phase Track Limited throughout the eighties. This used a synchronous pll AM demodulator[2] at intermediate frequency in a superheterodyne receiver.

Figure 1 shows the pll carrier recovery system of that receiver which is a type II system, ie it contains two perfect integrators these being an active integrator and the voltage controlled oscillator (vco). In servo parlance this is known as a proportional plus integral feedback loop. Although this is well known some of its characteristics as applied to this problem are apparently not well known.

Figure **1b** shows that the active filter can be redrawn as the equivalent sum of the proportional 'P' component and the integral 'I' component. This allows you to see more clearly what happens. **Figure 2** is the idealised response to a step offset of the vco. The 'P' component has a fast response but it eventually returns to zero. The 'I' component response is to gradually ramp towards the final control voltage needed.

When the response subsides, there is zero static error in the system. The loop may be opened without any effect. The same thing results if the input carrier also disappears for some time during a fade. The loop remains essentially locked and can provide the necessary carrier for effective synchronous demodulation of sidebands to continue undisturbed. When the carrier returns there is no re-locking as the loop never lost lock.

Another feature of the type II pll is that it offers the freedom to optimise the loop bandwidth without any restriction other than that the loop should follow any doppler shifts and vco drift. In the type I loop, setting the bandwidth correctly can result in the hold-in range of the pll being too small for practical use.

It is also necessary to have as small a loop bandwidth as possible. This is to prevent the control signal from frequency modulating the vco within the modulation band as this produces distortion.

Many such pll AM demodulators have appeared in up-market broadcast receivers. But because of this distortion, their audio quality was indistinguishable from the conventional envelope demodulator.

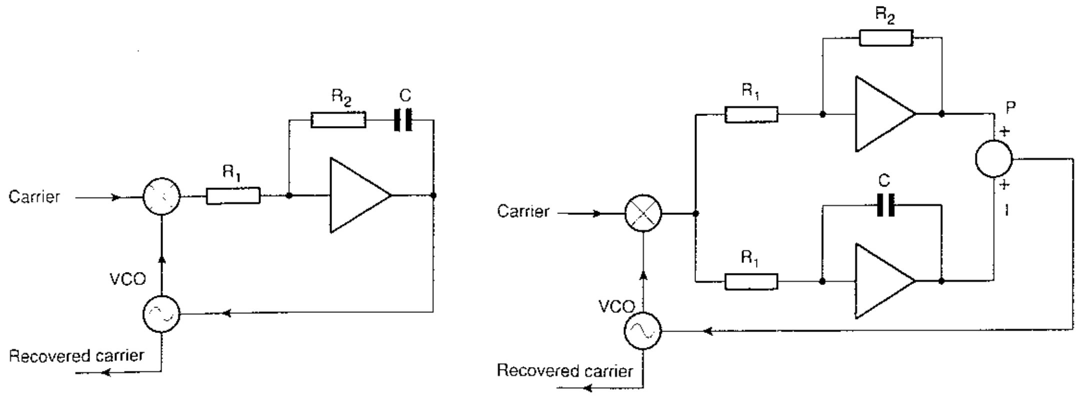

Fig 1 Carrier recovery by type II PLL; b) equivalent to a).

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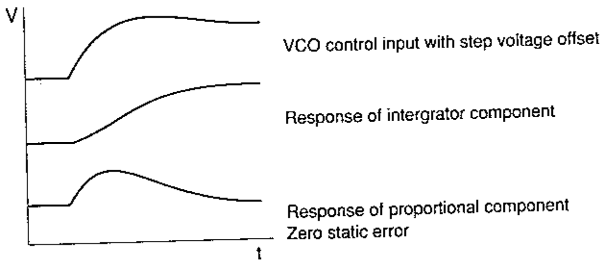

Fig. 2. Dynamics of type II PLL.

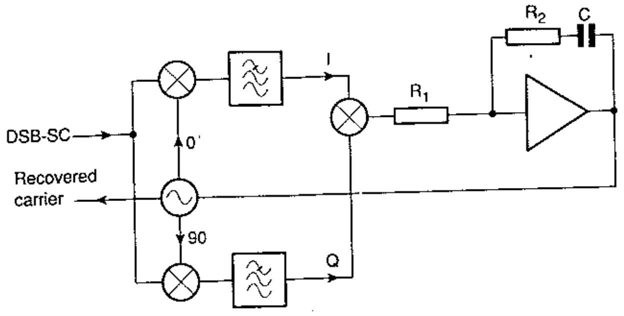

Fig. 3. Costas Loop with type II PLL.

The Costas loop

However, for the future, another old system brought up to date is preferred; this is the Costas loop[3–5], **Fig. 3**. It is suitable for AM full carrier or double sideband, or dsb, suppressed carrier reception. It relies directly on sideband information in the I, in-phase, and Q, quadrature channels which when multiplied together give an error signal.

The feedback error signal is intermittent in sound transmission and a special pll is required Again the type II loop serves the purpose as its, in principle, infinite memory capability allows the loop to stay in lock during modulation pauses. This time instead of acting from direct carrier phase information, it is the sidebands alone from which the virtual carrier phase is derived.

The great opportunity of the I/Q Costas loop is in I/Q direct conversion receivers where much of the former intermediate frequency processing can be equivalently replaced by on-chip audio processing whether analogue or digital. Multi-conversion superhets can be replaced by direct conversion receivers with equivalent performance but at a far cheaper cost and lower power consumption.

Although the synchronous receiver produces optimum results and also allows for electricity saving dsb broadcast transmission, a simpler non-synchronous technique[6] has been devised for the AM I/Q receiver. The superheterodyne is fast becoming obsolete.

Demodulation for FM

The hyperbole accompanying Pettigrew's FM demodulation circuit has in many ways obscured any real understanding of how it works. But, by separating the functions and using a simple test signal, its effectiveness can be clarified.

Figure 4 shows an unmodulated carrier of unit magnitude in the presence of an offset carrier of amplitude k. It is clear that both amplitude and phase modulation are produced When k is small say below 0.1, the difference frequency modulations are nearly pure sinusoids in phase quadrature With this information you can examine how the circuit performs with relative ease.

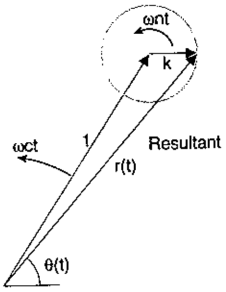

Fig. 4. Unmodulated carrier ωc rad/sec plus interfering carrier ωn rad/sec.

Figure 5 shows the simplified system. The ALL is assumed perfect as is the pll fm demodulator, which differentiates perfectly the phase modulation at its input. In being differentiated, the phase modulation is shifted by 90° to appear at the output of the fm demodulator, let us say for simplicity, as cos a.

Output from the ALL for small percentage amplitude modulation is also a cosine in-phase, say cos a again The final processing is the puzzle. As shown, there can never be cancellation however the amplitudes are manipulated. Therefore, at small values of carrier interference the system cannot work.

For large levels of interfering carrier it is necessary to use computer simulation This is in fact not too difficult. Using numerical differentiation it was possible to simulate the large signal case with less than 2k of Basic.

Results are as follows:

k	Improvement over pll o/p in dB
0.1	0
0.5	1
0.7	3
0.8	6
0.9	18
0.95	0

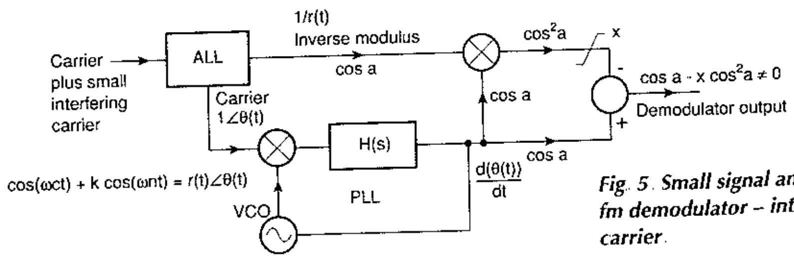

Fig. 5. Small signal analysis of fm demodulator – interfering carrier.

The improvement obtained is the result of some highly non-linear interactions but the significant improvement occurs within 3dB of the threshold, k=1, within a 2.2dB overall range from k=0.7 to k=0.9. Where the peak improvement occurs is a matter of adjustment but the above results are probably typical

Outputs of both the amplitude and phase-locked loops under these circumstances are pulses, which are not necessarily well matched. This indicates that the ALL pulse is being used more as a gating or sampling pulse. You might therefore suppose that the AM related pulse could be generated elsewhere Synchronous demodulation of the envelope, without ALL or limiter, could be devised to enable a pulse generator in this small range of k.

That aside, the pll frequency demodulator described by Pettigrew is fed from a constant carrier even at threshold. Presumably, it is considered that the best results will be obtained by simulating a limiter But it is known that a limiter is detrimental to threshold extension in phase locked loops.

Schilling[7] has noted that type II loops produce better threshold performance by virtue of the extra integrator. It is also shown[8] that above threshold, a limiter is of no value and that near threshold it is positively damaging

This is because, as the resultant carrier instantaneously falls to a low amplitude at the maximum rate of change of phase, the loop gain also falls to a low value. Consequently the loop does not track the rapid phase change and does not reproduce a sharp spike at its output. Maintaining full carrier level in all circumstances prevents this beneficial effect Again we come back to the pll design Is it a type I or type II?

If a type II pll were used for comparison in a receiver with slow agc but no limiter then any benefits may not look so great ■

References

1 Rieke. J W and Graham. R S. 'The L3 Coaxial System: Television Terminals', *BSTJ*. July, 1953.
2. Patent GB 2 077 533, Phase Track Ltd., 1980
3 Costas. J.P 'Synchronous Communications' *Proc IRE*. December 1956
4 Patent application, Phase Track Ltd, 1991
5. *Electronics World*. p84 January 1992
6 Forster, E C, patent application. 1994
7. Schilling. D J. and Taub, H. *Principles of Communications Systems*. 1971
8 Gardner, F M. *Phaselock Techniques*. 2nd ed. 1979