Do you know *Foster-Seeley?*

Amazed at the widespread misunderstanding of how the Foster-Seeley discriminator works, Richard Brice sets the record straight.

Despite the increasing use of phase-locked-loop fm detectors, the Foster-Seeley discriminator and its cousin the ratio detector still enjoy widespread use.

Sadly, familiarity has bred contempt for the principles at work in this apparently simple circuit, top right. It is still common to see descriptions of the operation of the discriminator which refer – without qualification – to the 90° phase-shift which exists between the primary and secondary of a tuned transformer'.

Yet such a phase shift only occurs under special circumstances. As a student, I found explanations of the circuit confusing. Rather than challenge the principles given, I opted to believe that a phase shift must exist between the primary and secondary voltage of all tuned transformers.

This fallacious belief was finally laid to rest when some empirical investigations proved this was not the case. A little research has uncovered that this confusing explanation of the Foster-Seeley discriminator has a long and distinguished history.

"...operation is dependent on the 90° phase shift which occurs at resonance between primary and secondary voltages of a tuned transformer."[1]

"It will be seen that both primary and secondary windings of the IF transformer are tuned. Now, when they are both tuned to resonate to the incoming signal (i.e., the normal carrier frequency) the voltage across the secondary, V_s, lags the voltage across the primary, V_p, by 90°."[2]

"Conventional discriminators use the composition of two vectors at right angles when there is no frequency deviation and when the frequency departs from its state of rest the angle between the vectors departs from 90°. Figure 2.6 [similar to diagram top right, next page] *shows an elementary balanced discriminator. Capacitors C tune the inductances to resonate at the centre frequency of the intermediate frequency band of the receiver... At resonance the voltage V1 [V_p] will be in quadrature with the voltages in each half of the secondary winding."*[3]

Foster-Seeley discriminator analysis

$$i_{A-C} = V_o\left(\frac{1}{R} + j\omega C\right)$$

$$V_{A-B} = V_o\left(1 + j\omega L\frac{(1+k)}{R} - \omega^2 L(1+k)C\right)$$

$$i_{A-B} = V_o\left(\frac{j}{\omega kL} - \frac{1+k}{kR} - j\omega C\frac{(1+k)}{k}\right)$$

$$V_{in} = V_{A-B} + j\omega L(1+k)(i_{A-C} + i_{A-B})$$

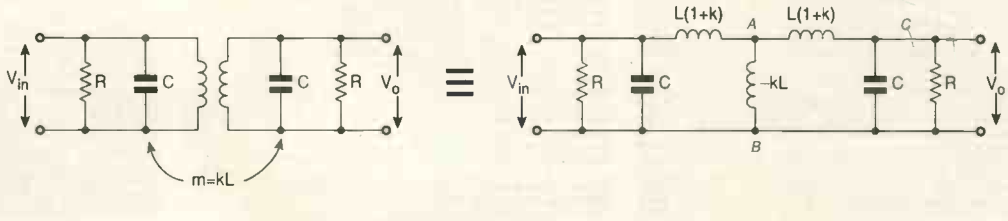
$$= V_o\left(\begin{array}{l} 1 + j\omega L\frac{(1+k)}{R} - \omega^2 L(1+k)C \\ + j\omega L\frac{1+k}{R} - \omega^2 L(1+k)C - \frac{1+k}{k} \\ - j\omega L\frac{(1+k)^2}{kR} + \omega^2 LC\frac{(1+k)^2}{k} \end{array}\right)$$

$$\frac{V_o}{V_{in}} = a\angle\theta$$

$$\mathrm{Tan}\theta = -\frac{\frac{\omega L}{R}\left(2 + 2k - \frac{1}{k} - k - 2\right)}{\omega^2 LC\left(\frac{1}{k} + k + 2 - 2 - 2k\right) - \left(\frac{1}{k} + 1\right)}$$

$$= \frac{Q\left(\frac{1}{k} - k\right)}{\omega^2 LC\left(\frac{1}{k} - k\right) - \left(\frac{1}{k} + 1\right)}, \text{ which if } \omega^2 LC = 1,$$

$$\mathrm{Tan}\theta = \frac{Q\left(k - \frac{1}{k}\right)}{k+1} \text{ and } \rightarrow \infty \text{ as k} \rightarrow \phi$$



Action of the discriminator relies on very loose coupling between primary and secondary windings of the IF transformer.

But, how can any phase-shift exist between the primary and secondary of a transformer if the flux closely couples both coils? The answer is – in the Foster-Seeley circuit it does not.

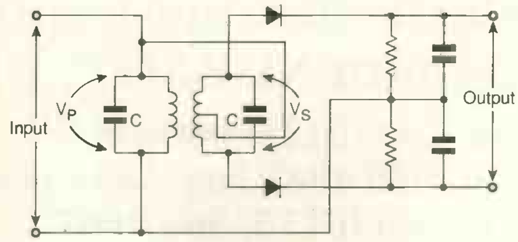
Circuit action relies on there being a very loose coupling between primary and secondary windings of the intermediate-frequency transformer. The diagram bottom left, and the associated working presents a more rigorous analysis[4]. Analysis also shows that when coupling between a transformer primary and secondary is perfect – equal to 1 – no phase shift exists between primary and secondary voltages. This is regardless of whether the windings resonate with parallel capacitances or not.

M. G. Scroggie in *Foundations of Wireless* appears to be one of the few writers who deemed it necessary to bother the reader with this crucial aspect of the discriminator's operation,

"*...because both windings are tuned exactly to the carrier wave and coupled only very loosely, voltages across them are 90° out of phase.*"

Some authors, perhaps sensing murky waters but being unsure as how to clear them, simply eschew explanation altogether. A recent, and widely set textbook[6] describes the Foster-Seeley discriminator thus,

"*The Foster-Seely (sic) detector, or its variant, the 'ratio detector' [uses] a single tuned circuit in a fiendishly clever diode arrangement to give a linear curve of amplitude output versus frequency over the IF bandpass.*"



Foster-Seeley discriminator – it is still common to see descriptions of this referring to a 90° phase-shift between the primary and secondary of the tuned transformer.

This explanation is unlikely to leave today's students crystal clear as to the operation of the circuit. Its author appears to use words as did Lewis Carroll's Humpty Dumpty who argued, "*when I use a word... it means just what I choose it to mean – neither more nor less*"[7] ■

References

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3. Maurice R.D.A., 'Television Engineering', Pentech Press, London, 1985.
4. Private correspondence with my friend Brian Pethers.
5. Scroggie, M.G., 'Foundations of Wireless', 8th edn, Butterworth & Co., London, 1971.
6. Horowitz, P. and Hill, W. 'The Art of Electronics', 1st edn, Cambridge University Press, Cambridge, 1980.
7. Carroll, L., 'Through the Looking Glass'.