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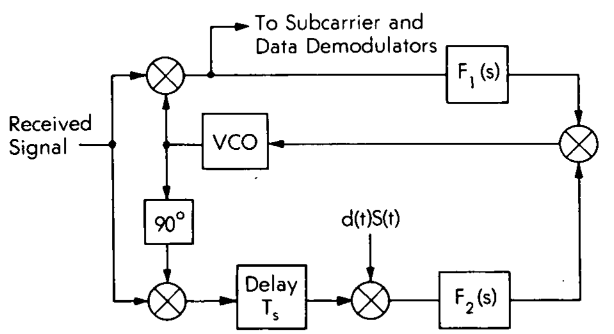
Data-Aided Carrier Tracking Loops

The problem:

To improve the performance of phase-lock-loop telemetry receivers which must acquire and track very weak, noisy signals.



T_s = reciprocal of data rate
d(t) = estimate of output data
S(t) = reference subcarrier in subcarrier tracking loop (square wave)

The solution:

Use the power in the composite signal sidebands to enhance the signal-to-noise ratio in the carrier tracking loop, thereby reducing the radio loss (noisy reference loss) and decreasing the probability of error of the receiver.

How it's done:

The subcarrier components of power in the received signal, being centered around the subcarrier frequency, are rejected by conventional phase-lock-loop receivers and hence are not available for improving the carrier tracking performance. On the other hand, the signal-to-noise ratio in the carrier tracking loop can be considerably enhanced if the power in the composite signal sidebands can be recovered. Thus, by adding a quadrature channel to the phase-lock-loop detector circuit of a receiver, there can be fed back a dc component into the carrier tracking loop VCO that is proportional to the power in the modulated data subcarriers.

The proposed modification is based on the principle of decision-directed feedback. For example, when the received signal is a carrier modulated by a single biphase-modulated data subcarrier, an estimate is formed of the biphase-modulated subcarrier term which, when fed back to the carrier tracking loop, can be used to recover the power in the sideband components for carrier tracking purposes.

The standard phase-locked loop used in present-day (deep space) telemetry receivers is depicted in the block diagram. The proposed modification makes use of a quadrature channel to insert into the VCO a dc component with power proportional to the biphase-modulated data subcarrier. The shape of the equivalent loop S-curve remains essentially unaffected by the addition of the quadrature channel; its amplitude, however, is increased in proportion to the power contained in the signal's sidebands, the phase jitter in the subcarrier tracking loop, and the conditional probability of error in the data detector. In general, the conditional error probability depends both upon the subcarrier and the rf phase-errors, and hence the exact solution to the problem requires a two-dimensional iteration. However, cursory examination of these two degradations indicates that they are small relative to the radio loss caused by the carrier-tracking-loop phase error, and hence essentially all of the sideband power can be recovered and used for improving this principal source of degradation.

(continued overleaf)

For the simple case discussed, very little additional equipment and complexity need be incorporated into current receiver configurations. In situations where several data and/or sync-modulated subcarriers are phase modulated onto a main carrier, an n-dimensional extension of this technique can be applied. The power in any of the subcarrier components can, in principle, be recovered as above. Also, cross modulation losses can be recovered and used for carrier tracking purposes. For example, several decision-directed subcarrier-data demodulators are employed in parallel. Each of these requires an input-delay element proportional to the reciprocal of the data in that channel. In order to form an estimate of the cross modulation component of interest, the outputs of the channels involved must be delayed by the complementary delay before multiplication. The delay in the carrier loop is then the sum of the delays corresponding to the reciprocals of the channel data ratio.

References:

1. Lindsey, W. C.: Optimal Design of One-Way and Two-Way Coherent Communication Links. IEEE Transactions on Communications Technology, Vol. COM-14, No. 4, August, 1966, p. 418.
2. Lindsey, W. C.: Determination of Modulation Indexes and Design of Two-Channel Coherent Communication Systems. IEEE Transactions on Communication Technology, Vol. COM-15, No. 2, April 1967, p. 229.
3. Lindsey, W. C.: Design of Block-Coded Communication Systems. IEEE Transactions on Communication Technology, Vol. COM-15, No. 4 August 1967, p. 524.

Patent status:

This invention has been patented by NASA (U.S. Patent No. 3,710,261). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to:

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