

Preface

The Costas loop has been invented in 1956 by an American engineer J. P. Costas. His original circuit was used for the synchronous demodulation of double-sideband amplitude-modulated signals with suppressed carrier. What Costas designed that time was a variant of the phase-locked loop (PLL), a circuit that had been known long before. We will see later why the conventional PLL failed in such an application. Today, Costas loops are mainly used for the detection of signals by making use of digital modulation techniques, such as binary phase shift keying (BPSK). It showed up that a BPSK signal has very similar properties like the formerly mentioned amplitude-modulated signal. Later, the Costas loop was extended for the application in quadrature phase shift keying (QPSK) and also in m-ary PSK. Costas loops are also found today in the demodulation of quadrature amplitude modulation (QAM) signals.

Like the PLL, the Costas loop is a synchronizing device. The incoming signal in both systems is usually a carrier having frequency f_C that is modulated with the transmitted signal. Both Costas loop and PLL incorporate a local oscillator, operating at frequency f_{Loc} , and this frequency is controlled in such a way that it locks onto the carrier in both frequency and phase, hence the name “phase-locked loop.” When a data transmission starts or when a PLL or Costas loop is switched on, the initial frequency f_{Loc} is not yet synchronized to the carrier frequency, but it must first get locked to that frequency. This process is referred to as acquisition process. With the PLL, two different acquisition processes have been defined: (1) the relatively fast lock-in process and (2) the slower pull-in process. For the PLL, a quantity called lock range f_L has been defined. When the initial frequency of the local oscillator is within that lock range, the system will lock within at most one beat note between carrier frequency f_C and initial local oscillator frequency f_{Loc} . The time to get locked is called lock time T_L . When the initial frequency of the local oscillator is outside the lock range but within another range called pull-in range f_p , acquisition will still take place but is much slower. The time required for the pull-in process is called pull-in time T_p . The dynamic performance has been extensively investigated in case of the PLL; here, the designer can make use of equation enabling to compute all these parameters (lock range, lock time, pull-in range,

pull-in time) explicitly as a function of loop parameters such as natural frequency f_n , damping factor ζ and gain factors of building blocks such as phase detector or voltage-controlled oscillator (VCO). Such equations enable the designer to tailor his/her device in order to fulfill a number of given requirements, e.g., locking within, say, 20 μ s.

It is surprising that this dynamic analysis has never been performed for the Costas loop, although it has been described in many textbooks and papers. A possible reason for that could be the higher complexity of mathematics. When I tried first to develop such design equations for the Costas loop, I got aware that the Costas loop presents more nonlinearities than the PLL, which complicates the mathematical treatment considerably. Only after introducing a number of simplifications and linearizations, I was finally able to get explicit mathematical expressions for lock range, lock time, pull-in range, and pull-in time for the Costas loop. The mathematical treatment is even more aggravated because different analyses must be performed for the different types of Costas loop. The corresponding design equations will be presented in this textbook.

Another aspect of the Costas loop overlooked by almost all authors is the design of “modified” Costas loops, i.e., of Costas loops that operate with so-called pre-envelope signal, also referred to as “analytical” signal.

Operating with the pre-envelope has a dramatic impact on the performance of the Costas loop. First, it is easily shown that the lowpass filters used in conventional Costas loops are no longer required. It can be demonstrated that this greatly improves the dynamic performance of the loop, i.e., the pull-in range of such modified loops becomes much larger. When the loop filter is implemented by a PI filter (proportional + integral filter), the pull-in range becomes even infinite. Of course, this is only of “academic” interest; however in a real circuit, the loop can lock onto every frequency that can be generated by the local oscillator.

Another promising technology that has been widely discarded by most authors is the use of “phasor rotators” in Costas loops. In such systems, the local oscillator is not realized as an oscillator whose frequency can be controlled by a control signal, but as a simple oscillator that generates a constant frequency. In order to get locked, the two output signals of the Costas loop—it will be shown that there are two such signals in each Costas loop—are considered to form a “phasor,” a complex quantity. Acquisition is obtained by a rotation of that phasor. Such a design offers some advantages: the complexity of the high-frequency portion is reduced, and the rotating circuits are easily implemented from some logic circuits.

The book is organized as follows:

Chapter 2 gives a short introduction to the Costas loop. It concentrates on the differences between phase-locked loop and Costas and shows by some simple examples where the PLL can be used and where the PLL fails to do the required job and should be replaced by the Costas loop.

Chapters 3 and 4 discuss the conventional Costas loops for BPSK and QPSK, where “conventional” means a loop that operates with real input signals and not with the pre-envelope signal. After theoretical investigation, design procedures are presented, including case studies for the design of analog and digital circuits.

Finally, Simulink models are shown (all MATLAB files on attached CD), which enable the designer to verify the design.

In Chaps. 5 and 6 modified Costas loops for BPSK and QPSK are discussed, including design procedure and simulation. These systems operate with the pre-envelope signal.

Chapter 7 presents theory and design of a Costas loop for m-ary PSK demodulation, with design procedure and simulation.

Chapter 8 presents Costas loop for BPSK using phasor rotation circuit with design procedure, case study for designing a digital Costas loop, and simulation.

Chapter 9 presents Costas loop for QPSK using phasor rotation circuit with design procedure, case study for designing a digital Costas loop, and simulation.

Chapter 10 presents Costas loop for demodulation of quadrature amplitude modulation (QAM) signals with theory, design procedure, and simulation.

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