Chapter 2
Application of Novel Signal Processing Algorithms for the Detection and Minimization of Skywave Interfering Signals in Loran Receivers

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ABSTRACT
Skywave interference commonly affects Loran receivers’ performance. Traditional skywave rejection methods that use fixed, worst-case, sample timing are far from optimal. This chapter reports on novel signal processing techniques for measuring in real-time the delay and strength of the varying skywave components of a Loran signal relative to the groundwave pulse. The merits and limitations of these techniques will be discussed. Their effectiveness will be assessed by theoretical analysis, computer simulations under a range of realistic conditions, and by testing using off-air signals. A prototype Loran system employing the proposed techniques is also presented. This work establishes a basis on which to design a Loran receiver capable of adjusting its sampling point adaptively to the optimal value in a constantly-changing skywave environment. Such receivers promise to improve significantly the accuracy and reliability of positioning under adverse operational conditions.

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INTRODUCTION

LOng RAnge Navigation (or Loran) is a pulsed, low-frequency (100 kHz) radio-navigation system for position fixing by reference to terrestrial transmitting stations. Loran-C was the third generation of Loran developed since World War II and it became one of the world’s most widely used terrestrial radio-navigation systems. The current system provides continuous, reliable and cost-effective navigation, location and timing services for both civil and military air, land and marine users. Although a long-established and well-known system, Loran has been studied intensively in recent years as a potential complement to the Global Navigation Satellite Systems (GNSS), especially the US Global Positioning System (GPS) [e.g., Federal Aviation Administration (FAA), Loran Accuracy Performance Panel (LORAPP), Loran Integrity Performance Panel (LORIPP) programmes]. The US Volpe Report (Volpe, 2001) and many other studies have demonstrated the vulnerability of GPS to accidental and intentional interference and identified Loran as a most promising complement, since it shares almost no vulnerabilities with GPS.

The combination of Loran and GPS has been explored in Europe in the form of Eurofix (van Willigen, 1989). This employs a data channel added to the Loran-C transmissions to broadcast differential GPS (DGPS) corrections. Eurofix went on-air in April 2001 at the Bø, Vaerlandet, Sylt and Lessay stations of the Northwest European Loran-C System (NELS). This integrated Loran-C/DGPS transmission provides high accuracy position fixing over long ranges. In addition, its introduction demonstrated the concept of using integrated Loran-C and DGPS to provide an uninterrupted navigation service even if one of the basic systems had failed, in accordance with the rational view of not relying on a sole-means system. This principle has driven the development of a system that provides true radio navigation redundancy and safety for a wide range of positioning applications, plus the precise timing of telecommunications infrastructures, all of which currently rely on GPS. This system is known as Enhanced Loran or eLoran (ILA, 2007).

Enhanced Loran is an internationally standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It takes full advantage of 21st century technology, including the use of advanced digital signal processing (DSP) techniques. These have produced dramatic improvements in the performance of receivers. By employing a data channel such as Eurofix to pass differential Loran data and integrity messages, an eLoran accuracy of 10-20m has been achieved in place of the 460m of traditional Loran-C. As a consequence, eLoran meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbor entrance and approach maneuvers, land- and mobile vehicle navigation, and location-based services. It is also a precise source of time and frequency for telecommunications systems.

Among the properties of Loran-C that underwent intensive evaluation in the development of eLoran was its integrity and, specifically, the confidence with which cycles of the 100 kHz signal could be identified within the pulses. This chapter sets out a contribution to that discussion by addressing the question of skywave contamination. In it, the term “Loran” will be used to encompass both traditional Loran-C and the new eLoran. Loran employs the groundwave components of the transmitted signals for position determination, since their propagation velocities are normally exceptionally stable in time. However, noise affects the received signals. Also, various propagation effects and the front-end filters of receivers alter the shapes of the received pulses. These factors all lead to inaccuracies in the measured positions. So, too, do unwanted skywave signal components received via ionospheric paths.

Historically, the ability of Loran-C receivers to resist this skywave contamination was its