Proximity Fuzes
Theory and Techniques

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Preface

This monograph deals with theory and design aspects of RF-FMCW and Laser proximity fuzes. The book begins with a short history of development of proximity fuzes. The successful development of the fuze by the US during the Second World War was an outstanding technical achievement. Though the Radar, a more complex system had been developed and used during the war, there were unique features of the proximity fuzes which made its development extremely difficult. The ability of the fuzes using vacuum tubes to withstand 'g' shocks of ten of thousands when fired from the gun, was considered a formidable task. The development of the fuzes was so significant that many experts consider this to be next only to the development of atomic bomb. The history of development in India from 1966 to 1975 is also briefly covered.

Lack of technical literature on the proximity fuzes was the key motivation to write this monograph. The book will be useful at many levels: Professionals who specialise in allied/areas such as a missiles, young engineers who are entering the fuze development programmes, military personnel who use these fuzes and electrical/ electronics engineers for general reading.

The book is divided into three main subject areas. The first section considers the basics of proximity fuzes. The second section deals with FMCW fuzes. The last section covers the latest Laser Proximity Fuzes.

Chapter 2 gives an overview of Proximity Fuzes. This chapter contains material everyone associated with proximity fuzes should know, in particular, the users and the decision makers. This chapter covers the evolution of CW proximity fuzes from fuzes developed during the second World War to the FMCW fuzes which became the workhorse fuze after the 1980s and continues to be most effective proximity-sensor till today. This chapter gives an overview of all of the subsystems of FMCW and the recent Laser proximity fuzes. The chapter also addresses the problem of 'g' - several tens of thousands which the fuzes for high speed artillery and anti aircraft shells have to withstand.

Chapter 3 on the fuze range equations is a standard material available in Radar texts but is included for the basic orientation and for the sake of completeness.

Chapter 4 deals with reserve battery and power sources required by all types of fuzes - FMCW, their variants and Laser proximity fuzes.

Chapters 5, 6 and 7 deal with of FMCW fuzes and their sub-systems.

Chapter 5 deals with voltage controlled oscillators. In particular the importance of phase and amplitude noise of oscillator is addressed because low phase and amplitude noise are a fundamental requirement of fuzes. The active devices which achieve the objective of low noise are considered and compared.

Chapter 6 on the mixers deals with highly linear mixers - Gilbert cell mixers and FET resistive mixers. High degree of linearity is a basic prerequisite of mixers since the modern fuzes operate in an intense environment of Electronic Counter Measure (ECM). ECM signals can penetrate into the receiver through the mixer non-linearity.

Chapter 7 deals with microstrip antennas for fuzes. These antennas can be used with a wide range of fuzes which requires a radiation pattern along the projectile axis such as fuzes for bombs, mortars and high angle artillery shells. Fuze antennas need a fairly high impedance bandwidth to reduce reflections from a common antenna system which most conventional ammunition are constrained to use. This chapter considers various options to achieve high bandwidth.

Chapter 8 on the FMCW fuzes contains the basic general principles of FMCW and explains the unique properties of FMCW fuzes .The problem of single antenna FMCW fuzes, that of the leakage of transmitted power with its attendant noise to the receiver are considered. The chapter demonstrates that a low noise VCOs and a highly linear mixer make the FMCW fuzes as one of the best proximity sensors.

The third section of the book discusses the pulsed laser proximity fuze with its two most important subsystems, viz., the laser sources, the photodetectors and nanosecond pulse generators to drive the laser source.

Chapter 9 covers the specific sources and their properties that make them eminently suitable for pulsed laser fuzes. In particular, the microslab solid state lasers which are capable of providing very high peak power short pulses required for anti-aircraft fuzes are described. Importance of noise in photodetectors due to solar background radiation and optimisation of APD gain to achieve high signal-to-noise ratio in laser receivers is given special attention.

Chapter 10 deals with nanosecond pulse generators. Fuzes which function at a range of few metres to tens of metres require pulses with a width of 2-10 nanoseconds. Techniques of achieving short nanosecond pulses based on Avalanche transistors and high speed MOSFETS are dealt with .

Chapter 11 on Laser proximity fuzes deals with principals of laser range finding as applied to very short ranges. Broadly various systems aspects, like the power requirement of fuze transmitter and the type of receivers required for achieving high dynamic range are described. System considerations like background solar radiation and attenuation in fog and clouds, detrimental to fuze performance are described.

21 April 2010 VK Arora
Delhi

Chapter 1

History of Proximity Fuzes

1.1 SIGNIFICANCE AND BACKGROUND OF THE RADIO PROXIMITY FUZE IN WORLD WAR II[1]

The radio proximity, or VT fuze for artillery shells represents a major contribution to the success of the war in Europe as well as in the Pacific. Its development, production, and military use is an outstanding example of collaboration by R&D groups, industrial organisations and the military services.

A fuze is that part of an artillery projectile which detonates the explosive charge and ideally would detonate the shell in the most optimum position to inflict maximum damage to the target. Early in the war, it became evident that speed, manoeuvrability, and heights attainable by modern military aircraft presented a method of attack against which fuzes currently available for anti-aircraft guns were relatively ineffective. Even with the improvements in directing anti-aircraft gunfire made possible by radar, low probability of hitting elusive attacking aircraft made the problem of defence against aircraft extremely important and urgent for a nation involved in the war.

The idea of proximity fuzes is not unique and was suggested independently by many in the United States and other countries prior to 1940. However, the obstacles in the way of actually developing a fuze of this type seemed insurmountable. Many technical experts, who had witnessed an anti-aircraft demonstration, had toyed with the idea of a proximity fuze. The small target area presented by an aircraft, practically forced a serious and urgent need for a fuze which would detonate in the vicinity of the aircraft.

The inherent disadvantages of the time fuze and the contact fuze stimulated the need for proximity fuze. The time fuze, which detonates a projectile at a specified time after it leaves the gun, has been widely used against aircraft and personnel. However, use of time fuzes requires, not only that time of flight from the gun to the aircraft be calculated precisely and immediately before firing, but fuze time be set accordingly. A slightest error in fuze time estimate or setting may cause the projectile to explode at a harmless distance from the target.

The probability of success of the contact fuzed projectile in an anti-aircraft role is extremely limited, since it must actually hit its target before it detonates. As range lengthens, this becomes almost impossible.

It has long been recognised that the efficacy of explosive projectiles would be greatly enhanced if these could be equipped with fuzes which would be actuated by the proximity to a target. For example, an anti-aircraft projectile which would automatically detonate when coming within lethal range of an aircraft would simplify fire control techniques and would be highly effective.

Although inventors had suggested almost every possible type of proximity fuze, they failed to indicate how the formidable development and engineering difficulties could be satisfactorily overcome. Such fuzes to be useful for artillery purposes, would have to be capable of withstanding the shock of tens of thousands 'g's when fired from a gun, in addition to undergoing a high rate of spin imparted to a shell. Many patents on proximity devices were issued in various countries, but they failed to suggest any concrete technique to solve formidable problem.

British scientists were working on proximity fuze devices for rockets and bombs at least as early as 1939. Captured documents indicate that German work on proximity fuze development had begun even earlier, as early as 1930's, and was still in process when hostilities ended in the Europe. The possibility that proximity fuzes of various types might be feasible, had been recognised for a long time. The American achievement, accomplished by no other country, was the actual development of a proximity fuze that would function and that could be manufactured by mass-production techniques. The development work, started during 1940, was carried out in the Department of Terrestrial Magnetism (DTM), Applied Physics Laboratory, National Bureau of Standards, and Crosley Corporation.

1.2 DEVELOPMENT WORK IN THE DEPARTMENT OF TERRESTRIAL MAGNETISM[1]

During August 1940, a group called Section-T of the National Development Research Council (NDRC) was established under Dr Merle Tauve of the Carnegie Institution. The Group led by Dr Tauve, and assisted by Richard Roberts was to conduct research in the Laboratory of Territorial Magnetism of Carnegie Institute, Washington. The Group was convinced that whatever method was selected, it would involve substantial electronics. They had begun firing vacuum tubes from a small gun and had found that these frequently survived the ordeal.

In September 1940, the British Technical Mission headed by Sir Henry Tizard, NDRC received a report from British that although Britishers were consuming thousands of vacuum tubes manufactured by two largest manufacturers of vacuum tubes in US towards the development of fuze, but they had not yet made a workable fuze. Both the US and the British considered similar approaches as follows:

(a) A radio fuze that would sense the proximity of the aircraft
(b) A radio fuze tracked by anti-aircraft gun's radar that would be triggered from the ground when its range was the same as that of the target.
(c) An acoustical fuze actuated by dominant resonance of the aircraft engine and propellers.
(d) An optical fuze actuated by the photodetector current at the frequency of projectile's rotation, in the presence of ambient light.

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About the Author

Shri VK Arora obtained his graduation in Physics from Delhi University in 1955 followed by DMIT in Electronics from Madras Institute of Technology in 1958. In 1959, he joined DRDL and worked on control and guidance of guided missiles till 1966. During this period he also completed a post graduate course on Guided Missiles from College of Aeronautics, Cranfield, UK, in 1963. From 1966 till 1980, the author worked in the field of Proximity Fuzes in Solid State Physics Laboratory, Delhi and pioneered the development of Proximity Fuzes for armed forces. In 1981, he joined Defence Science Centre to work on Lasers and became Director in 1985 and superannuated in 1996. He contributed significantly to the development of high power CO_2 gas dynamic Laser.

About the book

The monograph has been written to fill a void on the subject of Proximity Fuzes with a view on Indian Defence needs. The book provides an overview of theoretical, experimental and engineering aspects of Radar and Laser proximity fuzes. The FMCW systems and Laser proximity fuzes are dealt along with design and analysis of crucial subsystems to give a contemporary picture. The book is aimed to cater as a decision-aid regarding design, development, production, quality assurance of proximity fuzes. This book will cater to scientists and researchers in this field who wish to get a quick insight.

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