Second Edition

JOHN M. DOYLE

pulse fundamentals

Updated to stress practical applications of modern solid-state devices and circuits to a wide variety of electronic instruments and systems.

PULSE FUNDAMENTALS

2nd EDITION

John M. Doyle

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PREFACE

The second edition of this book bears little resemblance to its predecessor. The extensive changes were dictated, for the most part, by the continuing evolution of active devices. To reflect current practices, only solid-state devices are covered. The content has also been altered to comply with numerous requests for more quantitative information.

The reader is assumed to have completed courses in electric-circuit theory and bipolar transistor physics and circuits. The mathematical prerequisites are a working knowledge of algebra and trigonometry. Elementary forms of the differential and integral calculus are used occasionally where such use serves to enhance understanding. Thus the book should be readily understood by anyone engaged in a meaningful electronics program at the college level. It should also meet the requirements of graduate engineers, particularly those concerned with applications, who have not yet acquired suitable skills in this area.

Admittedly, some of the quantitative discussions are rather lengthy. In every such case, however, a careful step-by-step approach is used to provide sound insight into the operation of the device or circuit under investigation. A great deal of thought was given to the possibility of showing end equations only with detailed analyses contained in appendices. But appendices are often overlooked, and the resulting loss could far outweigh any advantages that may result from this approach.

The book is divided into two parts: (a) the steady-state and transient switching characteristics of selected devices and (b) switching and pulse circuits.

Devices included in Part 1 are the junction, avalanche, tunnel, backward, and semiconductor-metal junction diodes, the junction and insulated gate field-effect transistors, various thyristors, and the unijunction transistor. A separate chapter is devoted to integrated circuits. Attention is concentrated on the physical behavior of the devices. With this background, the reader should experience little difficulty in adapting any of the devices to any desired application. Without such knowledge, the capabilities of the industrial worker are definitely limited.

Part 2 is concerned with linear and nonlinear waveshaping, various amplifiers employed in pulse-type circuits, multivibrators, blocking oscillators, voltage comparators, voltage and current time-base generators, transmission gates, and basic counting circuits.

Throughout, the transistor is considered to be the prime active device. In Part 2 the discussion of transistor circuits is followed immediately by an investigation of counterpart circuits that use other devices covered in Part 1. This integrated approach should prove beneficial to the reader, for the similarities and differences between the various configurations is made apparent without delay.

Exercises are included at the end of each chapter and an answer book for all problems involving computation is available to qualified instructors upon written request to the publisher.

I am pleased to acknowledge my indebtedness to the many manufacturers who supplied information in the form of device characteristics and technical papers, the publishers who permitted excerpts from previously copyrighted publications, and to the reviewers whose comments led to numerous improvements in the book. An effort has been made to acknowledge all such assistance by appropriate notation in the references appearing at the end of each chapter.

As always, my wife Rita was ever ready to spend countless hours in helping with preparation of the manuscript, and it is to her that this book is dedicated.

John M. Doyle

Amesbury, Mass.
December, 1971

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1

Introduction

Pulse circuits are defined as those circuits required for the generation and control of precisely timed waveforms. They differ widely from those used in radio communications equipment, in which the waveform of the operating voltage is usually sinusoidal or a simple combination of sinusoidal waves. Some pulse circuits are used to develop square, sawtooth, trapezoidal, or peaked waves of voltage, which are required in indicating, timing, and modulating circuits of television, radar equipment, and so forth. The circuit-operating conditions in most cases range from *full on* to *full off* and do not fall into the simple classifications of class *A*, *B*, and *C* operation. The circuits, therefore, are named for the function they perform rather than for their type of operation.

1.1 Historical Developments

Pulses, in the form of dots and dashes, were used to convey intelligence by wire in the earliest days of electrical communication. Marconi used short and long pulses in his "wireless" to form the modulation envelope for radio-frequency energy.

The advent of the triode vacuum tube made possible modern radio communication and the transmission of intelligence by means of an amplitude-modulated carrier. In this scheme the prime-signal source is a sinusoidal-signal generator. In modern technology many electronic systems have been developed that require the use of pulses as the prime-signal source.

1.2 Typical Pulse Applications

Pulses are used in radar, which is an electronic system that detects the presence, range, and direction of objects. The block diagram of a typical radar system is shown in Fig. 1-1. It consists of a timer, modulator, transmitter, transmit-receive (TR) switch, antenna, receiver, indicator, and power supply.

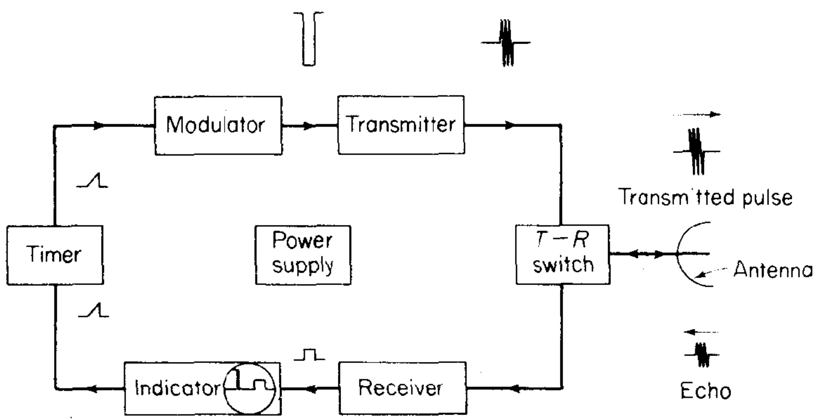

Figure 1-1. Block diagram of a radar set.

The timer synchronizes the indicator and transmitter circuits. At regular intervals it produces a pulse that causes the sweep (horizontal movement of the scanning spot) to start in the indicator. At the same instant, or after a precisely predetermined time, the timer produces a signal that is also applied to the modulator.

When the modulator receives the synchronizing timing pulse, it develops a high-voltage, high-power pulse that turns the transmitter on for a short time interval.

The transmitter is a very high frequency (vhf), high-power generator of radio-frequency (rf) energy. It produces a radio wave of constant frequency and amplitude during the short time during which it is turned on by the modulator.

The TR switch is operated electrically, and it effectively disconnects the antenna from the receiver during the production of the transmitter pulse and connects it to the transmitter. During the remainder of the operating period, the TR switch connects the antenna to the receiver.

The antenna acts as a radiator of the transmitter-produced energy when the transmitter is pulsed. A small portion of the radio wave transmitted from the radar set travels to the object (*target*) and is reflected as shown in Fig. 1-1. The reflected waves, called *echoes*, are picked up by the antenna and conveyed to the receiver. The antenna is designed to be directive for both transmission and reception so that the *bearing* (direction) as well as the *range* (distance) of the target may be determined.

The receiver amplifies the echoes and provides *video* pulses, called *pips*, of sufficient amplitude to produce visual indications on the indicator.

The indicator can be regarded as an electrical stop watch that measures precisely the small time interval required for the transmitter pulses to travel to the target and for the echoes to return. Because the speed of propagation of radio waves is known with great accuracy, the range can be determined as accurately as the time interval can be measured.

Pulses are also used in radio *telemetering*. Here certain variables, such as changes in temperature of the outer casing of a rocket, are sensed and measured in flight. This information is then transmitted to a ground station where permanent records are made for analysis by engineers.

A simplified explanation of telemetering can be given with the help of Fig. 1-2. The output signal of a pickup device, termed a *transducer*, is shown as a sinusoidal waveform. This signal is applied to several contacts on the

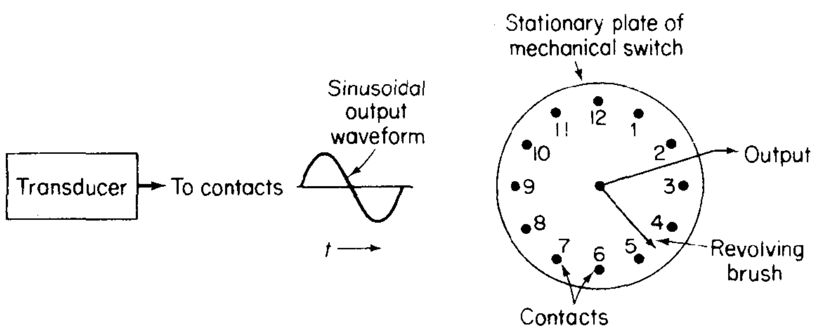

Figure 1-2. Sampling the output of a transducer.

stationary plate of a mechanical switch. A revolving brush then passes over each contact and samples the transducer output. Assuming that each contact is of uniform area and that the brush is revolving at a constant speed, the switch output is a series of pulses having uniform width, and the amplitude of each successive pulse is proportional to the corresponding amplitude of the signal wave, as shown in Fig. 1-3. The output of the switch is now *pulse-amplitude modulated*, abbreviated PAM. It is apparent that the successive pulses reproduce the signal wave rather faithfully. If the number of samples per second exceeds twice the highest frequency contained in the signal wave, the original signal can be reconstructed from the succession of pulses.

The PAM signal is next used to modulate an FM transmitter whose output is radiated by means of a suitable antenna.

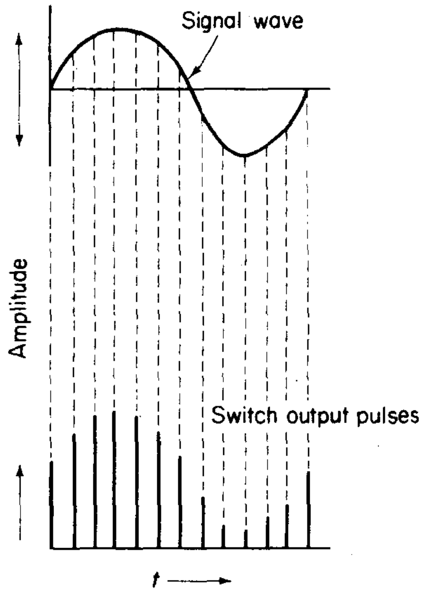

Figure 1-3. A pulse-amplitude modulated signal.

At the ground station the signal is picked up by a special type of antenna and applied to the input terminals of a highly sensitive receiver. The receiver amplifies the weak signal and separates the FM carrier signal from the PAM signal. The PAM output signal of the receiver is then applied to a detector, whose instantaneous output voltage is proportional to the instantaneous amplitude of the input voltage. This voltage is used to operate a mechanical reproducer that reconstructs an essentially faithful reproduction of the signal produced originally by the pickup transducer.

A reexamination of Fig. 1-3 shows considerable unallocated time between successive pulses. For example, the time required for each pulse may be 10 μsec and the elapsed time between pulses may be 100 μsec.

Use of this unallocated time introduces the possibility of *time-division multiplexing*, in which successive intervals of time are assigned to different signal (information) channels. In practice, this is exactly what is done in radio telemetering. One transducer may be used to record, say, temperature variations; separate transducers may measure other variables, such as atmospheric pressure and cosmic radiation. The output signal of each transducer is applied to successive contacts on the mechanical switch. This operation is shown in Fig. 1-4. The amplitudes of the successive output pulses from the switch are now proportional to the corresponding amplitudes of each signal wave.

At the output of the ground-station receiver, suitable filters are required to separate the various transducer signals from the composite PAM signal, but this filtering represents no great technical difficulty. Once separated, the individual signals are handled in the manner described previously.