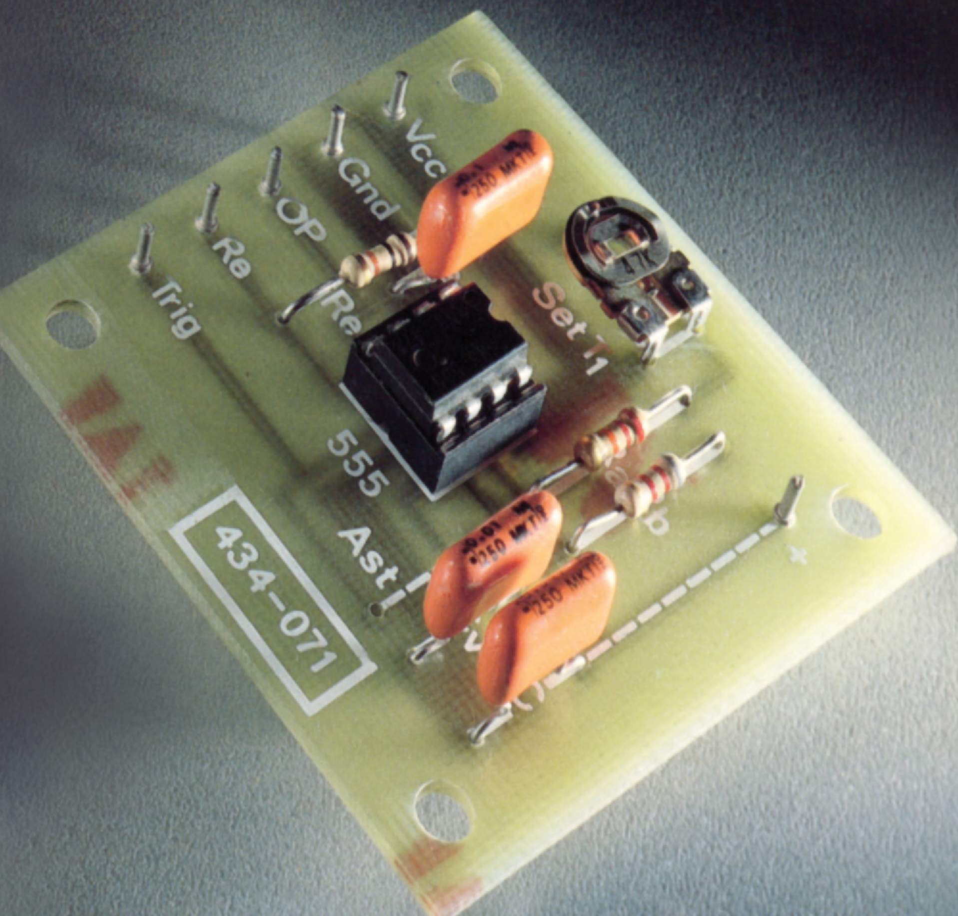
TIMER/GENERATOR CIRCUITS MANUAL

R. M. MARSTON



A NEWNES CIRCUITS MANUAL

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Timer/Generator Circuits Manual

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Contents

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Preface

This book is concerned mainly with waveform generator techniques and circuits. Waveform generators are used somewhere or other in most types of electronic equipment, and thus form one of the most widely used classes of circuit. They may be designed to produce outputs with sine, square, triangle, ramp, pulse, staircase, or a variety of other forms. The generators may produce modulated or unmodulated outputs, and the outputs may be of single or multiple form.

Waveform generator circuits may be built using transistors, op-amps, standard digital ICs, or dedicated waveform or 'function' generator ICs. One of the most popular ways of generating square and pulse waveforms is via so-called 'timer' ICs of the widely available and versatile '555' type, and many circuits of this type are included in this book.

The manual is divided into eleven chapters, and presents a total of over three hundred practical circuits, diagrams and tables. The opening chapter outlines basic principles and types of generator. Chapters 2 to 8 each deal with a specific type of waveform generator, and Chapter 9 deals with special waveform generator circuits. Chapter 10 takes an in-depth look at phase-locked loop circuits, and the final chapter deals with miscellaneous applications of the ubiquitous '555' timer type of IC. A special appendix presents a number of useful waveform-generator design charts, as an aid to those readers who wish to design or modify generator circuits to their own specifications.

The book is specifically aimed at the practical design engineer, technician and experimenter, but will be of equal interest to the electronics student and the amateur. It deals with its subject in an easy-to-read, down-to-earth, non-mathematical but very comprehensive manner. Each chapter starts off by explaining the basic principles of its subject and then goes on to present the reader with a wide range of practical circuit designs.

Throughout the volume, great emphasis is placed on practical 'user' information and circuitry, and the book abounds with useful circuits and data. Most of the ICs and other devices used in the practical circuits are modestly priced and readily available types, with universally recognized type numbers.

R. M. Marston

1 Basic principles

Electronics is primarily concerned with the business of signal or waveform processing and manipulation. This may involve the amplifying or shaping of one signal, or the mixing of two or more waveforms to give a complex modulated output, or the processing of a complex signal to extract its original components, or the use of one waveform to trigger a sequence of operations, etc. All these processes involve the use of waveform generators, which thus form a major class of circuit and may be designed to produce outputs with specific shapes (such as sine, square, or triangle), or to produce waveforms of exceptional purity or frequency stability, and may have single or multiple outputs, which may be modulated or unmodulated.

Specific waveforms can be generated directly, using, for example, oscillators or multivibrators, or they can be synthesized by using special *function generator* or phase-locked loop (PLL) techniques. Waveform generator circuits may be built using transistors, op-amps, standard digital ICs, or dedicated waveform or function generator ICs. This opening chapter looks at waveform basics and explains some of the techniques that are used in waveform generation.

Free-running waveforms

Electronic waveforms can be generated in either free-running or triggered form. Free-running types generate a waveform that completes each cycle in a period (P) and automatically repeats the generation process *ad infinitum*, repeating the cycles at a frequency (f) of $1/P$ Hz. Triggered types, on the other hand, generate a single waveform cycle on the arrival of each input trigger signal.

The four most widely used free-running waveforms are the sine, square, triangle and sawtooth types, and these are characterized by each having a unique harmonic structure, as shown in *Figure 1.1*. Thus, a ***pure* sine wave** generates a signal at its fundamental frequency only, and produces no harmonics (signals at precise multiples of the fundamental frequency), as shown in the diagram. All real sine waves are impure and generate unwanted harmonics. Sine wave purity is qualified by summing the strength of these unwanted harmonics and comparing them with those of the fundamental, to arrive at a final total harmonic distortion (THD) figure.

A ***pure* square wave** has perfect symmetry, switches between the high and low states in zero time, and generates an infinite number of odd harmonics with relative strengths directly related to their harmonic numbers. Thus, the seventh harmonic has a strength that is one-seventh of that of the fundamental, and so on.

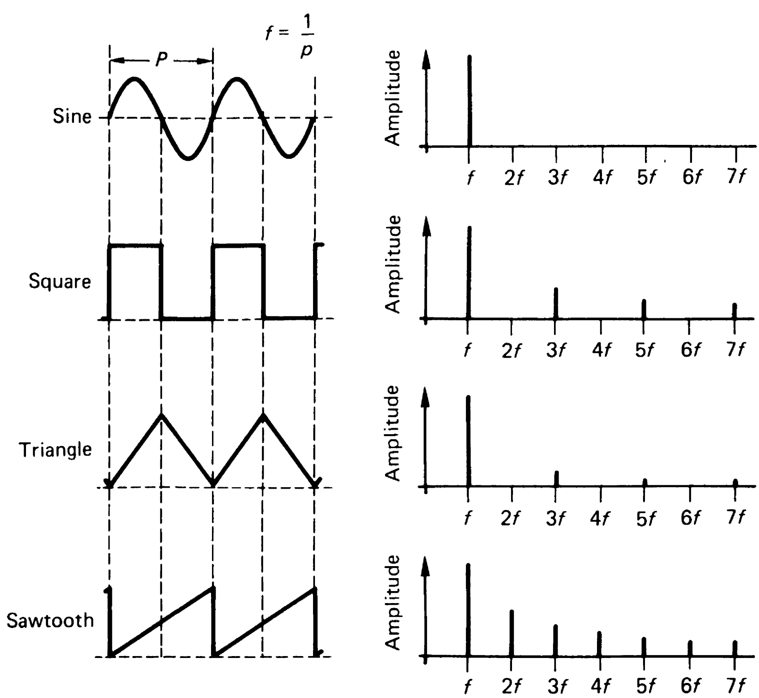

Figure 1.1 *The four most widely used free-running waveforms, showing their harmonic structures*

A ***pure*** **triangle wave** has perfect symmetry and linearity, but when analysed acts like an integrated squarewave. It produces only odd harmonics, but these are relatively weak and die away quite rapidly.

Finally, a ***pure*** **sawtooth** waveform rises with perfect linearity, switches between the high and low states in zero time, and generates an infinite number of even and odd harmonics, each with a strength proportional to the harmonic number, as shown in the diagram.

Triggered waveforms

Note from *Figure 1.1* that the shape of a free-running waveform cycle is quite independent of variations in frequency. Thus, if frequency is doubled, all horizontal waveform dimensions are simply halved, and the shape of each cycle is unaltered. Triggered waveforms give the opposite of this action, and the overall wave cycle shape varies with repetition frequency, as illustrated in *Figure 1.2*, which shows the two most popular triggered waveform types: the pulse and the sawtooth.

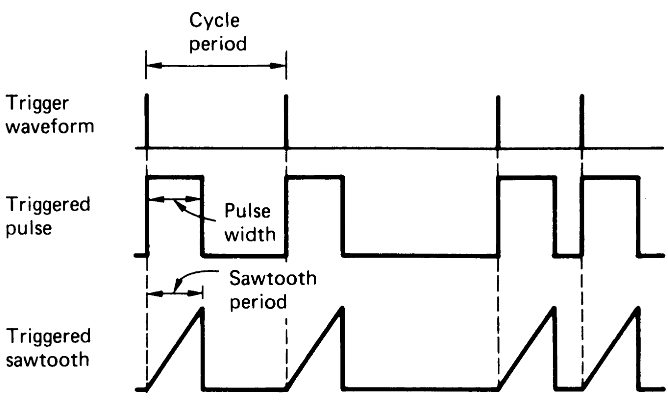

Figure 1.2 *Triggered pulse and sawtooth waveforms*

Thus, **triggered pulse** and **triggered sawtooth** waveforms are each characterized by the fact that their pulse or sawtooth width is absolutely constant, and is quite unaffected by variations in repetition period; the cycle wave shape thus varies with frequency, as shown.

Square-wave basics

Square waves can be generated either directly or by 'conversion' from an existing waveform. *Figure 1.3* illustrates the basic parameters of a

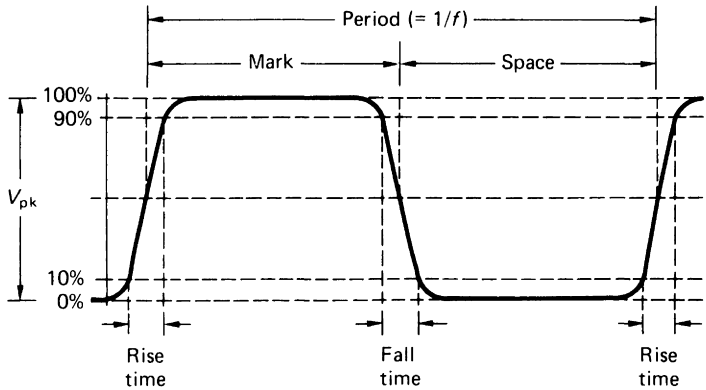

Figure 1.3 *Basic parameters of a square wave*

square wave; in each cycle the wave first switches from zero to some peak voltage value (V_{pk}) for a fixed period, and then switches low again for a second fixed period. The waveform takes a finite time to switch between states. The time it takes to rise from 10% to 90% of V_{pk} is known as its **rise time**, and that taken for it to drop from 90% to 10% of V_{pk} is known as its **fall time**.

Low-quality square waves have fairly long rise and fall times, and are easily produced via what are colloquially known as *squirt* generators. This type of waveform is useful in non-critical applications such as relay driving, LED flashing, sound generation, etc. High-quality square waves have very short rise and fall times, and are produced via so-called *clock* generators. This type of waveform is essential for correctly clocking fast-acting digital counter and divider ICs, etc.

In each square wave cycle the *high* part is known as its **mark** and the *low* part as its **space**. In a symmetrical square wave (such as *Figure 1.3*) the mark and space periods are equal and the waveform is said to have a 1:1 M/S ratio, or a 50% duty cycle (since the mark duration forms 50% of the total cycle period). Square waves *do not* have to be symmetrical, however, and their M/S ratios, etc., can be varied over a very wide range, as illustrated in *Figure 1.4*.

Note from *Figure 1.4* that the *mean* output voltage (V_{mean}) of each waveform, integrated over one complete cycle period, is equal to V_{pk} multiplied by the waveform's percentage duty cycle. Thus, if V_{pk} has a value of 10 V, the waveform (which has a 1:9 M/S ratio or 10% duty cycle) in *Figure 1.4(a)* will give a V_{mean} of 1 V; *Figure 1.4(b)* (which has a 1:1 M/S ratio or 50% duty cycle) will give a V_{mean} of 5 V; and *Figure*

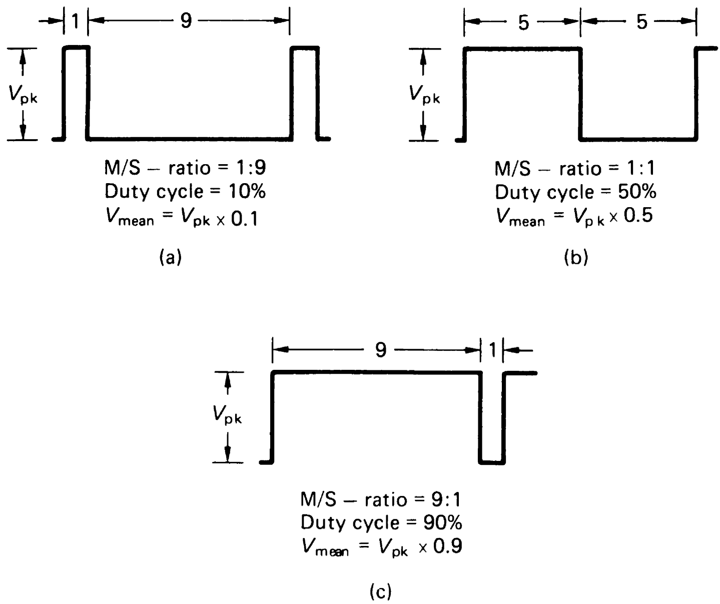

Figure 1.4 *Square waves with various mark/space ratios*

1.4(c) (which has a 9:1 M/S ratio or 90% duty cycle) will give a V_{mean} of 9 V. Thus, V_{mean} is fully variable via the M/S ratio or duty-cycle value.

Triangle or ramp waveforms

A pure triangle waveform has perfect symmetry, with equal rising and falling slope periods, as shown in *Figure 1.1*. Not all triangle waveforms are pure or symmetrical, however. Highly non-symmetrical waveforms are usually referred to as **ramp** generators, and *Figure 1.5* illustrates the typical range of waveforms that are available from a **variable-slope** ramp generator.

Special waveforms

Many special types of waveforms are also used in electronics.

Staircase waveforms rise between zero and some specific voltage value in a series of discrete time-related voltage steps and then switch to zero again. They are often used in curve tracers, etc.