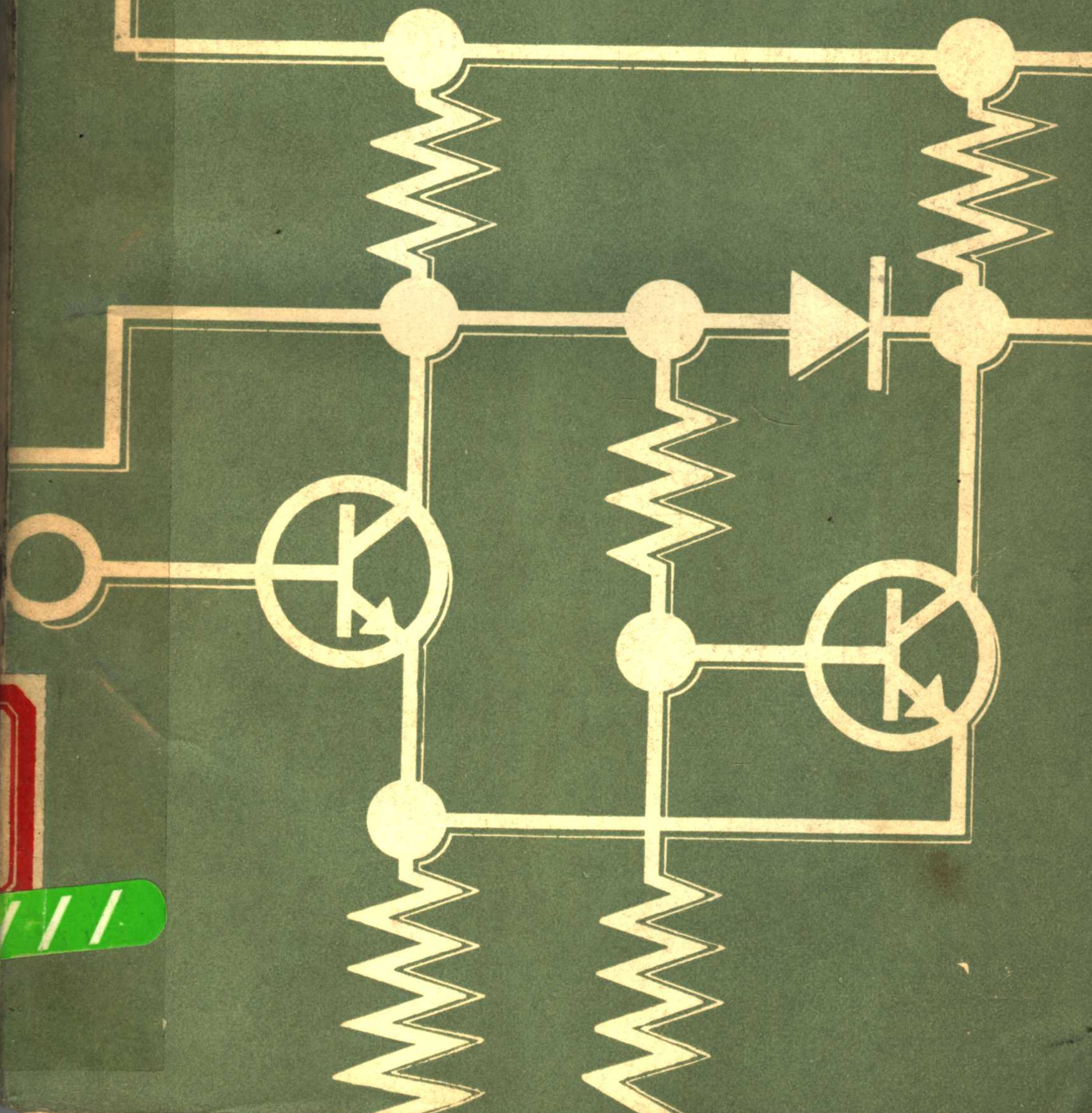
# Handbook of Electronic Circuits

G.J.Scoles



# HANDBOOK OF ELECTRONIC CIRCUITS

## Design, Operation, Applications

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# FOREWORD

## By Professor C. W. Miller, Head of Physics Department, The City University, London

To have worked in the field of electronics for some forty years as Graham Scoles has done, is a record not likely to be exceeded by many, and indeed, the history of electronics does not greatly exceed this period of time. Today the ubiquity of electronics needs no emphasis, and the multitudinous applications lead to a great variety of methods of design and engineering. Thus, in say space equipment, enormous design effort may be expended to ensure reliability; in the domestic market a similar effort is justified in saving almost trivial costs per unit. Techniques for computer aided design and design optimisation have been developed and play important roles. On the other hand, it must be remembered that there remains the need for electronic equipment as a service, and in many cases this is filled by a few workers or, indeed, perhaps a single individual producing a unique piece of equipment to fulfil a particular, perhaps limited, requirement. The number of such workers and the amount of equipment they produce is still very appreciable.

Under such conditions many of the advanced design techniques would be inappropriate even if time and cost did not prohibit their use. Additionally, a particular problem may require the spark of ingenuity. It is in such circumstances that the author of this book has made his own contributions and now seeks to share his experience with the reader. An approach of synthesis rather than analysis has been markedly successful in his own work, and no doubt can work for others. The concept of a 'mental oscilloscope' in dealing with circuits seems justified by results.

The basic circuits dealt with may obviously be used in a very great variety of applications and the author has not felt it desirable to limit himself to any particular aspect of electronic engineering. No book on electronics can be all-embracing, and the omissions of the present text (e.g. computer and communication circuits) are clearly meant to be those which the author considers to be adequately covered by other writers.

In reading the manuscript many of the circuits were recognised as old friends which the author had developed for particular purposes, and which have hitherto gone unpublished. Clearly, it is the author's hope that some of his own ingenuity should pass to the reader, and that by permutation, combination and addition, many future problems should readily be solved.

Simplified mathematical treatment is often justified, and certainly can clarify the problems. A word of warning, however, would indicate that it is often experience which determines those factors which can be disregarded from the outset, and the reader should be well aware of the considerable experience of the author in making such judgements.

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Chapter 1

# INTRODUCTION

## Scope and Objectives

It is apparent from the title that this is a book of electronic circuits but it is one that differs considerably from the majority of such books. Instead of first dealing with electronic theory in some detail and then proceeding to a mathematical analysis of a small number of selected circuits, it assumes that with the help of a simple explanation the reader already knows sufficient of the theory for him to understand the operation of virtually any electronic circuit. In this way it becomes possible to describe the uses and functioning of more than 200 different circuits, either using non-mathematical explanations or, where relevant, simplified formulae only. The circuits described can then be used as components of complete equipments. It thus becomes a simple matter to use a combination of basic circuits in order to design almost any piece of apparatus which makes use of the same principles.

So far as the author is aware, it has never been previously attempted to cover so wide a field. The present volume has been written to inform readers of the many possible circuit arrangements which, though possibly well-known to individuals, have never before been collected together and published. It is not in any way restricted to new or specialised circuits and many well-known arrangements in common use have also been fully described. The intention is to provide the reader with sufficient understanding of detailed circuits (and of circuits in general) to enable him to design with confidence equipment which will function satisfactorily. Using the circuits and techniques described, he should be able to solve virtually any of the circuitry problems likely to arise in practice.

The circuits include flip-flop and trigger circuits, waveform generating and distorting arrangements, peak-sensitive circuits and the like, but radio frequency amplifiers and the details of television receivers have purposely been omitted. There is already adequate coverage of such devices and the intention here is to describe circuits which are known to be practical and reliable by the author or his immediate colleagues and which are likely to be of direct interest or use to the users of electronics at whom the book is directed. This is not to say that every circuit will be of use to every reader, but an attempt has been made to cover as wide a field as possible.

It will be apparent that the circuits of computers and digital equipment in general have largely been omitted, even though nowadays their use is widespread. There are a number of reasons for this, quite apart from limitations of space and the prior existence of an extensive literature on the subject. Digital circuitry is based on the interaction of a multiplicity of unit circuits, each either similar to one another or of relatively few kinds. This means that the actual circuits tend to be standardised and inevitably take the form of ever-smaller integrated circuits and groups thereof. Large establishments tend to stock digital 'black boxes' and to use these to generate particular waveforms or to perform particular functions; it will be obvious that this technique can involve a capital outlay very many times greater than that of generating the same waveform from first principles, using perhaps two transistors and a dozen or so assorted components.

The circuits described in the following pages are basically simple (and often cheap) to build and are intended to work together with a minimum of mutual interaction. The components can nearly always be obtained from a number of suppliers and their assembly is largely a matter of following the simple rules laid down.

The descriptions are intended to explain precisely how the circuits function and also to indicate the uses to which they can be put. Sufficient information is provided, either in the text or on the diagrams to enable the various units to be built without difficulty. Chapter 4 deals with the general principles of the layout of electronic circuits and this information should be read in association with the more detailed descriptions.

The circuits obviously include some which are very well known and have been used for many years in electronic equipment, but a large number are believed to be novel and these have been specially devised in order to solve particular problems as they arose. They are included here in the expectation that the reader may also encounter these or similar problems in the course of his work and that these circuits may help him to solve them.

One chapter of the book deals in general terms with stabilising arrangements and here circuit details have purposely been omitted. This is because stabilising problems vary widely and no such thing as a typical stabilising circuit is possible. The descriptions are therefore confined to the basic principles of the various methods of stabilisation but, if these are understood, it should not be difficult for the reader to devise his own circuits. References are quoted which describe actual circuits and their component values, and in some cases these detailed designs may help to solve particular problems.

Further groups are concerned with circuits which are not strictly 'electronics' but which are closely allied to such matters. As well as a number of specialised rectifier circuits, they include circuits for filtering hum from power supplies, decoupling arrangements and phase shifters, as well as making some reference to non-linear resistance materials and their applications. In addition, the important (but rarely mentioned) problems of switching, fusing and protecting the actual circuits are explained in some detail.

The final group is devoted to various aspects of delay lines and pulse forming networks, together with pulse generators and the many ways in which they can be charged both from d.c. and a.c. sources. The output of such generators must be monitored and various ways of measuring pulse voltages and currents are also described.

**Readers:** The book has been written in the hope that it may prove of assistance to various kinds of readers, some of these being briefly listed here.

(1) *Workers in fields other than electronics who wish to know the kind of circuit which is available* so that they can then use it to solve a particular problem in their own field. Such workers may have some theoretical knowledge but little or no practical experience of electronics. It is hoped that the basic circuits described herein will provide them with 'bricks' from which their own equipment can be built. Obviously, such equipment cannot be guaranteed to work 'first time', but the fact that it is based on circuits which have been found to work satisfactorily (and in many cases sold to customers) should give confidence to the builder and encourage him to search for and find the cause of any malfunctioning.

(2) *Workers in electronics whose field of experience is different or more specialised and who have to design equipment or test gear using circuits or principles which are not familiar to them.* Such people may use the actual circuits as described or they may prefer to modify them somewhat to suit their exact requirements. In this connection, of course, it is normally quite irrelevant whether valves, f.e.t.'s* or transistors form the active elements of the actual circuits described.

(3) *Teachers of electronic circuit applications or theory who may wish to illustrate their lectures* by referring to circuits which have actually been used to solve particular problems or which are directly relevant to their

*See Section 18·1.

remarks. In addition, they may require a relatively large number of practical circuits which can be built in the laboratory by their students or which can be used as a source of various output waveforms or measurements. The fact that component values are shown on some of the diagrams or indicated in the text may assist in this respect.

(4) *Experimenters who wish to increase their experience or knowledge of what has been done already in the field of electronics.* Such people may be interested in the performance of the circuits or in knowing how certain results may be obtained, so that they can use the information to design equipment for their own use. Alternatively, they may build and test the circuits with no other object in view than the satisfaction of finding out exactly how they work.

(5) *The 'professionals' who design and use electronic circuits of all kinds.* Such people will be fully aware of the finer points of design and layout and will have a wide background of 'know how' on circuits generally. It is unlikely that they will use many of the circuits exactly as described, but it may well be that unless their background of experience is exactly parallel to that of the author, some of the principles and ideas may be new to them. These new ideas can then be added to those they already know and may at some future date be incorporated into their own designs. They are fully aware of how to use amplifying devices different from those described and will appreciate that much of the advice on general principles is intended to assist those whose experience is less than theirs. (It is to be expected that some of the simple circuits described in the following pages may thus end up in association with integrated circuits, M.O.S. devices,* digital circuitry and the like, even though the author would hesitate to advise relatively unskilled readers to do the same.)

One point which must be stressed is that strict mathematical analysis of this type of circuit is very rarely justified in practice. So long as the circuits are thoroughly understood, they can almost always be designed to give a desired performance by the use of simple arithmetic alone. This point is worth stressing, as there are many text books which devote several pages to an exact theory of a particular circuit but fail to suggest approximations which may be every bit as accurate in practice. The full theory may be justified in its context, but it may well have the effect of convincing a reader that such circuits can only be designed by people whose experience and mathematical ability are far greater than his. Provided that the would-be designer can first decide which components are responsible for each function, he can nearly always find a simple way of calculating the performance of a circuit to an accuracy sufficient for his purpose.

This contention is supported by over thirty years of experience in

*See Section 18–1.

circuit work and circuits so designed have been incorporated into radar equipment, telemetry, linear accelerators, pulse-stabilising systems and the like. In the majority of cases only minor adjustments have been found necessary on the bench and the various circuits have worked together without difficulty.

This point of view is particularly relevant when dealing with negative-feedback, a subject whose exact theory can be extremely complex. High quality, multistage amplifiers can be precisely designed with the aid of such theory but by providing the feedback over only one or at the most two stages at a time, the calculation of gain becomes merely a matter of determining the ratio of two resistances. Such stage-by-stage treatment avoids instability and enables the approximate gain to be determined with ease. Only rarely is it necessary in pulse work for the stage gain to be known exactly and, if it is, it is a simple matter to alter the value of a resistance by a small amount to meet the specification.

As an example of this general technique it is perhaps worth quoting the case of six pulse modulators forming part of a large, multistage linear accelerator which was required to be stabilised to better than 0.1%. The three interacting stabilising circuits were all designed by simple arithmetic and then built in 'hook up' form to enable the theory to be checked. The final units were next built and tested and when installed in the complete modulators, each one stabilised itself immediately it was first switched on. The accuracy was measured and was found to be of the order of 0.03%.

The point of this is that by breaking the system down into a number of individually simple stages, each one was easy to design and was inherently stable. This in turn meant that they worked together without difficulty when combined in the complete modulator.

This is not to say that the full theory is never justified as this would be quite untrue. However, in very many cases a circuit can be designed from first principles and its performance calculated using simplified theory to an accuracy greater than that actually required.

This simplified approach has been used in describing the various circuits and the formulae given are not necessarily those quoted elsewhere. This should simplify the design and enable the desired results to be obtained with the minimum of calculation. The use of approximate theory has been indicated in most cases, often with some explanation of where it has been simplified. No apology is made for this technique as its use has been fully justified over the years. In many such cases references are quoted which give the full theory and, of course, this can always be used if so desired.

**General Reference on Complete Circuits**

Markus, J., *Source Book of Electronic Circuits*, McGraw-Hill.

Chapter 2

# REFERENCES, CROSS-REFERENCES AND NOMENCLATURE

One of the many difficulties of a book of this nature is that in covering so many different circuits, much of the background must of necessity be omitted. This can be filled in by referring to text books, articles in the technical press, monographs and the like, but it is rare for the reader to have access to such references.

**Reference Books**

Accordingly, several books which cover the general theory and background have been selected and these should prove of assistance in explaining points with which the reader may not be familiar. Specific references are often quoted which in turn are a source of even fuller detail. This will enable the reader to find what he wants with least effort, whilst the subject can be investigated as deeply as he wishes by further reference.

**Articles and Patents**

In certain cases specific articles or original patents are quoted and these may be read as a background. Wherever possible, circuits now in common use are credited to their original inventors but in a number of cases it has not been possible to trace the original patents or articles. In some such cases, references have been found which refer to more recent use or modification of the circuits and these are quoted here. Where no references are given, it is because the author is unaware of the origin of the circuit or of its published use by others.

Apart from general references, quite a number of the circuits quoted are original and, so far as is known, have never been published elsewhere. Many have been patented and, where relevant, the patent references are quoted. This has been done mainly because Patent Specifications normally contain a full and precise explanation of how the circuit works and partly because some of the patents were still valid at the time of writing. Circuits for which no patent exists are available to all who wish to use them, but those patents which are still valid obviously must not be used in commercial equipment without consent. Their use for experimental purposes is allowed but the commercial limitation is strictly relevant. The circuits in this book have been described for their general interest and utility and the legal aspects have not been dealt with.

**Cross-references**

Quite apart from text books, special articles and patents, many of the circuits described have points in common or fall naturally into groups, Where this happens, they have either been collected into chapters based upon similarity of function or similarity of actual circuit arrangement, or else 'cross-referenced' to one another to emphasise similarities which are not immediately obvious.

A final point concerns minor differences in British and American nomenclature, particularly as some of the quoted books are British and some American. At one time the actual way in which circuits were drawn was different in the two countries, but in the 1940's the American diagrams became more and more like the British until now the only difference of any importance is that Americans use scattered earth (or ground) points whilst the British prefer to show a common bus-bar to which all earthed components are connected. As regards the actual words in current use, an attempt to find differences has produced a surprisingly small number of terms specific to the two countries, the vast majority of technical terms being identical. In case it may prove of assistance, however, a short list of differing words and terms is given at the end of this chapter. This is in no way complete and not all the terms occur in the book. Nevertheless, the list may help in resolving possible ambiguities and it is felt that its inclusion is worth while.

**Names and Symbols**

In writing a book on a subject to which people of many nationalities have contributed and which may be consulted by readers of many nationalities, one is faced with problems of nomenclature and of the symbols to be used to represent the various devices involved. However one chooses, there will be many to whom the names and symbols are not those they would use themselves and in such cases it can only be hoped that they will appreciate the difficulty facing an author and, where necessary, mentally translate any alien name or symbol into the one they know. This is most unlikely to affect their understanding of how actual circuits work, nor should it affect their understanding of the circuit diagrams.

With this aspect in mind, the author has therefore felt free to use the names and symbols familiar to him in drawing the various circuits and in explaining how they work, partly because this has made the explanations easier to write but more particularly because a good case can be made for their choice.

For example a thermionic amplifying device is variously known as a *valve* (British), *tube* (American) or *lampe* (French) according to the nationality of the user. 'Valve' is an abbreviation for 'thermionic valve' and 'tube' for 'electron tube' or 'vacuum tube', whereas the French 'lampe' presumably dates from the 'bright emitters' of the 1920's. A 'tube' to the author can mean anything from an electron tube such as a fluorescent lamp to a vacuum photo-electric cell, both of which are a far cry from an amplifying device having a hot cathode emitting electrons. The British term 'valve', on the other hand, covers two meanings, one being similar to the valve which controls the flow of liquid or steam along a pipe (or into an engine) and the other the concept of a one-way-only valve as in a pump. A 'thermionic valve' is thus a device which combines these two concepts with a thermionic cathode and must therefore be of the nature of an amplifier or a rectifier or both. The author (British) is perhaps a little biased in preferring to use the word 'valve' but he can only hope that any American readers will understand from the above brief explanation why he has done so and that they will make the necessary mental translation whenever the word appears. Both nationalities, of course, use the symbol V for the device and so no ambiguity should arise in reading the diagrams.

Another example is the transistor and here the question is one of symbol rather than nomenclature. 'Transistor', a word recently introduced into an existing technology, has automatically been absorbed into most languages and, presumably, means the same in them all. The original transistors were 'point-contact' devices and a symbol was then devised which indicated their construction very well. Unfortunately, it bears little resemblance to modern transistors and has the dual disadvantages of being messy to draw and of being non-symmetrical about a vertical axis. Although this symbol is by far the most widely used, an alternative symbol is often employed which is easier to draw and is symmetrical. In addition, it is sufficiently similar to the valve symbol to convey the idea of an amplifying device having a control 'electrode' whilst at the same time it is quite obviously a semi-conductor device. It is possible that one day this symbol will supersede the other and to familiarise readers with it, it has been used in Chapters 19 and 20. Most readers will, of course, recognise the two symbols, the more commonly used one being 

or  for p-n-p and n-p-n transistors respectively whilst the

corresponding preferred alternatives are  and .

Anyone who has cause to draw transistor circuits cannot fail to appreciate how much easier it is to show two lines crossed at right angles rather than to use the complex 'standard' symbol. The author is well aware that many engineers who are familiar with the simple symbol invariably prefer to use it when discussing or designing circuits, even though they may still use the other symbol when presenting the information in a formal medium. By using both kinds of symbol, the present volume familiarises the reader with the two alternatives and leaves him free to use whichever he chooses in his own work.

Apart from these two obvious examples, it is often difficult to decide when to use 'resistor' (a device having resistance) or 'resistance' (the property of a symbol shown on a diagram). This is particularly relevant when describing a complex circuit as it obviously has bearing on the properties of the component parts and yet equally refers to the devices which will be incorporated into the circuit if it is built up. In many cases the correct word is obvious from the context but in others it is more ambiguous. The author has endeavoured to be consistent but where real doubt exists has tended to use 'resistance' (the property of the component) rather than to name the component. Similar problems arise with 'inductor' and 'inductance' and with 'capacitor' and 'capacitance' and here the older terms 'choke' and 'condenser' can sometimes prove helpful. It is common practice to speak of a 'tuning coil' or a 'charging (or smoothing) choke' and where relevant this has sometimes been done. It is hoped that no ambiguities will result from this practice.

On the general subject of names, it is possible that newcomers to semi-conductors may at first have difficulty in remembering which devices are p-n-p rather than n-p-n or p-channel rather than n-channel.

The author certainly met this problem when first using transistors but has had no further trouble since devising an easy way of remembering. It is slightly facetious but it works! Assuming that it is normal for positive bus-bars to be shown above negative on a diagram or, alternatively, that the 'normal' polarity of 'H.T.' applied to an amplifier is positive (as with valves) then one merely has to remember that the names of devices using normal supplies start with the letter 'n' and that all others, being peculiar, start with the letter 'p'. This simple 'aide memoire' appears to be of