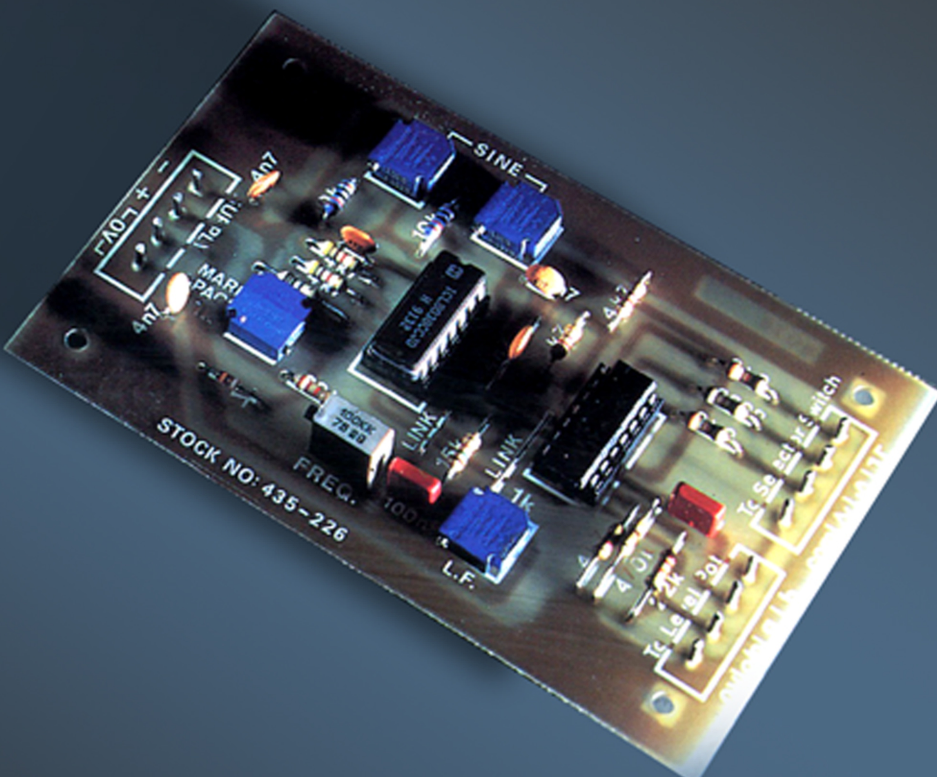
INSTRUMENTATION AND TEST GEAR CIRCUITS MANUAL



R. M. MARSTON

Instrumentation and Test Gear Circuits Manual

Newnes Circuits Manual Series

Audio IC Circuits Manual R.M. Marston
CMOS Circuits Manual R.M. Marston
Diode, Transistor & FET Circuits Manual R.M. Marston
Electronic Alarm Circuits Manual R.M. Marston
Instrumentation & Test Gear Circuits Manual R.M. Marston
Op-amp Circuits Manual R.M. Marston
Optoelectronics Circuits Manual R.M. Marston
Power Control Circuits Manual R.M. Marston
Timer/Generator Circuits Manual R.M. Marston

Instrumentation and Test Gear Circuits Manual

R.M. MARSTON

BUTTERWORTH
HEINEMANN

To Esther, with love.

Newnes
An imprint of Butterworth-Heinemann Ltd
Linacre House, Jordan Hill, Oxford OX2 8DP

PART OF REED INTERNATIONAL BOOKS

OXFORD LONDON BOSTON
MUNICH NEW DELHI SINGAPORE SYDNEY
TOKYO TORONTO WELLINGTON

First published 1993

British Library Cataloguing in Publication Data
Marston, R.M.
Instrumentation and Test Gear Circuits
Manual. – (Newnes Circuits Manual Series)
I. Title II. Series
621.3815

ISBN 0 7506 0758 0

Library of Congress Cataloguing in Publication Data
Marston, R.M.
Instrumentation and test gear circuits manual/R.M. Marston.
p. cm. – (Newnes circuits manual series)
Includes index.
ISBN 0 7506 0758 0
1. Electronic circuits. 2. Testing – Equipment and supplies.
I. Title. II. Series.
TK7867.M355 92–24955
621.3815'48–dc20 CIP

Printed and bound in Great Britain by
Biddles Ltd, Guildford and King's Lynn

Contents

This page intentionally left blank

Preface

This unique book is primarily a manual of modern instrumentation and test gear circuits of value to the industrial, commercial, or amateur electronics engineer or designer. It presents the reader with almost 500 outstandingly useful and carefully selected practical circuits, diagrams, graphs and tables, backed up by over 60 000 words of highly informative 'how it works' and 'how to design it' text. The practical circuits range from simple attenuators and bridges to complex 'scope trace doublers, timebases, and digital frequency meters.

The manual is split into twelve chapters. The first explains basic instrumentation and test gear principles, and the remainder are devoted to practical circuitry. Chapter 2 deals with the design of passive attenuators, and Chapter 3 with passive and active filter circuits, including those used in oscillators and DFMs. Chapter 4 takes an in-depth look at modern 'bridge' circuits, and presents a unique range of high-precision 'laboratory grade' practical designs. The next seven chapters progress through analogue and digital metering techniques and circuitry, signal and waveform generation, and power-supply generation, etc., presenting hundreds of practical circuits on the way. The final chapter deals with a variety of specialized items of test gear, including bargraph meters, probes, go/no-go testers, capacitance and frequency meters, transistor testers, Q-meters, and oscilloscope accessories, etc.

The book, though aimed specifically at the practical design engineer, technician, and experimenter, will doubtless be of great interest to all amateurs and students of electronics. It deals with its subject in an easy-to-read, down-to-earth, mainly 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. All of the practical circuits have been designed, built, evaluated and fully copyright protected by the author.

Throughout the volume, great emphasis is placed on practical 'user' information and circuitry, and this book, like all others in the *Circuits Manual* series, abounds with useful circuits and data. Most of the semiconductor devices used in the practical circuits are modestly priced and readily available types, with universally recognized type numbers.

R.M. Marston 1992

1 Basic principles

This first chapter starts off by looking at the basic terminology of modern electronic measurement and signal generating systems, then surveys the many different types of practical instrumentation and test gear system that are available. It ends by looking at the vexed question of whether it is better to buy or build certain types of test gear.

Basic terminology

The terms **instrumentation** and **test gear** mean different things to different people. In the context of this volume, an *instrumentation circuit* is one that translates an intangible quantity such as voltage, resistance, inductance, speed or temperature, etc., into a tangible form (such as an analogue or digital meter reading or an alarm signal, etc.) that is meaningful to a human operator. Such circuits consist of a *converter* that changes the intangible quantity into an easily processed form (such as a d.c. voltage), and a *translator* that changes that into a tangible form.

If the instrumentation circuit gives an output that is read close to the point of conversion (see *Figure 1.1*), it may be called a *metering system*, but if it is one that enables the reading to be

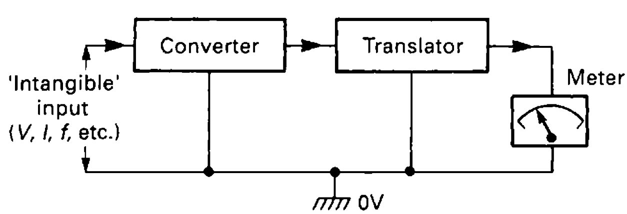


Figure 1.1. *Basic metering system.*

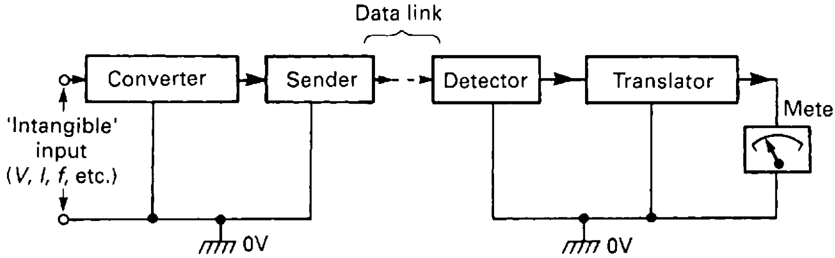


Figure 1.2. *Basic telemetering system.*

made at a point very distant from that of conversion (see *Figure 1.2*) it is known as a *telemetering* system. In the latter case a *sender* and a *detector* are interposed between the converter and the translator and are interconnected via a *data link* such as a ground line or an infra-red or radio link, etc.

A piece of **test gear** (or test **equipment**) is a unit specifically designed to generate, simulate, or analyse electrical/electronic signals or parameters. It may be designed for either *laboratory* or *industrial* use. Laboratory test gear is usually very versatile and meant for use in a wide range of general applications. Industrial test gear is specialized and designed to perform a dedicated function or production-testing task. Thus, a laboratory RF signal generator (see *Figure 1.3*) may be able to generate good CW, AM or FM sine-wave signals over the full 100kHz to 220MHz frequency range and to give an output fully variable from zero to hundred of millivolts, but an industrial RF generator (see *Figure*

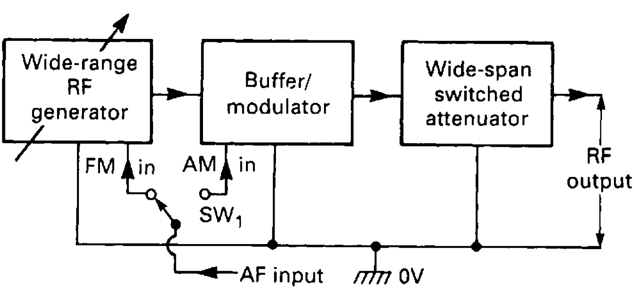


Figure 1.3. *A laboratory RF signal generator is a versatile wide-range instrument.*

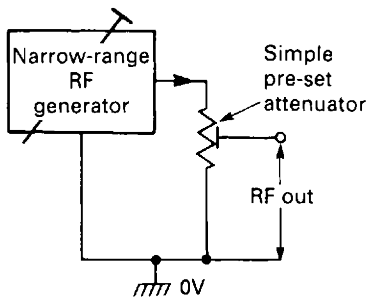


Figure 1.4. *An 'industrial' RF signal generator is usually a simple non-flexible circuit.*

1.4) may simply be designed to pump out a 465kHz CW signal at 100μV.

Most practical electronic testing operations call for the use of two or more items of interconnected test gear. For example, the items needed to carry out a simple performance check on an audio amplifier are a variable sine-wave generator (to generate a test signal), a wide-range a.c. millivoltmeter (to read input/output signal levels and thus facilitate frequency response checks), and a 'total harmonic distortion' or THD meter (to check the amplifier's reproduction quality or fidelity). If such a performance-testing facility is made by **temporarily** interconnecting or 'hooking up' a number of individual items of test gear (see *Figure 1.5*), the resulting assembly is known as a *test rig*, but if it is made by

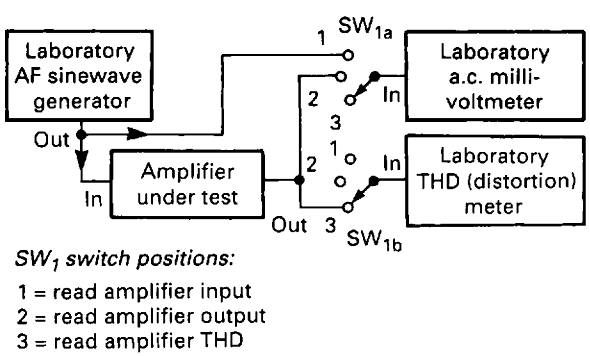


Figure 1.5. *This amplifier-testing* **test rig** *is made by temporarily interconnecting a number of items of laboratory test gear.*

permanently interconnecting a number of test-gear items (see *Figure 1.6*) the resulting unit is known as a *test set*. Many industrial test-gear engineers spend their working lives eternally designing new test sets for use on their company's production testing and quality control lines.

Note that some of the above technical terms can be interchanged. Thus, a simple multimeter is an item of *test gear*, but when in use it becomes a *metering system*. Again, a THD meter is correctly called an item of *test gear* if it requires the use of an external low-distortion sine-wave generator, but should be called a *test set* if it has such a generator built in.

Test sets are usually far easier to use than temporary test rigs. Thus, to measure the dB voltage gain of an amplifier via the *Figure 1.5* test rig, the sine-wave generator should be set to give (say) 1V output from the amplifier (read with SW_1 in position 2), and the amplifier input voltage must then be read (with SW_1 in position 1) and the 'gain' value calculated from the difference between the two readings. This same measurement can be made via the *Figure 1.6* test set by merely setting the attenuator input to 1V (read in SW_1 position 1) and then adjusting the attenuator setting to give the same reading (in SW_1 position 2) from the amplifier output, at which point the dB gain value can be read directly from the attenuator setting.

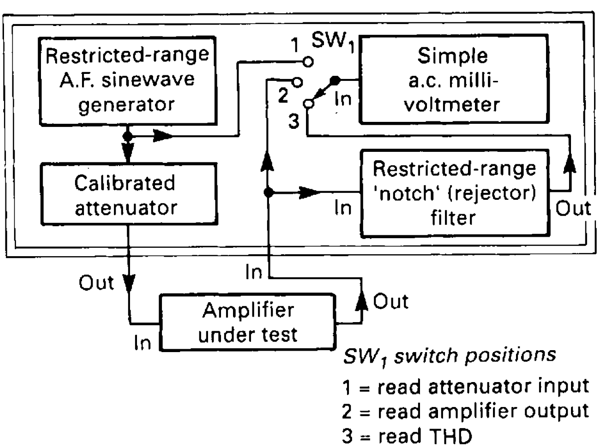


Figure 1.6. *This amplifier-testing* **test set** *is made by permanently interconnecting a number of items of dedicated (industrial) test gear.*

Types of test gear

There are four broad categories of test gear, and these can be named as **generators**, **indicators**, **composites**, and **standards**. A **generator** is simply any item of test gear that acts as a source of signals or power (e.g. AF and RF signal or pulse generators, power supplies, etc.), and an **indicator** is simply any item of test gear that gives a visual or audible indication of the absolute or relative value of a monitored parameter (analogue and digital meters, audio/visual **go/no-go** testers, and oscilloscopes, etc., are examples of these).

A **composite** is any item of test gear that can directly carry out a complete test action and contains the equivalent of two or more individual items of test gear ($L-C-R$ bridges and 'distortion' meters are classic examples of 'composite' test gear). A **standard** is any item of test gear that has such high precision that it can be used to calibrate or corroborate the accuracy of other items of test gear; precision voltage references, crystal frequency standards, and precision R and C substitution boxes and attenuation boxes are typical examples of these.

'Generator' types

The following 'generator' types of test gear are in common use:

(1) *AF sine-wave generators*. These are designed to generate low-distortion (typically 0.1 per cent at 1kHz) low frequency (usually 20Hz to 30kHz) sine waves, and are normally based on a Wien-bridge or Twin-T oscillator. *Figure 1.7* shows an example of a thermistor-stabilized Wien-based design that can be used in fixed-frequency 'industrial' application, and *Figure 1.8* shows, in block diagram form, how a wide-range version of the oscillator can be used, in conjunction with a sine–square converter and a variable attenuator, to make a laboratory sine–square waveform generator.

(2) *LF function generators*. These generate a basic 'triangle' waveform from which simultaneous sine and square waveforms are synthesized; typically, they can span the 1Hz to 100kHz range and their sine waves produce about 2 per

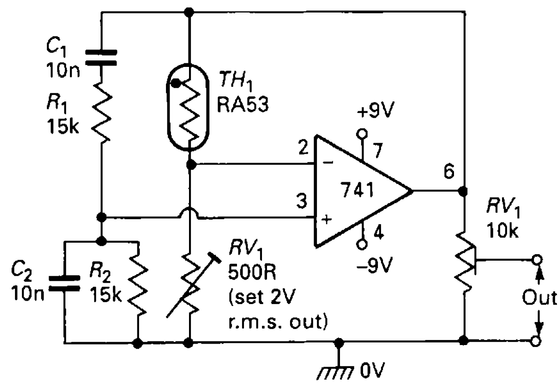


Figure 1.7. *Simple 'industrial' 1kHz Wien-bridge sine-wave generator.*

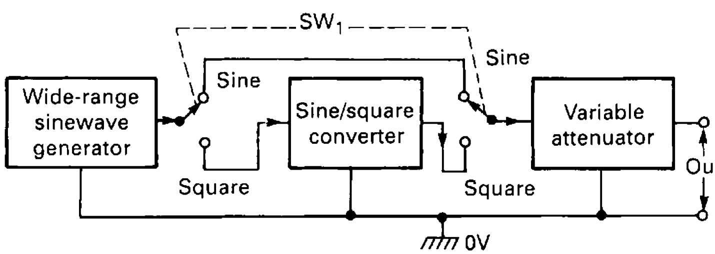


Figure 1.8. *Block diagram of a wide-range laboratory-standard sine/ square generator.*

cent distortion at 1kHz. Usually, the operating frequency can be controlled either resistively or via an external voltage, enabling the frequency to be voltage-swept if required. Several companies produce dedicated 'function generator' ICs that enable a complete generator to be built from a single chip.

(3) *Pulse generators.* These produce an output pulse on the arrival of a suitable input trigger signal, which may be generated either internally or externally. *Figure 1.9* shows the block diagram of a simple pulse generator that produces a single variable-width output pulse on the arrival of each rising edge of a rectangular input signal. *Figure 1.10* shows a modified version of the above generator, in which the initiation of the output pulse can (when SW_2 is

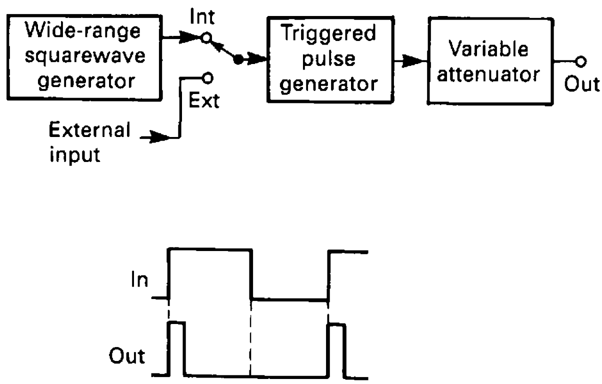


Figure 1.9. *Typical pulse generator block diagram.*

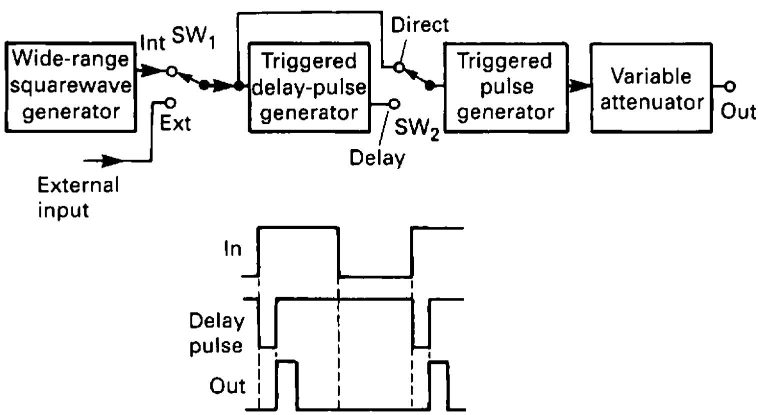


Figure 1.10. *Typical delayed-pulse generator block diagram.*

set to the 'delay' position) be delayed by a period equal to the width of the delay-pulse generator. Typically, both pulse widths can be varied from a fraction of a microsecond to hundreds of milliseconds.

(4) *RF generators*. These produce high-frequency sine-wave outputs (of 100kHz upwards), and usually have some type of modulation facility (AM and/or FM) and some means of varying the output signal amplitude; *Figures 1.3* and *1.4* show (in block diagram form) examples of laboratory and industrial (dedicated) RF generators.

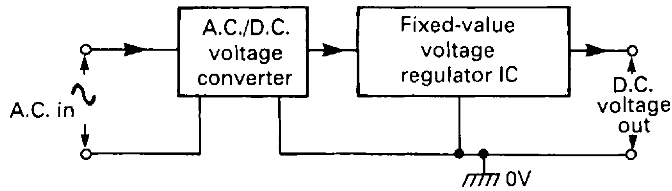


Figure 1.11. *Typical 'industrial-type' stabilized P.S.U.*

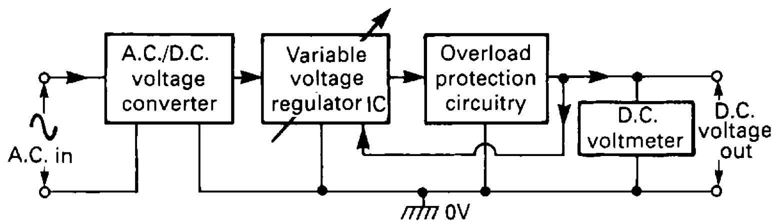


Figure 1.12. *Typical 'laboratory standard' P.S.U.*

(5) *Stabilized power supplies.* These generate a mains (A.C. power line) derived D.C. supply in which the output voltage remains constant in spite of wide variations in load current, etc. Modern versions of these are usually based on one or more dedicated 'voltage regulator' ICs. Industrial versions of such a PSU (power supply unit) usually consist of little more that a transformer–rectifier–capacitor A.C./D.C. converter and a fixed-value voltage regulator IC, as shown in *Figure 1.11*. Laboratory-type PSUs are more complex, and include a variable-voltage regulator IC, overload protection circuitry, and an output voltage monitor (see *Figure 1.12*).

'Indicator' accuracy

The next major category of test gear is the 'indicator', which usually consists of some type of analogue or digital meter. Before looking at the various types of indicator, mention must be made of the system of specifying the accuracy of meters.

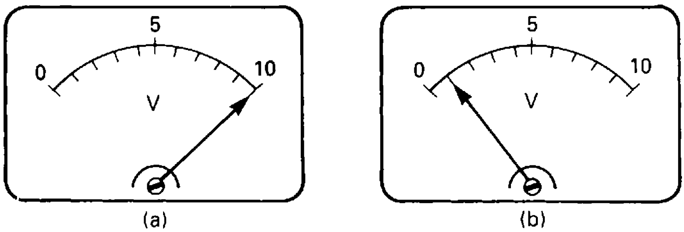


Figure 1.13. *This 10V meter has a basic 'accuracy' (see text) within 3 per cent of F.S.D.; its readings are accurate to within (a) 3 per cent at 10V, and (b) 30 per cent at 1V.*

The accuracy of analogue meters (i.e. moving coil types, etc.) is specified by the statement that the actual meter reading is 'accurate to within $\pm x$ per cent of the F.S.D. value of the meter'. By convention, this statement is usually abbreviated to the simple but rather ambiguous statement that the meter has an 'accuracy of x per cent', the remaining qualifying parts of the full statement being accepted (by practical engineers) as implicit and self-explanatory. Thus, if a meter has a specified 'accuracy' of 3 per cent (a typical value) and has an F.S.D. (full scale deflection) value of 10V, as shown in *Figure 1.13*, it is implied that the meter has a true input in the range 9.7 to 10.3V when it reads 10V, and in the range 0.7 to 1.3V when it reads 1V. Note in the latter example that meter errors may be as high as 30 per cent.

Digital meters usually give three or more digits of readout, as shown in *Figure 1.14*. A simple 3-digit type can give a maximum reading of 999. Most general-purpose digital voltmeters (DVMs) can give a maximum reading of 1999, and are known as $3\frac{1}{2}$-digit DVMs; high-precision types can give a maximum reading of 19 999 and are known as $4\frac{1}{2}$-digit DVMs. Their precision is fully specified by the statement that their reading is 'accurate to within $\pm x$ per cent of the actual reading, $\pm y$ digits'. By convention, this

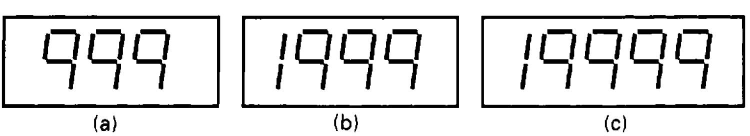


Figure 1.14. *Full-scale readings on digital meters with (a) 3 digits, (b) $3\frac{1}{2}$ digits, and (c) $4\frac{1}{2}$ digits.*

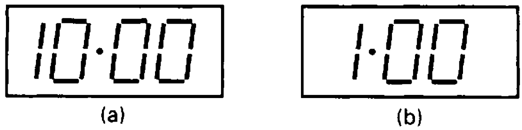


Figure 1.15. *This $3\frac{1}{2}$ digit meter has a full-scale sensitivity of 19.99V and a basic 'accuracy' (see text) within 0.5 per cent ±2 'digits': its readings are accurate to within (a) 0.7 per cent at 10V, and (b) 2.5 per cent at 1V0.*

statement can be abbreviated to a simple statement that the meter has an 'accuracy of *x* per cent, ±*y* digits'. Thus, if a $3\frac{1}{2}$-digit 19.99 voltmeter has an 'accuracy' of 0.5 per cent ±2 digits (a typical value), as shown in *Figure 1.15*, it is implied that its reading are accurate to within 0.7 per cent at 10V, and to 2.5 per cent at 1V0.

'Indicator' types

The following 'indicator' types of test gear are in common use:

(1) *Analogue meters.* These are designed to give a visual representation of a monitored parameter value by moving a pointer or a dot or bar of light a proportionate distance across a graduated scale. *Figure 1.16* shows examples of a 7V reading given on 10V meters using (a) moving pointer and (b and c) ten-LED bar-graph and dot-graph 'moving light' displays.

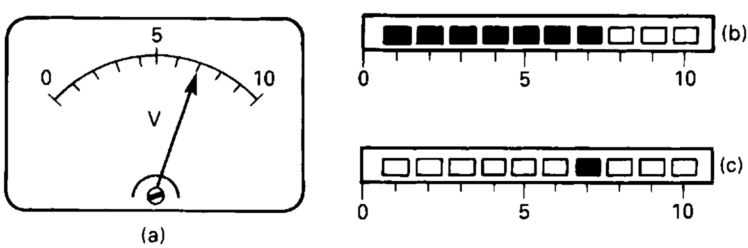


Figure 1.16. *Representations of 7V readings on 10V meters of the following types: (a) moving pointer; (b) 10-LED bar graph, (c) 10-LED dot graph.*

The reader should note that analogue meters have two major advantages over digital types. The first is that they give clear indications of measurement variations (digital displays present a confused jumble of numbers under this condition), making them uniquely well suited to applications such as 'peak point' and 'null point' indicating. The second great advantage is that they can be inscribed with both linear and non-linear scales, enabling, for example, a single meter to read both linear and dB voltage values.

In instrumentation and test gear applications, the most widely used type of analogue meter is the 'moving coil' type. These are actually current-indicating meters in which the test current flows through a coil and causes the meter's pointer to deflect by a proportional amount. The coil has a finite resistance, and the performance of the meter can thus be depicted by presenting it as shown in *Figure 1.17*; in this instance the meter has an F.S.D. sensitivity of 100μA and an internal resistance of 1000Ω, and thus has 100mV generated across its terminals at F.S.D.

The sensitivity of the *Figure 1.17* meter can be effectively reduced (so that it needs a greater current to give a F.S.D. reading) by shunting the meter's terminals with a suitable resistor (R_x), as shown in *Figure 1.18*. Alternatively, the meter can be made to act as a D.C. voltage indicator by wiring it in series with 'multiplier' resistor R_x as shown in the '10V F.S.D. meter circuit of *Figure 1.19*; here, the 100μA meter has, by definition, a basic sensitivity of 10KΩ/V, so R_m (which equals the sum of R_x and the meter's internal resistance) needs a value of 100kΩ. The meter can be made to indicate A.C. current values by

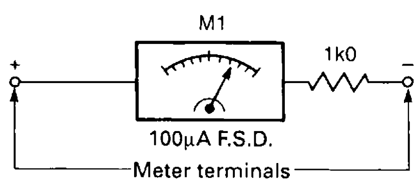


Figure 1.17. *Representation of a moving-coil meter with an F.S.D. sensitivity of 100μA and 1000Ω internal resistance.*

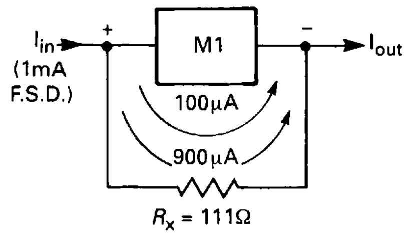


Figure 1.18. *External shunt (*R_x*) used to convert the above meter to read 1mA F.S.D.*

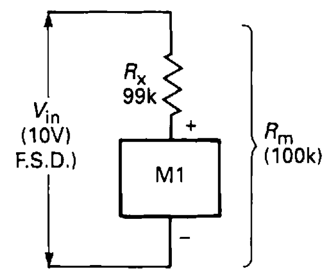


Figure 1.19. *Series multiplier resistor* R_x *used to convert the 100μA meter to read 10V F.S.D.*

feeding them to the meter via a bridge rectifier; *Figure 1.20* shows how the meter can be made to indicate A.C. voltage values by feeding them to the meter via a multiplier resistor (R_x) and a bridge rectifier.

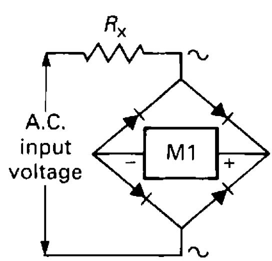


Figure 1.20. *Multiplier resistor and bridge rectifier used to convert the 100μA meter to an A.C. voltmeter.*

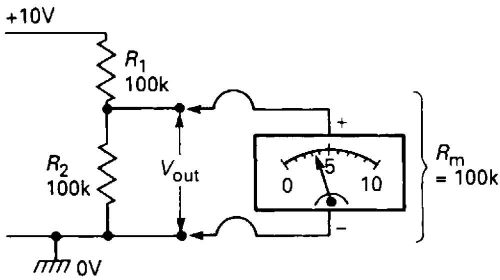


Figure 1.21. *This voltage divider gives an unloaded output of 5V, but this simple test meter gives an output reading of 3.3V, due to its loading effect.*

(2) *Analogue multimeters.* These consist of a good-quality moving coil meter with a wide span of switch-selected A.C. and D.C. voltage and current ranges, plus a battery-powered addition that enables the meter to indicate a wide range of resistance values. When using a simple multimeter, always consider its effect on the circuit under test; *Figure 1.21* illustrates this point. Here, the R_1–R_2 divider gives an unloaded output of 5V, but when the meter is connected across the output its 100k R_m value shunts R_2 and reduces its effective value to 50k, thus reducing the output voltage to the 3.3V value indicated by the meter.

(3) *Electronic analogue multimeters.* These unite a normal moving coil meter with an electronic buffer/amplifier and a high-impedance input attenuator, as shown in *Figure 1.22*, to greatly increase the meter's effective sensitivity

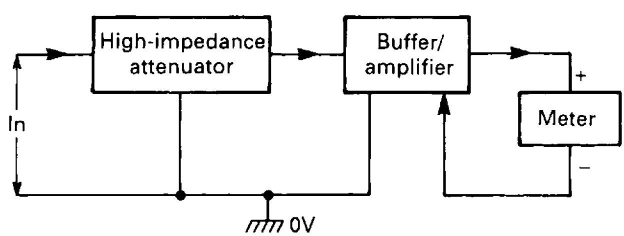


Figure 1.22. *Block diagram of an electronic analogue multimeter.*