

RADIO AND ELECTRONIC COMPONENTS VOL. VI

Connectors
Relays and Switches

G. W. A. Dummer and N. E. Hyde

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Radio and Electronic Components: Volume Six

CONNECTORS, RELAYS AND SWITCHES

BY

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SIR ISAAC PITMAN & SONS LTD.

First published 1966

ED72/02

SIR ISAAC PITMAN & SONS LTD.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, BOUVERIE STREET, CARLTON, MELBOURNE
22-25 BECKETT'S BUILDINGS, PRESIDENT STREET, JOHANNESBURG
ASSOCIATED COMPANIES
PITMAN MEDICAL PUBLISHING COMPANY LTD.
46 CHARLOTTE STREET, LONDON, W.1
PITMAN PUBLISHING CORPORATION
20 EAST 46TH STREET, NEW YORK, N.Y. 10017
SIR ISAAC PITMAN & SONS (CANADA) LTD.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381-383 CHURCH STREET, TORONTO

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G. W. A. Dummer
and
N. E. Hyde
1966

FOREWORD

(Contributed to Volume One)

BY

SIR ROBERT RENWICK, Bt., K.B.E.

*(President of the Radio and Electronic Components
Manufacturers Federation)*

Few people outside the electronics industry appreciate the vastness of the field in which radio components are now being used. Domestic radio and television sets absorb well over a million components a day, yet this figure is several times surpassed by the number of components made for telecommunications equipment, navigational aids, radar installations, industrial electronics, etc. This field is being steadily widened as the scope of electronics expands in nuclear electronics, computers for business machines, medical electronics, guided weapons control systems, etc. Some 40,000 people* in over 150 factories* are now being employed in the radio and electronic components industry alone and component parts are being made at the rate of four million pieces a day, while exports of components have reached the figure of some £1 million per month.* The importance of this effort to the nation cannot be over-emphasized and the component industry is rightly proud of its fine achievements.

In spite of the size and importance of this industry there have not been any books on components such as resistors and capacitors until the author introduced this series. I am sure the value of these books will become immediately apparent and will increase as the electronics industry grows and expands its spheres of activity. This first book on "Fixed Resistors" is an authoritative volume, rightly written from the point of view of the user. It sets out to help him in choosing the right resistors for his purpose, and the comparison charts of the characteristics of many different types of resistor are most valuable in helping this choice. It covers every aspect of fixed resistor design and usage, and if the remaining volumes are as comprehensive in their coverage of the field, they should certainly fill a wide gap in the present technical literature.

I can imagine few people more qualified to write these books than the author. He had a long background of experience in the radio industry before he joined the Telecommunications Research Establish-

* In 1956.

ment in 1939, where he created a group working on radar synthetic trainers during the early part of the War. The ingenuity and complexity of some of the circuits used must have given him valuable experience in the practical use of components. He was awarded the M.B.E. for his work on radar trainers during the War and was also awarded the American Medal of Freedom (with Bronze Palm) by the United States of America for his contribution to this field.

In 1944 he began research and development of components for radar equipments and is now head of a team of specialists working on components and techniques at the Royal Radar Research Establishment. He is an I.E.E. Premium Award winner, has written many authoritative articles on components and techniques affecting components, and has travelled and lectured extensively. He is a member of the Joint Services Radio Components Research and Development Technical Committee and the Radio Components Standardization Committee. He is also chairman of the R.C.R.D. Sub-committee on Fixed and Variable Resistors, and chairman of the R.C.R.D. Panel on Transistor Components. He is chairman of the N.A.T.O. Sub-committee on the Standardization of Resistors, and represents the United Kingdom on the N.A.T.O. Sub-committee for the Standardization of Capacitors.*

I think the introduction of this series of books is timely and I am certain that they will make a valuable contribution to the designer's knowledge of radio and electronic components. I hope they will aid British Industry in the production of electronic equipments.

* In 1956.

PREFACE

It has been said that components are the bricks with which all electronic equipments are built and that the reliability of a modern complex electronic equipment is determined by the reliability of the weakest component.

A wider knowledge of the characteristics of components should, therefore, help designers and users of all types of equipment. As the range of components is so wide they are covered in several volumes of which this volume (Volume Six) is the last in the series. The first volume dealt with Fixed Resistors, the second with Variable Resistors, the third with Fixed Capacitors, the fourth with Variable Capacitors, and the fifth with Wires and R.F. Cables. The book *Modern Electronic Components* has been written to cover the complete range of electronic components and also to include additional data on operating conditions of components. Miniature components data is now available annually in the *British Miniature Electronic Components Data Series*, published by Pergamon Press Ltd., Oxford.

The subject of connectors, relays and switches is of particular importance as all rely on contacts for their efficient operation. Contact phenomena have therefore been dealt with in some detail.

This book may help when reliability and rating problems in connectors are involved. Although some relays and switches may be replaced by semi-conductor devices, there will be a requirement for plugs and sockets for some time, even for microminiature assemblies.

This is the first book to be devoted specifically to connectors and it is hoped that it will fill a gap in the technical literature and be of value to all designers and users of electronic equipments.

G. W. A. D. & N. E. H.

ACKNOWLEDGMENTS

THE authors would like to acknowledge the help received from many sources: from industry, from E.R.A., and from universities and government establishments. They take pleasure in acknowledging the help in proof reading and suggestions from J. H. Brentnall, D. Clarke, F. Clish, A. Fairweather, H. G. Manfield, C. H. Miller, J. Pullen, K. Russell, S. C. Schuler and H. White.

The views expressed in this book do not necessarily represent the views of the Ministry of Aviation, and the authors have endeavoured to be impartial in assessing the characteristics of the components described.

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CHAPTER 1

GENERAL INFORMATION ON COMPONENTS

A BRIEF HISTORY OF COMPONENT DEVELOPMENT IN GREAT BRITAIN

THE first radio components incorporating resistance, inductance and capacitance might be considered to be the constituent parts of the Hertz loop, although the Leyden jar had been used as a capacitor for many years, and resistors had previously been used in the field of electrical power.

Faraday, in the 1850's, discovered that silver sulphide possessed a high negative temperature coefficient of resistance, anticipating the modern thermistor, and in the late 1880's the first aluminium electrolytic capacitor was made in Germany.

The first carbon-composition resistor was made as far back as 1885, and the first inductor for radio purposes might well be considered the Hertz loop itself in 1887. The two-electrode valve was introduced in 1904 and the three-electrode valve in 1907, and with the growth of radio telegraphy using these valves, transmitters and receivers were designed and built, with the designer of the equipment constructing all the necessary components.

The 1914-18 War gave a marked impetus to the development of radio communications, and with the advent of the three-electrode valve in quantity, components began to assume the form roughly as we know them now. After the First World War the component industry itself began to develop. The British Broadcasting Company started programme broadcasting on 14 November, 1922, and from about that time up to about 1930 many component manufacturers began to specialize in individual components, from which the home constructor used to make radio receivers. Resistors were used in large quantities as grid leaks, anode loads, etc., and consisted of carbon compositions of many kinds compressed into tubular containers and fitted with end caps. Paper-dielectric capacitors were mainly tubular types enclosed in plain bakelized cardboard tubes, with bitumen or similar material sealing the ends. The terminations were frequently brought out radially and not axially. Bakelite-enclosed stacked-mica capacitors, fitted with screw terminals and with the bottom of the case sealed with bitumen, were also in common use. Rectangular metal-cased and plastic-cased types were also used. Electrolytic capacitors were mainly wet types in tubular metal cases. Cracked-carbon film-type resistors were introduced from

Germany in about 1928 and by 1934 were being manufactured in quantity in this country.

From 1930 onwards the home construction of sets diminished and many component manufacturers and radio set-makers worked together. Techniques for component manufacture in quantities improved, and some ten million radio sets were in use in the United Kingdom in 1939. The standards to which components were made were those of domestic radio. Pan-climatic protection was unnecessary and the self-compensating action of the radio valve made wide tolerances and poor stability generally acceptable. Apart from certain electrical engineering applications, telephone companies, a few sections of the instrument industry and the Services, no very high standard was required of the component manufacturer. The first step towards improved components was taken in 1938, when the Royal Aircraft Establishment began type-approval tests to Wireless Telegraphy (W.T.) Board Specification K 110, on a wide range of components for Air Force use. Directorate of Communications Development (D.C.D.) specifications were drawn up and standard lists of components prepared.

The 1939-45 War made it essential to produce large quantities of components quickly. The introduction of radar into the Services meant that still more components, including many new types, were required. The need for increased production, which amounted to approximately three times the normal peace-time output, and the shortage of materials led to Inter-Services rationalization of components, commencing in 1941 with the formation of the Inter-Services Communications Components Committee (I.S.C.C.) and followed by the formation of the Inter-Services Components Technical Committee (I.S.C. Tech.C.) in 1942—now the Radio Components Standardization Committee (R.C.S.C.). An example of the success of this rationalization is that in 1942 there were 1,500 different plugs and sockets in use in the Ministry of Aircraft Production alone, and after rationalization only 200 were retained by the *three* Services. Other examples are—some 10,000 different resistor types were reduced to 1,300 preferred items; 8,000 fixed-capacitor types were reduced to 750 preferred items; and 700 types of transformer laminations were reduced to 32 preferred items. Similar reductions were made in other components. Inter-Services technical specifications for components were also drawn up by the I.S.C. Tech.C. and these are constantly being revised by the R.C.S.C. These specifications were, and still are, purchasing documents, and they also contain the inspecting procedure for accepting components and for type approval.

It was becoming apparent by 1942 that major improvements in component design were necessary, and in 1943 the Joint Services Radio Components Research and Development Committee (R.C./R.D.C.) was

formed to stimulate and co-ordinate research and development on new components and materials. Experience in the Pacific war emphasized the defects in component design under conditions of prolonged humidity and led to the necessity for improved sealing. Pressurized and sealed equipments required components which would operate at high temperatures. Pack sets and miniature equipments led to effort being devoted to reducing the size of components and many miniature types were introduced. High precision was also required in components for radar systems and for multi-channel communication receivers, etc. All this led to establishments and industry, often sponsored by the R.C./R.D.C., developing new materials and components intended to satisfy the many conflicting requirements.

Waxed tubular paper-dielectric capacitors and some metal-cased types were replaced by metal-cased tubular types with Neoprene end seals. Metallized paper-dielectric capacitors were developed. Improved control of the temperature coefficient of ceramic-dielectric capacitors was introduced by manufacturers and new high-permittivity ceramic mixes developed. Glass-enclosed and sealed Grade 1 fixed resistors were developed but did not go into production. Many manufacturing improvements were introduced into Grade 2 resistor production and testing. Work on sealed variable resistors was sponsored by the R.C./R.D.C., and many types are now available. Transformers operating at higher temperatures, oil-filled and sealed in metal cans, were developed and, more recently, resin "potted" transformers have been introduced. Sealed relays and indicating meters were also designed and produced.

All these developments resulted in improved components for use by the Services, and the component of today bears little resemblance to its earlier counterpart, being smaller and lighter, and operating over a wider temperature range under adverse climatic conditions. Even so, modern requirements ask for still higher standards, particularly in reliability, and, with the advent of the transistor, still more miniaturization. There is little doubt, therefore, that research and development work will continue in order to improve the performance of components even as we know them today.

Microminiaturization techniques have led to the development of thin-film components and have made a major change in the shapes of components for the first time in many years. Recent developments in integrated circuits, where semiconductor components are fabricated directly with no interconnexions, again are making a major change in shape.

TEMPERATURE AND HUMIDITY CATEGORIES OF COMPONENTS

In 1939, temperature and humidity tests for Service components were to the W.T. Board Specification K 110. This consisted of a dry heat test (6 hr at 70°C) followed by two humidity cycles (6 hr at 60°C and 95 per cent relative humidity). Early in the war, a cold cycle was introduced (at - 30°C) between the two humidity cycles. The spread of the war into different climates, and the arduous operational conditions, led to a new specification, RCS 11, which superseded K 110 and was, in turn, superseded by Defence Specification DEF 5011. The temperature and humidity categories for this specification are given in Table 1.1.

TABLE 1.1. TEMPERATURE AND HUMIDITY CATEGORIES OF COMPONENTS
Service Categories—Specification DEF 5011

1. *Temperature Categories*

Category	Temperature Range (°C)
T.1	-25 to + 70
T.2	-55 to + 70
T.3	-55 to + 85
T.4	-55 to +100
T.5	-55 to +125
T.6	-55 to +150
T.7	-55 to +200
T.8	-65 to +100

2. *Humidity Classifications*

Class	Conditions	
	1st Group	2nd Group
H.7	6 accelerated damp heat cycles (16 hours at +53 to 57°C, 95% R.H.)*	56 days damp heat (continuous at 38 to 42°C, 90 to 95% R.H.)
H.6	As above	As above
H.5	2 accelerated damp heat cycles	21 days damp heat
H.3	1 accelerated damp heat cycle with assisted recovery	4 days damp heat with assisted recovery

* N.B. H.7 has four extra cold cycles alternating with the last four humidity cycles—the sequence ending with a humidity cycle.

The British Standards tests for commercial components are summarized in Table 1.2.

TABLE 1.2. TEMPERATURE AND HUMIDITY CATEGORIES OF COMPONENTS
B.S.I. Categories—Specification B.S. 2011 : 1963

1. *Temperature*

Cold	Dry Heat
—10°C	40°C
—25°C	55°C
—40°C	70°C
—55°C	85°C
—65°C	100°C
	125°C
	155°C
	200°C

Any Cold may be combined with any Dry Heat temperature and the component quoted as, for example, 10/70 or 40/100. Here the first figure gives the minimum (negative °C) and the second the maximum operating temperature.

2. *Humidity Classification*

Class	1st Group	2nd Group
4A	1 accelerated damp heat (16 hrs at 55°C, 95–100% R.H.) plus 6 hrs assisted drying	4 days long-term damp heat (40°C, 90–95% R.H.) plus 6 hrs assisted drying
4	None	As above but no assisted drying
21	2 accelerated damp heat cycles (as above)	21 days (as above)
56	6 accelerated damp heat cycles (as above)	56 days (as above)
56C	As for Class 56 but with 4 extra cold cycles alternating with last 4 damp heat cycles	56 days (as above)

An International Electrotechnical Commission (I.E.C.) Publication No. 68—"Recommended basic climatic and mechanical robustness testing procedure for components for electronic equipment"—is now available and is summarized in Table 1.3.

Whilst the salient points in these three specifications have been

summarized briefly, it should be remembered that these categories are subject to amendment by the authorities concerned.

TABLE 1.3. TEMPERATURE AND HUMIDITY CATEGORIES OF COMPONENTS
I.E.C. Categories—I.E.C. Publication 68

Severity	Temperature (°C)		Humidity
	Dry Heat	Cold	
1	200	—	—
2	155	—	—
3	125	—65	—
4	100	—55	6 accelerated humidity cycles (16 hours at 55°C, 95–100% R.H.) 56 days long term damp (continuously at 40°C, 90–95% R.H.)
5	85	—40	2 accelerated humidity cycles (as above) 21 days long term damp (as above)
6	70	—25	1 accelerated humidity cycle (as above) plus 6 hours assisted drying
7	55	—10	4 days long term damp (as above) 4 days long term damp (as above) plus 6 hours assisted drying
8	40	—	10 days long term damp (as above)

N.B. Components can be classified in groups of any combination of the above categories.
Three figures are quoted—

1st . . . low temperature
2nd . . . high temperature
3rd . . . humidity severity

e.g. Group 454 = —55°C, +85°C and humidity severity 4.
Group 668 = —25°C, +70°C and humidity severity 6.

VIBRATION AND SHOCK CATEGORIES

In Specification RCS 11, a vibration resonance search (10 to 150 c/s) test was incorporated mainly to cover transport vibration frequencies. Early in 1961, Specification DEF 5011 introduced additional endurance vibration testing in addition to wider vibration frequencies (5 to 5,000 c/s). Acceleration tests at 13g, 50g and 100g applied for five minutes, together with shock tests of 4,000 bumps at 1 inch amplitude, were also introduced in this specification. B.S. 2011 also introduced vibration and shock testing, and the tests in both specifications are summarized in Table 1.4.

MISCELLANEOUS CATEGORIES

Other tests, such as mould growth, salt spray, soldering, low air density, etc., are also required, and Table 1.5 summarizes these tests specified in Specification DEF 5011.

TABLE 1.4. COMPONENT ENVIRONMENT TEST SPECIFICATION. *Shock and Vibration Requirements*

	DEF 5011	British Standard B.S. 2011
Vibration	<p><i>Severity Class 1</i> Frequency Range 5–500 c/s, Endurance 10 hr total, 3.5π in. per sec, 5 to 60 c/s shared equally between resonances having $Q \geq 3$, or 10 hr constantly sweeping if no resonances</p> <p><i>Severity Class 2</i> Frequency and Amplitude as Class 1 Endurance 144 hr total shared equally between resonances having $Q \geq 3$. If resonant-free, 96 hr at three selected frequencies</p> <p><i>Severity Class 3</i> Frequency 5 to 5,000 c/s Amplitude Resonance search up to 2g, 5–5,000 c/s Endurance—100 hr sweeping at 10g, 30–2,000 c/s Functional, if required by component specification 30g, 30–5,000 c/s</p>	Frequency Range 10–150 c/s up to 10g Endurance for 144 hr sweeping from 10–150 c/s
Acceleration (sustained)	<p>Severity A1 13g Applied for 5 min</p> <p>Severity A2 50g in each plane</p> <p>Severity A3 100g and sense</p>	None
Shock Bump	4,000 bumps, 1 inch free drop, peak deceleration 36–44g at high, low or room temperature	4,000 bumps, peak acceleration 36–44g at high, low or room temperature
Shock Pulse	<p><i>Severity</i> <i>Square Pulse</i> <i>Rise Time</i> <i>Duration</i></p> <p>1 50g 0.25 to 0.5 msec 12 msec</p> <p>2 75g 0.5 to 1 msec 10 msec</p> <p>3 100g 0.5 to 1 msec 6 msec</p>	None

TABLE 1.5. TESTS IN SPECIFICATION DEF 5011 SUMMARIZED IN
ALPHABETICAL ORDER

<i>Acceleration</i>	A1 13g, A2 50g, A3 100g; 5 min in each plane and sense (total 30 min)
<i>Air Density</i>	D1 = 0.370 (30,000 ft) D2 = 0.014 (100,000 ft) D3 = 0.003 (130,000 ft)
<i>Bumping</i>	4,000 bumps at 40g, at high and/or low temperature
<i>Damp Heat Accelerated</i>	55°C \pm 2°C 95 to 100 per cent R.H. (cyclic variation 2 to 3°C). Duration 16 hr plus 5 hr cooling
<i>Damp Heat Long-term</i>	40°C \pm 2°C R.H. 90 to 95 per cent H3 4 days, H5 21 days H6 and H7 56 days
<i>Endurance</i>	2,000 hr at upper category temperature with electrical load applied
<i>Fire Risk</i>	In flame 60 sec max. Extinguish in 15 sec
<i>Humidity Classes</i>	H6 6 damp heat (accelerated) 56 days, ltdh H5 2 damp heat (accelerated) 21 days, ltdh H3 1 damp heat (accelerated) plus 4 days long-term damp heat H7 New class—similar to H6 but includes 4 cold cycles (<i>Note:</i> H4 Commercial class—omitted)
<i>Mould Growth</i>	26–30°C, 95–100%, R.H. for 28 days
<i>Robustness of Terminations</i>	Tensile Bending Torque Torsion
<i>Salt Mist</i>	Spray 2 hr 15°C to 35°C. Store 7 days at 33–37°C, 90–95 per cent R.H. Repeat for total of 28 days
<i>Sealing</i>	Differential pressures—2, 14 and 45 lb/in. ²
<i>Shock</i>	3 severities— S1 50g duration 12 msec S2 75g duration 10 msec S3 100g duration 6 msec
<i>Shelf Life</i>	3 years under natural conditions of temperature, humidity and air pressure

ltdh: long-term damp heat

TABLE 1.5—*contd.*

<i>Soldering</i>	<p><i>Iron:</i> Temp. 300°C to 350°C Medium and small bit sizes Tinning within 2 sec Heat resistance for further 8 sec <i>Bath:</i> Temp. 245–255°C Tinning. 2 sec $\pm \frac{1}{2}$ sec Heat resistance. 350°C $\pm 10^\circ\text{C}$ Further 3 to 4 sec</p>
<i>Standard Atmospheric Conditions</i> <i>Reference (i) & (ii)</i>	<p>(i) Temp. 20°C, 1,000 mb (ii) Temp. 19–21°C R.H. 63–67 per cent Pressure 860–1,060 mb</p>
<i>Measurements</i>	Temp. 15–35°C, R.H. 45–75 per cent
<i>Recovery within 1°C of</i>	Pressure 860–1,060 mb
<i>Assisted recovery</i>	<p>Lab. temp. $\pm 1^\circ\text{C}$ R.H. 73–77 per cent Pressure 860–1,060 mb Temp. 53–57°C R.H. 20% max. Pressure 860–1,060 mb</p>
<i>Sequence of Test Conditions</i>	<p>(i) Mechanical followed by rapid change of temp.; Dry heat; Dry cold; Low air-density; Accelerated damp heat; Soldering and fire risk (ii) Long-term damp heat (iii) Endurance (iv) Shelf life (v) Biological (vi) Corrosion</p>
<i>Temperature Categories</i>	<p>T1 25/70 T2 55/70 T3 55/85 T4 55/100 T5 55/125 T6 55/150 T7 55/200 T8 65/100</p>
<i>Temperature Dry Cold</i>	<p>3 Severities—25°C —55°C —65°C Period: 2 hr (or as specified)</p>
<i>Temperature Dry Heat</i>	<p>6 Severities + 70°C + 85°C + 100°C + 125°C + 150°C + 200°C</p>
<i>Temperature Rapid Change</i>	<p>One hour at each upper and lower temperature limit of severity, with 3-min change-over period. Total of 10 cycles</p>