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CONTENTS

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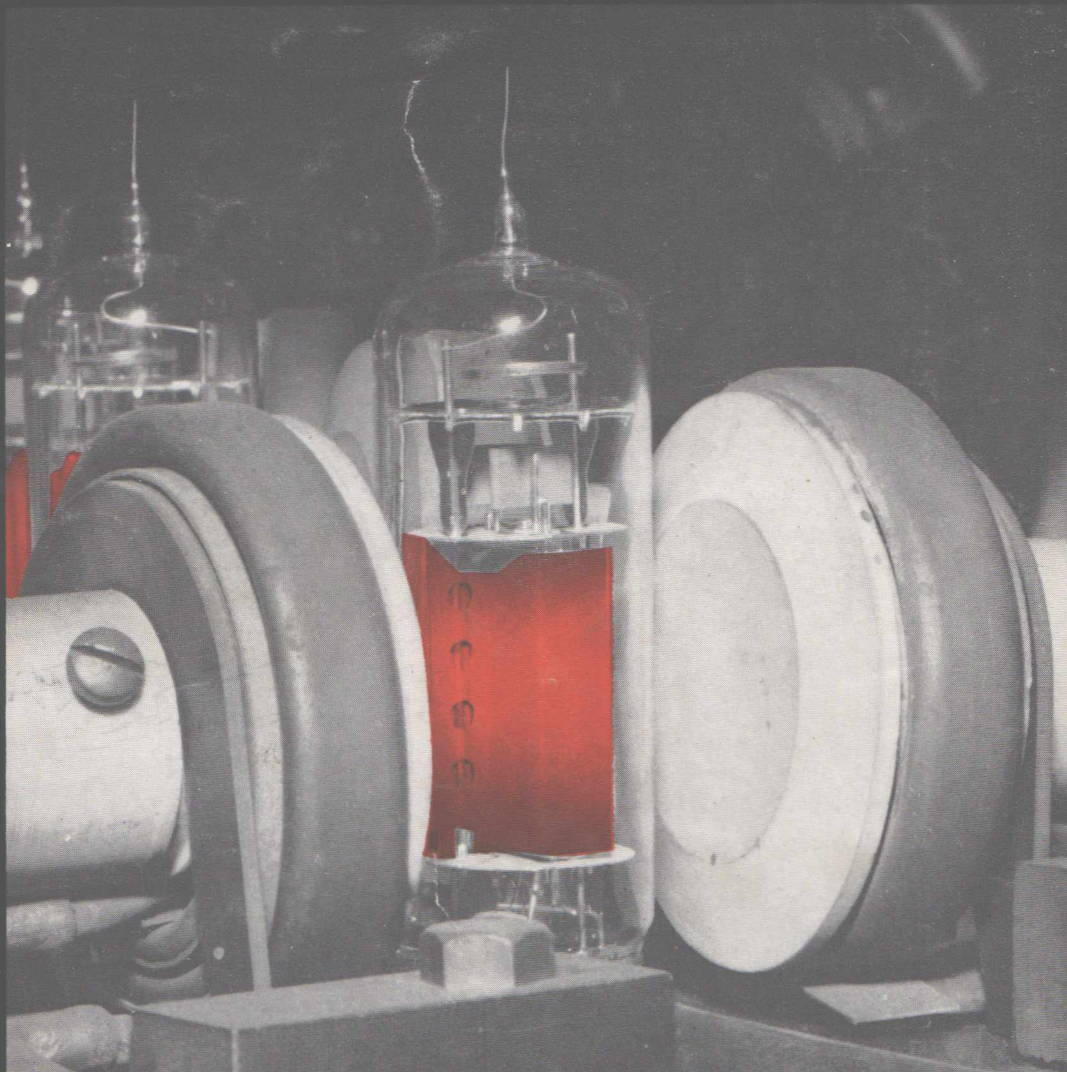

Induction heating of valve electrode structure during evacuation process at Hendon works

PHILIPS Tubes for HF Heating

The Philips range of industrial oscillator triodes—for induction and dielectric heating application, and ultrasonic generators—has been specifically designed for hard factory use under conditions of varying load, fluctuating supply and operation by electronically unskilled personnel. Thus they differ substantially from standard transmitting-type tubes intended for the carefully controlled conditions of broadcast stations.

The present article attempts to clear up prevalent misconceptions associated with the choice of such a tube, lists factors of prime importance in selection and operation, and demonstrates the advantages to be derived from the choice of a tube from the Philips Industrial Oscillator range.

The selection of Philips rectifiers will be the subject of a future article.

The advantages and applications of HF heating have been thoroughly dealt with in the literature[(1)(2)(3)].

Until recently, the oscillator tubes used in conjunction with HF heating installations were exclusively types originally developed for communications equipment. However, under industrial conditions, such a tube will usually be subjected to a widely varying load, wide temperature variation, fluctuations in supply and heater voltage and severe shock and vibration (not to mention the fact that at times electronically unskilled personnel will be involved).

Variation in tube loading would then result in considerable fluctuations in both the power delivered by, and that dissipated in, the tube. Thus very special attention has to be given to the matching arrangements and protective devices to ensure against overloading of either the anode or grid. Even if a tube type larger than the application really warrants were to be employed—which may preclude the possibility of overload—this does not overcome the problem of power variation in the load.

The basic purpose of the present article is to assist the user in the choice and application of a tube suitable for such stringent operational conditions, pointing out the inherent advantages of Philips industrial oscillator tubes.

SOME FACTORS IN TUBE SELECTION AND USAGE

1. Select a tube with adequate ratings. "Cost-cutting", using overrun tubes, is false economy.

Should the operational requirements appear to be marginal for a given tube type, the manufacturer has to decide whether he should spend more on protective devices, or employ a larger tube. For the Philips industrial oscillator range, upper operational limits are clearly defined by the absolute maximum ratings.

2. Do not misinterpret the tube data figures, or use untenable rules of thumb: consider the overall end result required.

(a) Do not calculate an "efficiency" figure based on the ratio of output power to *rated* anode dissipation. An efficiency figure only has significance in relation to the actual working conditions, i.e., using actual anode dissipation. Far from implying poor tube design, a large anode dissipation rating could imply a considerable dissipation margin during normal operation. Furthermore, a tube incorrectly chosen on a "good efficiency" basis, according to the above, may in fact be entirely unsuited to HF heating application. Even the slightest deviation from matched load condition may cause the anode to be heavily overloaded.

(b) Even a correctly calculated efficiency figure may be an inadequate tube figure of merit. Normally the efficiency of a tube is defined as the ratio of output to input power under matched conditions. However, this definition need not be of practical value in a HF generator. *In practice, the most efficient generator is that which can satisfactorily heat the largest amount of material in the shortest time, at a given maximum anode input power.*

Some tubes (not intended for industrial application) which provide a high efficiency under matched conditions, will, with even the slightest deviation from material load resistance, cause either the anode or the grid to be overloaded. With other tubes both the output power and the input power will fall off sharply in this case, and *it is clear that even the highest efficiency will not be useful if the output power is too low to heat the workpiece.*

(c) Sometimes a "desirable" ratio between maximum grid dissipation and maximum anode dissipation is quoted. However, these figures have no relation to each other. Moreover, in a normal oscillator, maximum anode and grid dissipations will never coincide. The maximum anode dissipation will occur at maximum load, whereas the maximum grid dissipation will occur under "off load" conditions, or under lightly loaded conditions.

In fact, no more and no less than the normal criterion applies — that there should be a good safety factor between normal operating conditions and limiting values.

Furthermore, one should not adopt as an overriding criterion that the grid drive requirements be low. Naturally, this would help to improve the overall "theoretical" efficiency, but not necessarily the practical efficiency as defined in 2(b) above. The latter may be even vastly improved for a tube type which requires comparatively high grid drive.

Comparatively high grid drive requirements do not necessarily imply greater chance of excessive grid dissipation. Reasoning which indicates to the contrary, completely neglects possible improvements which a tube manufacturer may have incorporated in the grid structure of his tubes. The grid dissipation limit is determined by the dimensions and material of the grid structure.

(d) Do not overstress the importance of breakdown voltage rating considered alone.

A tube with an extremely high breakdown voltage will in general have a lower efficiency at low anode voltages, and in tube design a compromise should exist between breakdown voltage rating, performance at low voltages and ultimate price of the tube.

It should also be remembered that the ability of a tube to withstand enormous voltage transients is to a large extent wasted if the "safe" passage of a transient only results in damage to the load or electrodes. A suggestion worthy of note is to incorporate a small smoothing filter (consisting of a small resistance and capacitance) in the equipment. This filter, although much too small for smoothing of the normal ripple of the power supply, should be sufficient for filtering out the narrow peaks and transients of the mains. The slight increase in cost and the slight decrease in efficiency would normally be outweighed by much reduced probability of flash-over, both in the oscillatory circuit and between the electrodes.

(e) Do not assume that use of forced-air cooling will automatically allow one to exceed, to some extent, the absolute maximum anode dissipation limit for radiation-cooled tubes. This would apply only if the bulb temperature were the limiting factor. With many radiation-cooled triodes, any increase of anode dissipation would cause the maximum allowable anode temperature to be exceeded. This cannot be avoided by forced-air cooling.

(f) When an intermittent anode dissipation rating is given, do not interpret "intermittent" as being closely akin to "continuous".

In fact, for an appreciable increase in the permitted anode dissipation limit, the "on" time may be only of the order of 20 secs., with a maximum duty factor (the ratio of "on" time to the total repetition period) of the order of 40%. Thus close attention must be given to the published data before taking such a step.

A comprehensive treatment of intermittent tube operation (centred on tubes type TBL 7/8000 and TB 5/2500) has been undertaken by Dorgelo and van Warmedam[4].

3. Note, and observe, the limits laid down for permissible filament voltage fluctuation: do not expect long life if this is not adhered to.

As will be demonstrated in the last section of this article, there are overriding advantages in using thoriated tungsten filaments in industrial oscillator tubes. The following remarks apply more or less specifically to such filaments.

The filament voltage tolerances are a compromise between life and emission. Any voltage above the nominal value will shorten the life of a tube. In practice, the filament life will also be influenced by many other factors, such as gas content which may lead to "poisoning". As the danger of poisoning will be less at higher temperatures, this makes the ratio between life at higher voltage and life at nominal voltage less unfavourable. However, in general, voltages of more than 5% above the nominal value will considerably shorten the life of the tube. It should be realised that much depends on the length of the periods during which the over-voltage is applied. When using a tube from the Philips industrial oscillator range, transient over-voltages will hardly have any influence at all, as the thermal capacity of the filaments is such that this will hardly have any influence on the filament temperature.

Summarising, it can be said that any over-voltage will reduce the life of the filament, but that within certain limits it will never lead to immediate destruction of the filament or its emissive properties.

Contrary to this, an under-voltage will increase the life down to a certain limit, but at this point it may immediately destroy the emissive properties of the filament. Consequently, a voltage of 10% below the nominal voltage will only be acceptable if the filament is over-dimensioned so that the emission will be sufficient even at this low voltage.

4. Select a tube specifically designed for industrial oscillator service.

Going further, investigate whether or not special features claimed for particular tube types will improve the product, cut the rejection rate, and reduce the operational time.

Philips offer a special range of industrial oscillator tubes—not merely transmitting tubes with little or no modification—but tubes in which the complete electrode assembly has been designed to suit industrial conditions and usage. The electrode materials used have properties which will remain constant under varying temperature, and which can be subjected to heavy electrical and mechanical loading.

Consider these features:

—Long life under the most unfavourable conditions.
—No shorting problems associated with filament deformation resulting from frequent switching and large mains voltage fluctuations.
—Robust filament structure reduces incidence of filament fracture.
—Filament voltage fluctuations of +5 and —10% allowed for most tubes in the range.
—"All glass" radiation cooled tubes, and forced-air cooled types, possess high anode thermal capacity enabling them to cope with short-term overloads and to allow intermittent* operation with high anode dissipation. (For water cooled types the maximum anode dissipation is already so high that overloading is very unlikely.)
—Large margin in grid dissipation owing to the use of the comparatively new "K"-material, specially developed for industrial applications. *Tube performance is no longer limited by grid dissipation.*
—*Additional advantages* obtainable using the *Philips Constant Power types* within the Industrial Oscillator Range (refer to final section of this article).

* Refer also to 2(f) above.

5. In so far as it is feasible, operate the tube according to the recommended "typical operation" conditions listed in the tube data.

This will help to ensure that operation is within the ratings, and will ensure an efficient operational condition. This is important in industrial applications, where testing facilities are usually quite limited. Furthermore, such standardisation usually allows faster fault diagnosis, or, for example, quicker determination of reasons for a low output power, etc.

To obtain full benefits of the Constant Power types, it is necessary to use the value of feedback factor specified. Thus, in such a case, operation according to the recommended conditions is then so much the more important.

SPECIFIC POINTS CONCERNING THE PHILIPS RANGE

1. Survey Chart and Advantages of DC Supply

An extensive survey chart has been included, which lists the complete range of Philips industrial oscillator tubes (Constant Power types have been clearly designated). It should be noted that only single-phase, full-wave rectification circuits have been included for the lower power types, whilst only three-phase rectification circuits have been included for the higher power range—for continuous operation in all cases. This choice of configurations has been dictated in part by space limitations and partly by the advantages accruing from their use.

In order to find the available power in the load, the value of the output given under "Operating Conditions" should be reduced by circuit losses and driving power.

2. Construction

(a) Cathode

Although much higher peak emissions can be obtained with oxide cathodes, and even higher with dispenser cathodes[6], there is no need for such high emissions in tubes designed for industrial oscillator applications.

Oxide-coated cathodes operate at a comparatively low temperature (1000-1200°K) which can be approached by the surrounding electrodes themselves. This is a basic drawback to their use. Furthermore, the heavy evaporation of barium contained in the cathode material can

SURVEY OF INDUSTRIAL

TYPE NUMBER ▶	TB 2.5/400	TB 3/750 (5867)	TB 4/1500 (Constant power tube)			TB 5/2500 (7092) (Constant power tube)				TBL 6/4000 (7753) (Constant power tube)	
Type of cooling	natural	natural	natural			natural				forced air	
Filament voltage (V)	6.3	5	5			6.3				6.3	
Filament current (A)	5.8	14.1	32.5			32.5				65	
MAXIMUM RATINGS (Absolute Maximum)	Single-phase, full-wave rectification (continuous operation)		Three-Phase Rectification Circuits (continuous operation)								
Frequency for full ratings (Mc/s)	150	100[1]	50			50				50	
Anode voltage (KV)	2.7[2]	2.7[2]	7			7				8	
Anode current (A)	0.180	0.360	0.560			0.750				1.0	
Anode dissipation (KW)	0.150	0.250	0.500			0.800				1.7	
Anode input power (KW)	0.512	0.975	2.5			4				7	
Negative grid bias (KV)	0.300	0.500	1.25			1.25				1.25	
Grid current (A):											
loaded	0.040	0.085	0.21			0.30				0.40	
unloaded			0.28			0.40				0.50	
Maximum grid bias Resistor (K Ω)	200	100	15			10				10	
OPERATING CONDITIONS	Single-phase, full-wave rectification (continuous operation)		Three-Phase Rectification Circuits (continuous operation)								
Frequency (Mc/s)	50	41	50			50				50	
Anode voltage (KV)	2[2]	2.25[2]	6	5	**4**	6	**5**	4	3	7	6
Anode current (A):											
loaded	0.170	0.340	0.350	0.430	**0.535**	0.600	**0.700**	0.700	0.700	0.9	0.9
unloaded	—	—	0.090	0.100	**0.150**	0.120	**0.150**	0.170	0.200	0.2	0.2
Grid bias resistor (K Ω)	3.75	3.33	4.2	3.5	**2.7**	3	**2.5**	2	1.5	2.5	2
Feedback (%)	—	—	15	15.5	**20**	13	**17**	20	25	15	16
Grid current (A):											
loaded	0.034	0.060	0.12	0.13	**0.15**	0.15	**0.16**	0.18	0.20	0.25	0.28
unloaded	—	—	0.18	0.20	**0.225**	0.26	**0.28**	0.30	0.34	0.30	0.35
Anode input power (KW)	0.420	0.935	2.1	2.15	**2.14**	3.6	**3.5**	2.8	2.1	6.3	5.4
Anode dissipation (KW)	0.120	0.250	0.460	0.480	**0.490**	0.760	**0.780**	0.640	0.540	1.45	1.3
Anode output power[3] (KW)	0.290	0.665	1.64	1.67	**1.65**	2.84	**2.72**	2.16	1.56	4.85	4.1
Driving Power	10 (W)	20 (W)	—	—	—	—	—	—	—	—	—
Load resistance (matched) (K Ω)	—	—	9	6.4	**3.8**	5.4	**3.8**	3.0	2.25	3.85	3.3
Tube plate efficiency (%)	69	71	78	77.5	**77**	79	**78**	77	74	77	76

[1] A maximum frequency of 150 Mc/s allowed, when max. permissible values of anode voltage and input power reduced to 1.8 K V and 0.65 K W respectively.

[2] Mean value.

[3] Makes no allowance for output circuit efficiency factor.

OSCILLATOR TUBE DATA

TBL (W) 7/8000 (6961 and 6960)	TBL (W) 7/9000 (Constant power tube)		TBL (W) 6/14 (7804 and 7805) (Constant power tube)		TBL (W) 12/25 (6618 and 6617)			TBL (W) 12/38 (7806 and 7807) (Constant power tube)			TBL (W) 12/100 (6078 and 6077)		
L—forced air W—water	L—forced air W—water		L—forced air W—water		L—Forced Air W—Water			L—Forced Air W—Water				L—Forced Air W—Water	
12.6	12.6		6.3		8			8				17.5	
33	33		130		98			130				196	
Three-Phase Rectification Circuits (continuous operation)													
55	50		30		30			30			4	15	30
7	8		8		13			13			15	13.5	12.5
1.8	1.8		4.0		4.8			5.0				12.5	
6	6		10 (L) 15 (W)		15 (L) 20 (W)			20 (L) 20 (W)				45 (L) 100 (W)	
11	12		30		60			60				165	
1.25	1.25		1.6		1.5			2.0				1.2	
0.50 0.70	0.40 0.50		1.5 2.0		0.80 —			1.5 2.0				3.5 —	
10	10		10		10			10				—	
Three-Phase Rectification Circuits (continuous operation)													
50	50		30		30			30				15	27.5
6	7.2	6.2	7	**6**	12	10	8	**12**	10	8		12	10
1.5 —	1.5 0.37	1.4 0.4	3.5 0.7	**3.3** **0.51**	3.2 0.52	3.2 0.50	3.2 0.48	**4.5** **0.65**	4.5 0.63	4.5 0.62		12 —	10 —
1	1.85	1.5	0.95	**1.0**	2.0	1.6	1.1	**1.1**	1.0	0.9		1000 V bias	800 V bias
—	17	17	25	**26**	16	17	19	**16**	19	24		(4)	(5)
0.40 —	0.36 0.47	0.37 0.47	0.95 1.35	**0.80** **1.10**	0.50 0.74	0.50 0.77	0.50 0.80	**0.90** **1.22**	0.90 1.30	0.90 1.35		2.25 —	2.0 —
9	10.8	8.68	24.5	**19.8**	38.4	32.0	25.6	**54**	45	36		144	100
2.7	3.3	2.5	6.8	**5.5**	9.4	8.7	7.7	**15**	13.7	12.8		36	25
6	7.55	6.16	17.7	**14.3**	29	23.3	17.9	**39**	31.3	23.2		108	75
300 (W)	—	—	—	**—**	—	—	—	**—**	—	—		3.5 (KW)	2.7 (KW)
—	2.3	2.1	1	**0.87**	1.8	1.45	1.10	**1.45**	1.10	0.8		—	—
67	70	71	72	**72**	75.5	72.5	70	**72.5**	70	64.5		75	75

(4) $V_{gp} = 1700$ V.

(5) $V_{gp} = 1500$ V

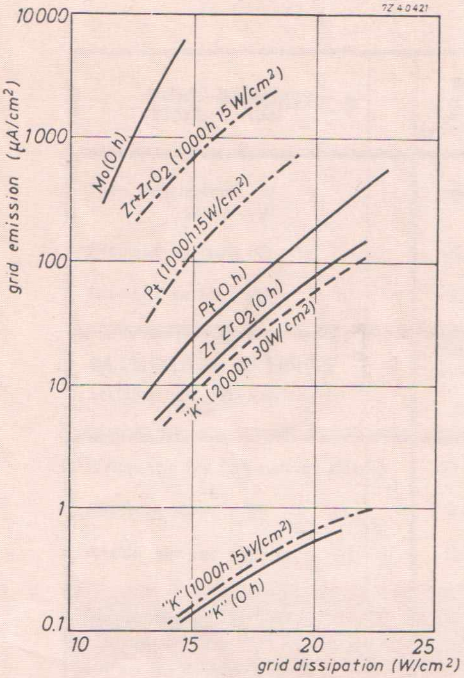

Fig. 1. Thermionic emission of different grid materials as a function of the grid dissipation. The K-material has a lower thermionic emission than other materials, which hardly changes after thousands of hours of operation.

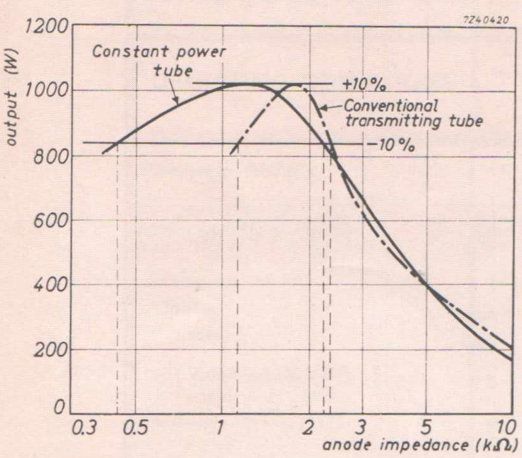

Fig. 2. The output power as a function of the load resistance for a conventional transmitting tube and for a "constant-power" triode.

cause the grid itself to become emissive, particularly when it is heavily loaded and therefore hot. Such grid emission can disturb the operation of the oscillator and shorten tube life.

On the other hand, thoriated-tungsten cathodes as used throughout the Philips range, operate at about 2000°K which is sufficiently higher than the temperature of the surrounding electrodes as to make back-heating negligible. Secondly, the evaporation of thorium (and tungsten) at 2000°K is very low compared with that from oxide or dispenser cathodes.

Additionally, in order to prevent deformation of the filament as a result of frequent switching and large mains-voltage fluctuations, the filaments of the Philips industrial oscillator tube range are made of fairly thick thoriated-tungsten wire of special composition and crystal structure. This has an additional advantage in that the amount of thorium stored in such a thick wire is large compared with the amount that is evaporated from the surface. Since ample filament power is used, sufficient emission is ensured during a long life.

(*b*) *Grid*

Even a very small amount of thorium deposited on the grid would give rise to troublesome thermionic emission. To avoid this, the grids of tubes in the Philips industrial oscillator range utilise the comparatively new "K"-material[5]. This can withstand very high temperatures for long periods, and its thermal emission is much lower than that of other materials, as demonstrated in Fig. 1. Furthermore, this low value remains constant after thousands of hours of operation.

With the use of "K"-material grids, the Philips range has the feature that the permissible grid input power is so high as to prevent it ever constituting a limitation with the correct circuit design. Furthermore, "K"-material is ductile and this, together with relatively large grid-to-cathode spacing, ensures a good mechanical safety margin. Its deformation even under intermittent loading is particularly small.

Actually, Philips have overcome the grid-loading problem, not by reducing the grid input power (which would require a high g_m, and hence small grid-to-cathode spacing), but instead by using a grid material capable of withstanding heavy electrical loading, in conjunction with a relatively large grid-to-cathode spacing.

(*c*) *Anode*

The radiation-cooled types have anodes consisting of a thick-walled block of graphite, sintered on to the surface of which is a coating of zirconium, which improves the heat radiation and has good gettering properties. The thermal capacity of such an anode is thus sufficient to permit both a controlled degree of intermittent loading (refer also to 2(f) of the first section of this article) and short-term overloads.

Types which are forced-air or water cooled have a copper anode which forms part of the envelope. Such anodes are very thick-walled, again providing high thermal capacity.

3. Constant Power Tubes

As stated above, additional advantages can be derived from the choice of a Philips Constant Power tube—refer to Fig. 2. With a load resistance variation of the order of 3 to 1, the power delivered by these tubes changes by no more than ±10%, provided they are operated according to recommendations.

The theoretical basis for these tubes has been established by Dorgelo[7], and it involves the design choice of optimum μ in conjunction with the low secondary emission exhibited by a "K"-material grid.

4. Tubes Outside Standard Industrial Range

Besides those tabulated, Philips can supply tubes to handle both lower and higher amounts of power. Such tubes have proved extremely reliable in industrial application and include types such as 833A and 810, details of which are available on application.

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Components

"Miniwatt"

PRINTED COIL TUNER TYPE NT 3011

This TV tuner is a slightly modified version of the original Printed Coil tuner type NT 3009[1]. It is mechanically identical to, and electrically interchangeable with, the latter and can be used as a direct replacement.

Modifications

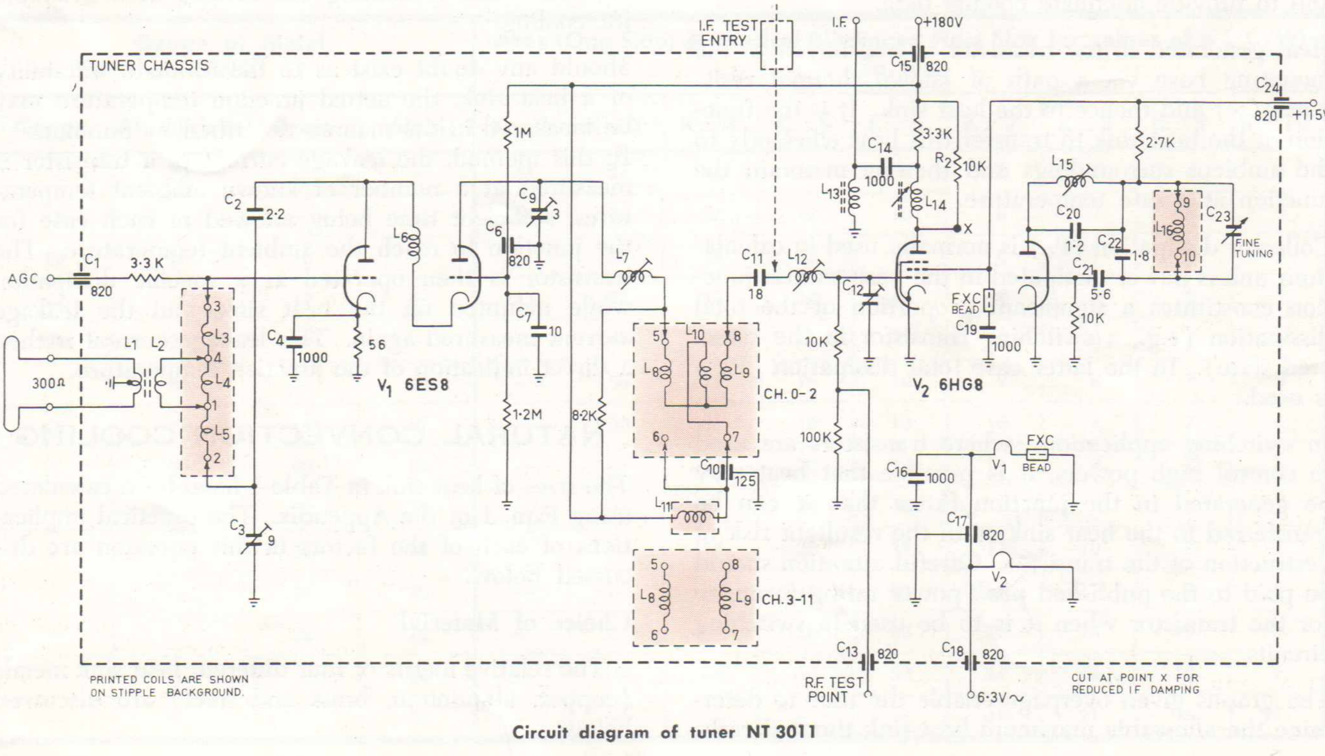
For fringe area TV reception it is necessary to use high-gain aerial structures, often consisting of a multiplicity of arrays. In many cases these do not match the input impedance of the tuner, resulting in mismatch at the RF amplifier input. The new tuner NT 3011 has a modified RF stage which is more tolerant to aerial mismatch, has higher image rejection and provides higher signal/noise ratio under conditions of fringe area reception. The modifications involve new coil strips, a different value of damping resistor at the RF input grid and a change in the cathode circuit of the input stage. The technical data of the NT 3011 are similar to those of the original Printed Coil Tuner type NT 3009[1]. The new coil strips are **not** interchangeable with those of the original tuner.

Markings on coil strips:

NT 3011	CZ O to CZ 11
NT 3009	AU O to AU 11

Reference:

1. Printed Coil Tuner, *Miniwatt Digest*, Vol. 1, No. 7, p. 102, April 1962.



Circuit diagram of tuner NT 3011

HEAT SINKS FOR POWER TRANSISTORS

To satisfy the need for clear and quickly interpreted information on permissible transistor dissipation, a series of graphs has been prepared for the present range of Miniwatt power transistors. Associated with these graphs are tables which will enable the rapid selection of a heat sink of sufficient size to maintain the transistor junction temperature within its permissible limit.

One of the most important of the published ratings by which a transistor is selected is the maximum permissible dissipation at a specified ambient temperature (T_{amb}). This dissipation rating is not always published directly, but is determined from the maximum permissible junction temperature (T_{jmax}) on which it is directly dependent. It is the aim of this discussion to provide a rapid means of selecting a transistor with a dissipation rating suitable for the job in hand and to provide adequate cooling data.

Heat generated in the transistor is transferred to the mounting base via a path of known thermal resistance (K) and thence to the heat sink. It is the function of the heat sink to transfer this heat efficiently to the ambient surroundings and thereby maintain the junction at a safe temperature.

Collector dissipation (P_C) is normally used in calculations unless power dissipated in the base-emitter junction constitutes a significant proportion of the total dissipation (e.g., a switching transistor in the saturated state). In the latter case total dissipation (P_{tot}) is used.

In switching applications, where transistors are used to control high powers, it is possible that heat may be generated in the junction faster than it can be transferred to the heat sink, with the resultant risk of destruction of the transistor. Careful attention should be paid to the published *peak* power rating formulae for the transistor when it is to be used in switching circuits.

The graphs given overpage enable the user to determine the allowable maximum heat-sink thermal resistance when dissipation and ambient temperature are known. If, for electrical reasons, it is necessary to insulate the transistor from the heat sink with a mica washer, a larger heat sink will be required for a given dissipation in order to compensate for the thermal resistance of the mica. Separate graphs have been drawn for this case. Care should be taken to ensure that the surface on which the transistor is to be mounted is reasonably flat: a lead washer or silicone grease will improve the thermal contact with the heat sink by helping to eliminate air pockets.

Knowing the thermal resistance of the heat sink, one may then select a suitable size by reference to either Table 1 or 3. In the calculation of these sizes the effect of radiation from the transistor case (which will improve the cooling) has been neglected.

Where the chassis of the equipment is used as a heat sink, due allowance must be made for all holes or cut-outs when estimating the surface area available for cooling.

Should any doubt exist as to the ultimate suitability of a heat sink, the actual junction temperature may be measured in the manner described by Simmons[1]. In this method, the leakage current of a transistor is measured at a number of known ambient temperatures, sufficient time being allowed in each case for the junction to reach the ambient temperature. The transistor is then operated at a specific dissipation while mounted on the heat sink, and the leakage current measured again. This leakage current is then a direct indication of the junction temperature.

NATURAL CONVECTION COOLING

The sizes of heat sink in Table 1 have been calculated using Eqn. 1 of the Appendix. The practical implications of each of the factors in this equation are discussed below.

Choice of Material

The relative merits of four different heat sink metals (copper, aluminium, brass and steel) are discussed below.

Copper has the highest thermal conductivity of the metals under consideration and will be used for heat sinks requiring low thermal resistance with minimum surface area in a light gauge of metal.

Use of a copper heat sink with a nickel plated transistor case minimizes the possibility of electrolytic corrosion between the two dissimilar metals in contact.

Aluminium has a high thermal conductivity combined with a light weight and low cost for given heat sink effectiveness. It will be the obvious choice for heat sinks of low thermal resistance where weight and cost are the prime considerations.

Brass will not normally be chosen unless its use is dictated by mechanical or electrical considerations.

Steel is the most suitable material where moderate values of thermal resistance and low cost are important. The most common application of steel will be where a transistor is mounted directly on to the equipment chassis as a heat sink.

Castings are frequently used as heat sinks. It should be noted that the thermal conductivity of a cast metal may not be as high as that of sheet metal due to the porosity of the material. This is normally offset by increased thickness of the casting.

Table 2 provides a comparison of typical heat sink materials. Costs are based on moderate quantities of material as would be used by manufacturers in quantity production.

Additional Information

2-AC128 Audio Amplifiers

Subsequent to the publication of Circuits Nos. 412 and 412/0.7 (Vol. 1, No. 12, and Vol. 2, No. 1), further investigation has shown that it is desirable in adverse circumstances to improve the stability margin. This can be achieved in a simple manner through introducing a phase lead by connecting a 390 pF capacitor in parallel with the 39 KΩ feedback resistor (R_{13}).

As can be seen from Table 1, neither the material nor thickness is particularly important for the smallest sizes of heat sink.

In addition to metals, a ceramic with good thermal conductivity has been used where an insulated heat sink was required[2].

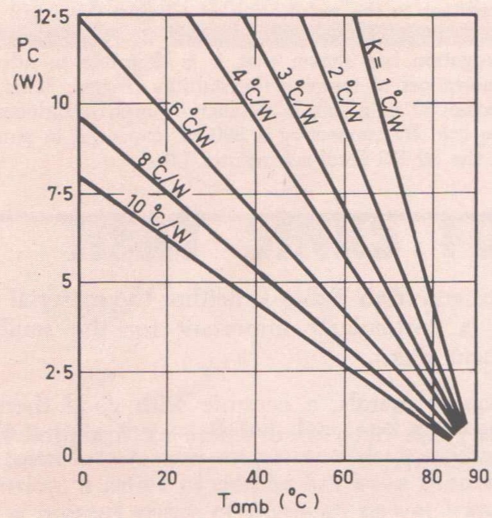
Table 2—Comparison of materials for a Heat Sink of Given Surface Area and Thermal Resistance

Metal	Rel. Cost	Rel. Wt.
Copper	2.1	2.1
Aluminium	1.0	1.0
Brass	6.4	7.4
Steel	1.8	13.4

Table 1 — Heat Sink Sizes for Natural Convection Cooling (both sides effective)

Gauge of Metal (SWG)				Area (One Side) of Vertical Blackened Heat Sink for values of K (°C/W) (Sq. Ins.)								
Copper	Aluminium	Brass	Steel	K=2	K=3	K=4	K=5	K=6	K=7	K=8	K=9	K=10
16	12	—	—	53	24	16	12	9	8	7	6	5
18	14	—	—	**64**	26	17	12	10	8	7	6	5
20	16	10	—	87	30	18	13	10	8	7	6	5
22	18	12	—	145	34	19	14	10	9	7	6	5
24	20	14	—	—	**44**	22	15	11	9	8	7	6
26	22	16	10	—	56	25	16	12	9	8	7	6
28	24	18	12	—	100	31	18	13	10	8	7	6
—	26	20	14	—	—	**38**	20	14	11	9	7	6
—	28	22	16	—	—	51	**24**	16	12	9	8	7
—	—	24	18	—	—	112	32	**19**	13	10	8	7
—	—	26	20	—	—	—	48	23	**15**	11	9	8
—	—	28	22	—	—	—	150	35	**20**	14	10	8
—	—	—	24	—	—	—	—	50	24	**16**	**12**	9
—	—	—	26	—	—	—	—	—	41	21	15	**11**

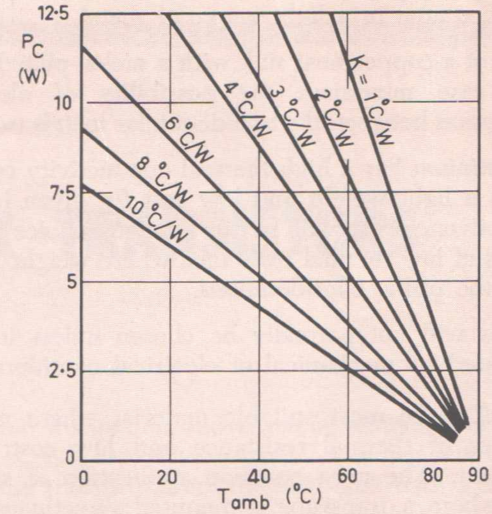
Maximum Permissible Thermal Resistance (K) of

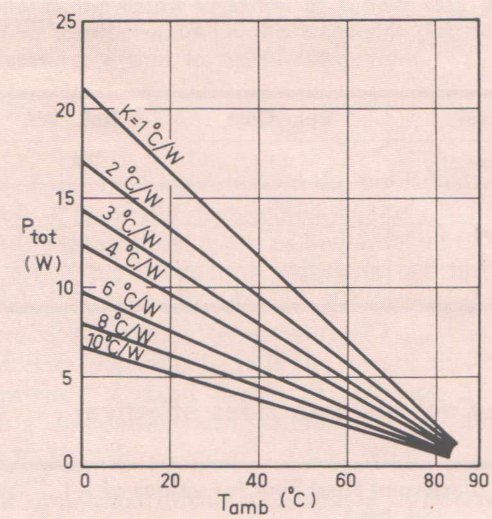


OC26

◀ without insulation

with mica and lead washers ▶

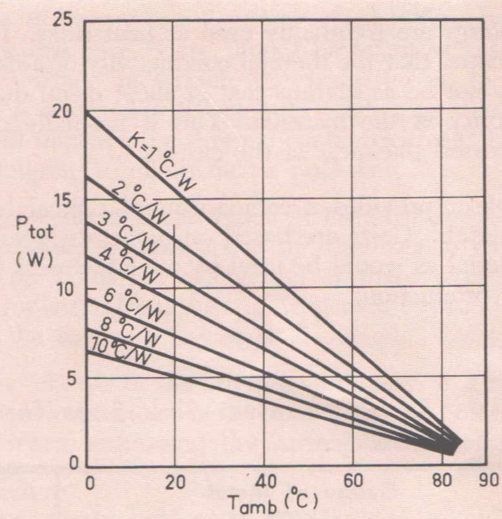


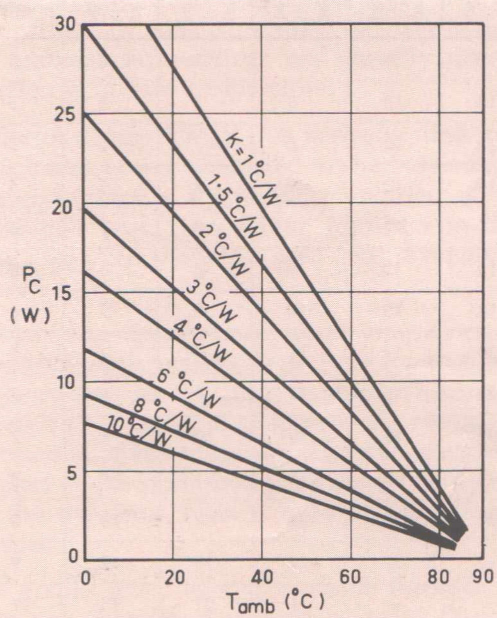


OC22-OC24

◀ without insulation

with mica and lead washers ▶

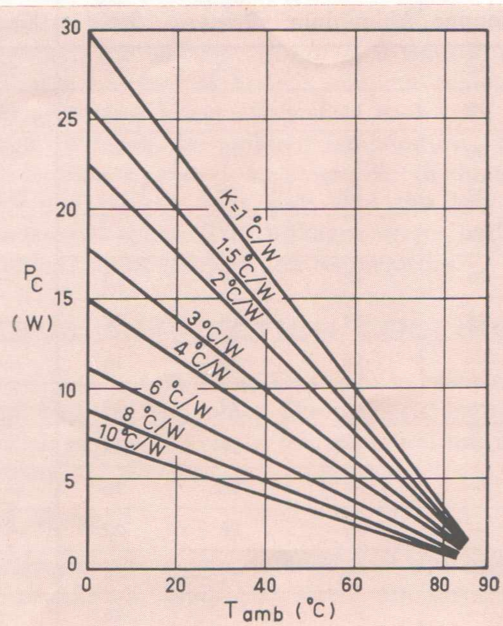


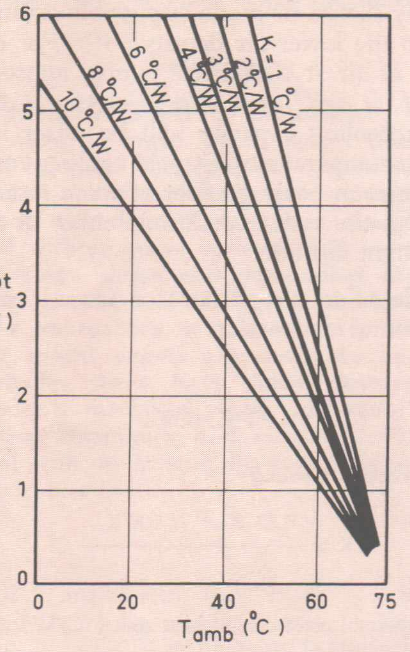


ASZ15-ASZ18

◀ without insulation

with mica washer ▶

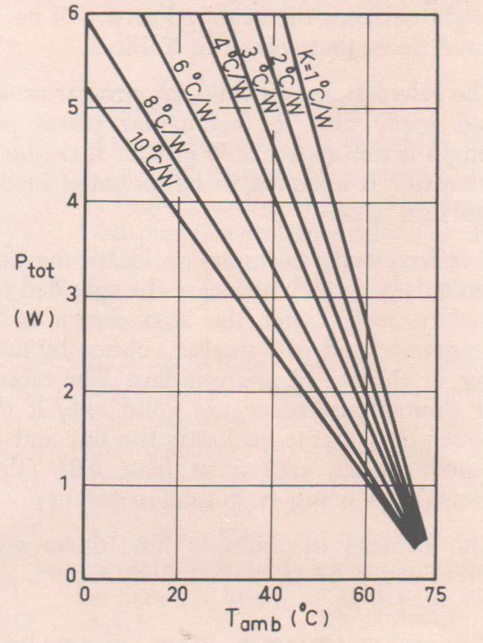




AUY10

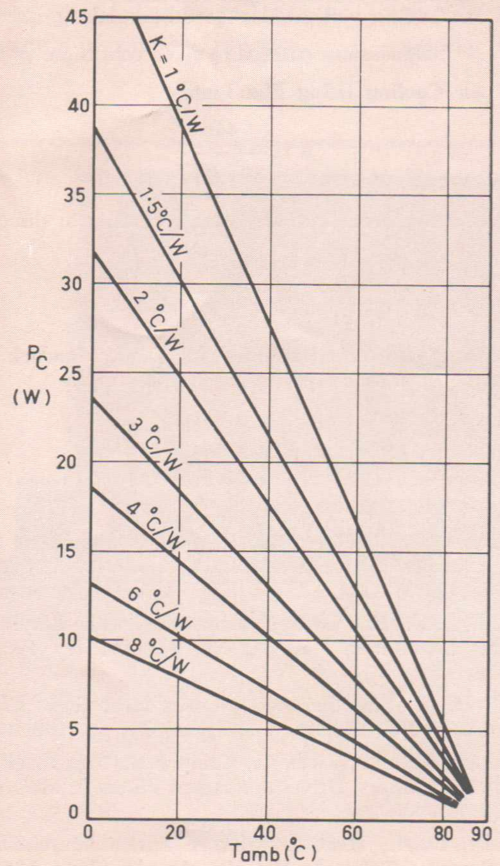
◀ without insulation

with mica and lead washers ▶



ADZ11 & ADZ12

without insulation



Surface Area and Thickness

If the smallest possible overall dimensions of heat sink are desired for a given thermal resistance it will be necessary to choose a heavy gauge of metal. As progressively lighter gauges of metal are used it will be seen from Table 1 that the required surface area increases until it reaches impractical proportions and finally increases towards infinity without any further improvement in cooling. Between these two extremes, for each value of thermal resistance, there is an optimum surface area which results in minimum volume and hence weight, of a given material. These values are printed in bold figures in the Table. The saving in weight is, of course, more significant for the heavier metals.

Surface Finish

A polished metal surface has a very poor emissivity, the best finish being a matt black paint (or anodising in the case of aluminium). The smaller the surface area, the more beneficial the effect of blackening. A matt paint finish of any colour is considerably better than a bright surface. Table 1 has been prepared on the basis of a blackened heat sink, but the thermal resistance of bright heat sinks may be calculated with the aid of Eqn. 1 of the Appendix.

Mounting Attitude and Shape of Heat Sink

Vertical mounting, with both sides of the heat sink exposed to convection, provides the best transfer of heat. All calculations have been made on the basis of such a vertical blackened heat sink, the tabulated area being that of one side only.

Thermal resistance of horizontal heat sinks may be calculated with the aid of Eqn. 1 of the Appendix. As a general rule it will be found that for horizontal bright surfaces the required area will be from two to three times that shown in Table 1.

The calculations are valid for circular or square plates and apply also to rectangular plates provided the length is not appreciably greater than the width. The transistor is assumed to be mounted in the centre of the heat sink.

It is frequently necessary to locate the heat sink in a limited space, in which case the specified *total* exposed surface area (twice the area shown in Table 1) is accommodated in a smaller volume by means of folding, or the use of multiple fins. The tabulated values of thermal resistance are valid *only* if the ratio between the volume enclosing the fins and the total exposed surface area is at least 0.24 (the heat sink dimensions being expressed in inches).

The benefits of multiple fins, ducts and "chimney effect" have been evaluated by Gill[3].

FORCED AIR COOLING

Without the use of forced air, values of thermal resistance below 2.0 °C/W are difficult to achieve using practical sizes of normally stocked gauges of sheet metal.

The sizes of heat sink listed in Table 3 are calculated for an air velocity of 1000 linear ft./min. For other air velocities the required area may be calculated using Eqn. 2 of the Appendix.

The cooling due to radiation and conduction, which is small compared with that due to forced convection, has been neglected entirely in the calculations. For this reason, the metal used and its thickness are of little importance, but obviously all the factors listed above which tend to improve the cooling in the case of natural convection will also help to increase the safety margin with forced convection.

Table 3—Flat Plate Heat Sink Sizes for Forced Air Cooling, both sides effective (using 1000 linear ft./min., parallel to depth)

Depth (ins.)	Width of Heat Sink (ins.)		
	K=1.0	K=1.5	K=2.0
6	$5\frac{3}{4}$	$3\frac{7}{8}$	$2\frac{7}{8}$
5	$6\frac{3}{8}$	$4\frac{1}{4}$	$3\frac{1}{4}$
4	7	$4\frac{5}{8}$	$3\frac{1}{2}$
3	$8\frac{1}{8}$	$5\frac{1}{2}$	$4\frac{1}{8}$
2	10	$6\frac{5}{8}$	5

OPERATION AT HIGH ALTITUDES

When equipment is to be used at high altitudes, a special study should be made of possible cooling problems due to the lower air density[4][5]. For example, the density of air at 40,000 feet is only approximately 50% of that at sea level. To a certain extent this decrease in cooling capacity will be offset by a decrease in air temperature. Typical cooling curves will show a maximum cooling effect at some intermediate altitude, with the worst conditions either at sea level or at maximum altitude.

The altitude effect is greater for forced convection than for natural convection.

APPENDIX

Natural Convection Cooling

$$K = \frac{6.55\ K_{er}^{\frac{1}{4}}}{(\lambda\epsilon)^{\frac{1}{2}}} + \frac{100\ K_{er}}{S} \quad \ldots\ldots\ldots\ldots (1)$$

Where K = thermal resistance of heat sink (°C/W)
ϵ = thickness of material (ins.)
S = surface area of heat sink (one side) (sq. ins.) (N.B.: both sides being effective)
λ* = 380 for copper
= 210 for aluminium
= 110 for brass
= 46 for steel
K_{er}* = 1.0 for horizontal bright heat sink
= 0.5 for horizontal blackened heat sink
= 0.85 for vertical bright heat sink.
= 0.45 for vertical blackened heat sink

* Dimensions omitted to avoid confusion.

Forced Air Cooling Using Flat Plate

$$K = \frac{446}{W\sqrt{DV}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where D = depth of heat sink (ins.) parallel to direction of air flow
W = width of heat sink (ins.)
V = velocity of air (linear ft./min.)

(This survey has been compiled by D. J. Hancock of the "Miniwatt" Electronic Applications Laboratory.)

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2. McPhee, K. H., Cooling Transistors with Beryllia Heat Sinks, *Electronics,* Vol. 34, No.18 (5th May 1961), pp. 76-78.
3. Gill, H., Getting the Most from a Heat Sink, *Electronic Industries,* Vol. 21, No. 8 (Aug. 1962), pp. 100-103.
4. Henney, K., and Walsh, C., Components Handbook, Vol. 2 (Ch. 7, "Blowers, Drive Motors and Filters"), McGraw-Hill, 1958.
5. Drake, D. T., Heat Transfer in Subminiature Electronic Equipment, *Teletech,* Vol. 12, No. 6 (June 1953), pp. 111-113.

AIDS FOR TEACHING ELECTRONICS

Education is essentially progressive. At present we are witnesses to major changes which reflect both the increasing tempo of technological development generally, with electronics in particular, and the present state of world prosperity. With greater school attendance figures than at any previous period in history, and with so many undeveloped countries of the world reaching sovereign status and demanding accelerated development, the acute shortage of teachers is world-wide. In the circumstances, new approaches to educational problems must be studied and one might expect electronics to be exploited in this respect. Already, there have been developed electronically-operated teaching machines which are severally capable of presenting tuition, examining and assessing. This present articles does not deal with devices of this type, but with aids for the teaching of electronics itself.

"Miniwatt" announces the availability of teaching aids in two categories:

1. Equipment for electronic training.

2. Coloured film strips dealing with a range of electronic subjects, illumination and fundamentals of nuclear physics.

ELECTRONIC TRAINERS

These consist of assemblies comprising a pre-wired framework with regulated power supply and capable of accommodating up to ten pre-wired display-size electronic panels. The larger model is provided with ample bench and storage space and is intended for the use of the instructor, while the smaller size is for student use.

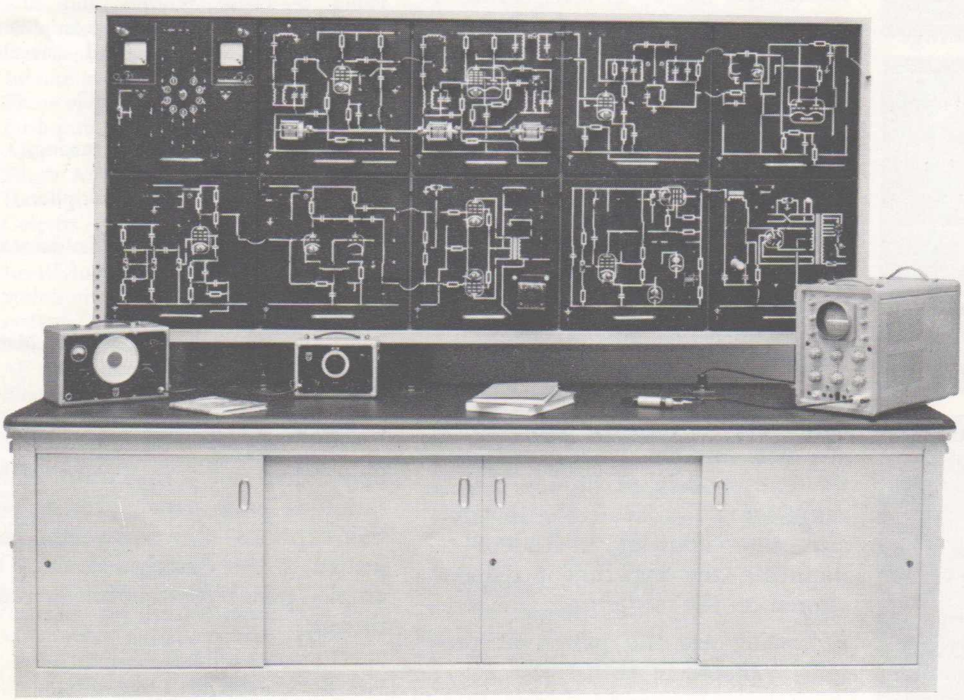
Trainer for Class Display

This larger model is shown in Fig. 1(a). It consists of a cabinet and a frame capable of accepting up to ten panels simultaneously. The display frame may be raised or lowered to suit the needs of the occasion.

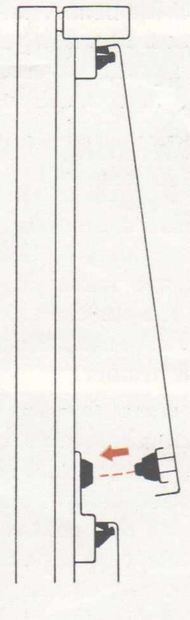
The individual panels, of which there are 17 currently available, can be fitted or removed easily and rapidly. Nevertheless, they are held securely and cannot be dislodged accidentally by knocks or vibration. The main electrical connections are made automatically as a panel is fitted, as shown in Fig. 1(b).

Approximate overall dimensions of this trainer are 78″ high × 104″ wide × 26″ deep.

The cabinet is fitted with wheels and has provision for extra bench space in the form of hinged side flaps which, when raised, increase the overall width to 140″.

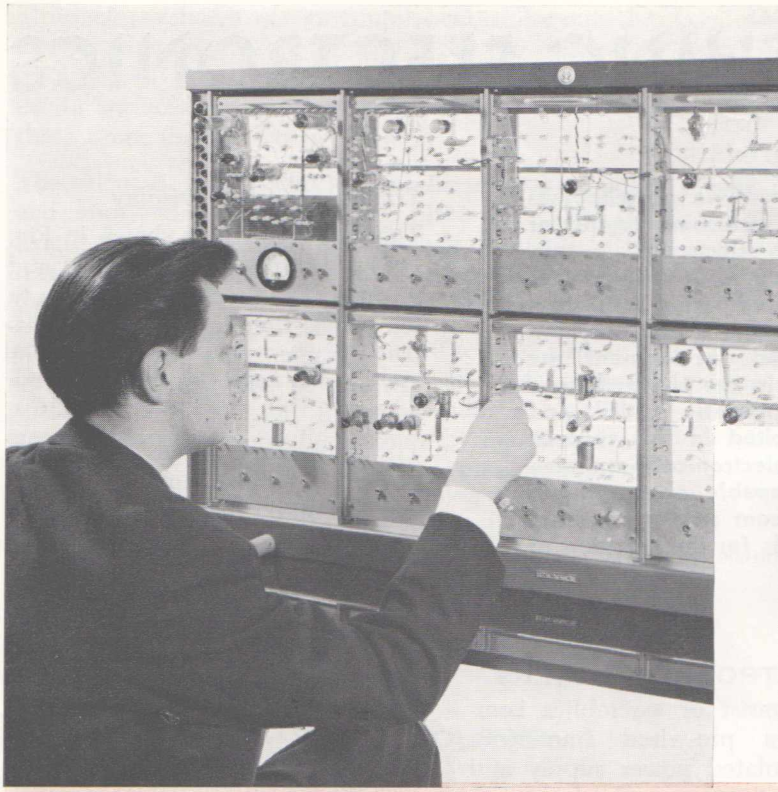


(a) Cabinet and display frame.



(b) Method of inserting a panel, showing electrical connections.

Fig. 1. Electronic trainer for class instruction.



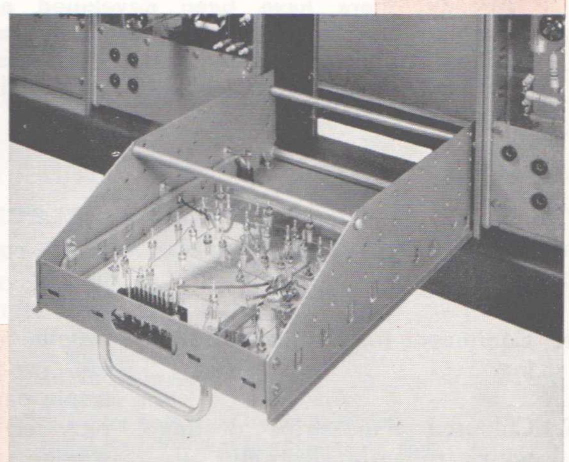


Fig. 2. Trainer for students' use.

▲ (a) Framework complete with panels.

(b) A panel lowered to show method of connection. ▶

Student Trainers

This model is shown in Fig. 2(a). It is somewhat smaller than the class display unit and is not provided with bench, table or storage amenities. Fig. 2(b) shows a close-up of a panel lowered to show the method of connection.

Panels Available

Some 17 panels are available as described hereunder, while more will be added in the future. The panels are made in two sizes—a larger one for the class trainer and a smaller cheaper model for the student trainer.

The panels for the class trainer have circuits drawn on their faces as can be seen in Fig. 1(a). Certain active components are removable from the front, while many of the passive components may be changed by means of plug and socket connections. For this purpose, the component is built into a relatively large housing which is printed on the face to simulate the circuit diagram and be readily identifiable to a large class. Fig. 3 shows a typical component assembly.

The panels for the student trainer are smaller and cheaper than the class trainer type, but are equally functional and robust. A typical panel is shown in Fig. 2(b). As can be seen, all active and passive components are removable, but the latter are not housed in assemblies as with the larger model. Not only are the components in full view, but the *wiring panel is transparent,* allowing easy tracing of the circuit.

Although, obviously, the panels are not interchangeable between the two models of trainer, a full range of 17 is available in each size, thus allowing a student to duplicate any experiment demonstrated on the larger unit.

Following are the panels at present available in both sizes:

Panel 1—Measurement of Valve Characteristics.
Panel 2—Rectification.
Panel 3—Stabilisation with valves.
Panel 4—Audio frequency power amplifiers.
Panel 5—Phase splitters and miscellaneous AF voltage amplifiers.
Panel 6—Pre-amplifiers and correction filters.
Panel 7—Detection and AVC.
Panel 8—IF amplifier.
Panel 9—Superheterodyne mixing, tracking, etc.
Panel 10—RF amplifiers, multipliers, counters, etc.
Panel 11—Demonstration of fundamental electrical laws, etc.
Panel 12—Multivibrators.
Panel 13—RF oscillators.
Panel 14—Various amplifiers, oscillators and generators.
Panel 15—RF power amplifiers.
Panel 16—Transistor circuits III.
Panel 17—Transistor circuits II & I.

Space does not permit a full elaboration of each panel, even though the captions above do less than justice to the description. For example, panel 10 description reads in full:

(a) RF pre-amplifier.
(b) Buffer stage for a transmitter.
(c) Frequency multiplier.
(d) Transitron oscillator.

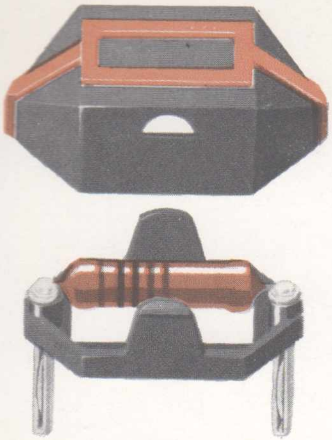


Fig. 3. Typical plug-in component assembly for passive elements of class trainer.

(e) Transitron Miller integrator.
(f) Phantastron.
(g) AF R-C amplifier.
(h) Limiter.
(i) Anode-bend detector.
(j) Grid-leak detector.
(k) Infinite impedance detector.
(l) Video amplifier.
(m) Step counter.

Following is a survey of circuits possible with the whole 17 panels:

1. AF triode amplifier.
2. AF pentode amplifier.
3. RF amplifier.
4. IF amplifier with bandpass filter.
5. Mixing circuit (multiplicative).
6. Mixing circuit (additive).
7. Diode detector.
8. AVC and tuning indicator.
9. Anode-bend detector.
10. Grid-leak detector.
11. Infinite impedance detector.
12. Phase splitter circuits.
13. Push-pull power amplifier, Class A, AB and B.
14. Single AF power amplifier.
15. Hartley oscillator.
16. Colpitts oscillator.
17. Crystal oscillator.
18. Rectifying circuits.
19. Stabilisation of voltages, different systems.
20. Tube measurements.
21. AF oscillators.
22. Blocking oscillator.
23. Multivibrator, cathode-coupled.
24. Multivibrator, anode-coupled.
25. Multivibrator, astable, monostable and bistable.
26. Phantastron.
27. Schmitt-trigger.
28. Cathode followers.
29. Grounded-grid amplifier.
30. Reactance-tube modulator.
31. Saw-tooth generator (vacuum tube).
32. Saw-tooth generator (thyratron).
33. Voltage doubler.
34. Negative power supply.
35. RF power amplifier.
36. Frequency multiplier.
37. Frequency dividers (step counter).
38. Modulator (for AM signals).
39. Video amplifier.
40. Eccles-Jordan circuit.
41. Bridge circuits.
42. Low-pass, band-pass and high-pass filters.
43. Differentiator and integrator circuits.
44. Demonstration of electrical laws, such as Ohm, Kirchhoff, Thevenin, etc.
45. Resonance circuits.
46. Limiters, diode, triode, pentode.
47. Neon tube, saw-tooth generator.
48. Differential amplifier.
49. Transitron-Miller integrator.
50. Investigation of VDR and NTC resistors.
51. Transitron.
52. Ringing oscillator.
53. RC & RL circuits.
54. Discriminator circuits.
55. Direct voltage amplifier.
56. Electronic relays.
57. Measurement of transistor characteristics.
58. Common base amplifier.
59. Common emitter amplifier.
60. Common collector amplifier.
61. Small-signal amplifier with transistors.
62. Emitter-follower and phase-splitter circuits.
63. Small-signal amplifier with transformer coupling.
64. Hartley oscillator with transistors.
65. Colpitts oscillator with transistors.
66. Crystal oscillator with transistors.
67. Schmitt trigger with transistors.
68. Multivibrator astable, monostable and bistable with transistors.
69. Blocking oscillator with transistors.
70. RC oscillator with AF transistor.
71. Investigation of thermal stability of transistors.
72. Single power amplifier circuits with transistors.
73. Push-pull power amplifier circuits (class A, AB, etc.) with transistors.

All panels are supplied complete with any valves, semiconductors, etc., essential for their functioning.

FILM STRIPS

Film strips in colour are available with the following titles:

1. Classification of Electron Tubes.
2. The Diode.
3. The Triode.
4. The Cathode-Ray Tube.
5. Photo Emission.
6. The TV Picture Tube.
7. Luminescence of Gases and Solids.
8. Introduction to Nuclear Physics.
9. The Tetrode-Pentode.
10. The Gas-Filled Diode.
11. The Thyratron.
12. The Ignitron.
13. The Crystal Diode—Part 1.

Fig. 4 shows black-and-white reproductions of typical frames in film strips. The originals, of course, are much more impressive, being in colour.

Explanatory Booklets

Each film strip is accompanied by an explanatory book, in which each frame—reproduced in colour—is discussed to convey to the teacher a succinct explanation of the main points and intention behind it. These booklets are supplementary only, and in no way are they intended to eliminate a suitable exposition by the teacher.

CONCLUSION

It is believed that the offers made in the foregoing represent distinct aids to the more efficient teaching of electronics. The "Miniwatt" Electronics Division would be glad to discuss further details with interested parties.

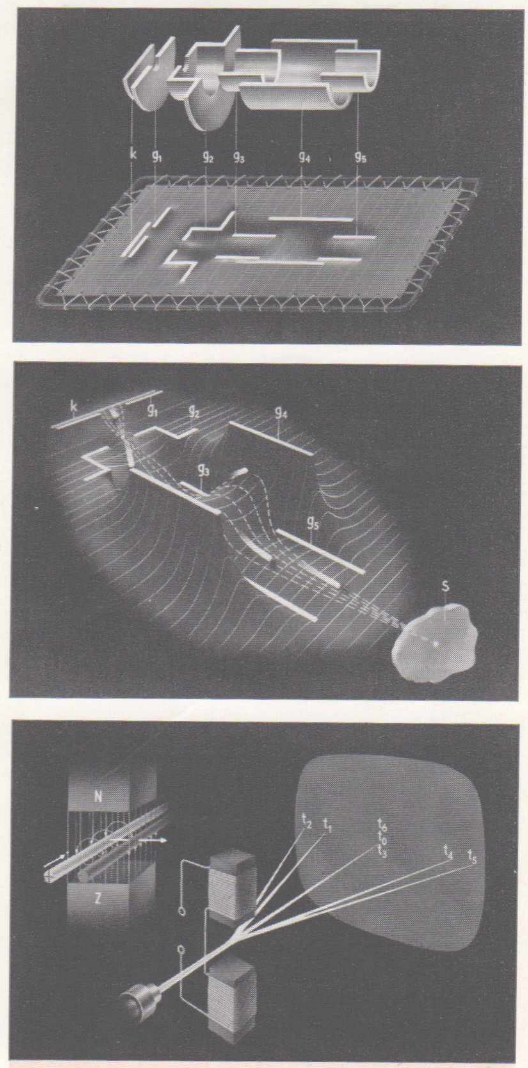


Fig. 4. Typical frames from film strip on TV picture tubes.

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- ELECTRONIC VALVES AND TUBES
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- CATHODE-RAY TUBES
- LIGHT-SENSITIVE DEVICES
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