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The Weston VAMISTOR®

Ruggedization—Another Weston First in Exposure Meters

"Westonia"

John Parker, Editor

W. A. Graham, Technical Editor

WESTON ELECTRICAL INSTRUMENT CORP.,
A Subsidiary of Daystrom, Incorporated,
614 Frelinghuysen Avenue,
Newark 5, N. J., U. S. A.

THE WESTON VAMISTOR®

A Thermally Fused Metal-to-Ceramic Precision Resistor

Introduction

DURING the last decade, there has been a strong trend toward miniaturization of components. In most cases, the changes have been directed toward considerably improving performance under increasingly arduous environmental operating conditions. In the case of precision resistors, this has been especially true during the last four years.

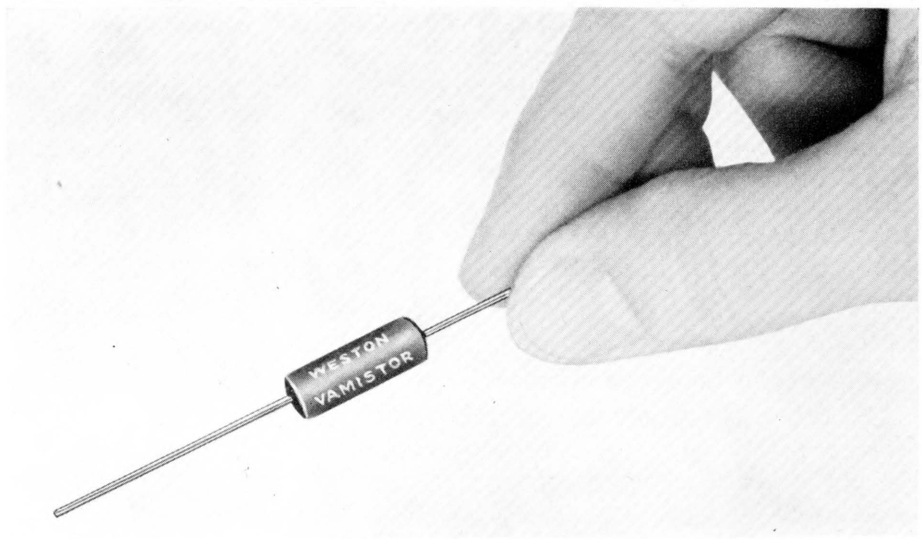


Figure 1—The Weston Vamistor.

The field of precision resistors is virtually completely dominated by the wire-wound resistor. This unit has the advantages of high precision of adjustment, good stability and low reproducible temperature coefficient of resistance. Inevitably, however, something still remains to be desired. During World War II, many periods of critical procurement occurred with respect to nickel and chromium. These shortages were difficult to overcome then, but other more major obstacles are currently being met in producing and using high-precision high-stability resistors. Due to difficulties in wire drawing and handling, the wire has a definite minimum diameter. This can cause the finished resistor to be somewhat bulky when high values of resistance are required. By the nature of wire winding too, considerable inductance and mutual capacitance exists between layers. For this reason, the wire-wound resistor has been limited to d-c or very low frequency a-c usage.

World War II and its aftermath saw increasing use made of film resistors; i.e., pyrolytically deposited carbon, boron carbon and latterly by metal film resistors. These types have considerable advantages over wire-wound spools in high-frequency a-c usage and small volume design, but considerable disadvantages in precision of adjustment, long term stability and low reproducible temperature coefficient.

This paper deals with the characteristics of a precision resistor to be offered under the registered trade name "VAMISTOR."

Description and Construction of the Vamistor

The Vamistor, currently under production at the Weston Electrical Instrument Corporation, Newark, New Jersey, has the conventional external appearance of an insulated film resistor and is shown in Figure 1.

The resistive unit consists of a cylindrical ceramic tube with a conducting band of silver fired on each end of the cylinder. These bands extend $\frac{1}{16}$ of an inch inside the tube's internal surface, over the annular surface at each end, and for $\frac{3}{16}$ of an inch on the external surface, and have an extremely tenacious bond to the ceramic cylinder.

The internal surface of the cylinder is prepared with a high-temperature fired glaze coating, and the resistive element proper is deposited on the internal surface between the two conducting silver bands. The resistive film is prepared from a highly refined and carefully controlled alloy of the nickel chromium family and after deposition of the film on the internal surface, a firing treatment is given to disperse the deposited film evenly throughout the body of the glaze. Although using nickel chrome alloy of the same family as that of the wirewound resistor, the bulk requirement for volume production is a great deal less, since many tens of thousands of Vamistors can be made from a single pound of material. This fact can be of very considerable importance during periods of critical procurement. Since the glaze coat is of the order of 0.002 of an inch thick, the resultant resistive coat now assumes many of the desirable properties of the "volume type" resistor. These desirable properties include high physical strength and toughness for the resistive coat as opposed to the usual fragility of most deposited metal films, which are usually of elemental thickness. Nevertheless, the thickness of the film is still small enough to give low skin effect phenomena at high radio frequencies, i.e., the Vamistor film has performance virtually identical with current film resistors. Adjustment of resistance of the dispersed film is made, as in film resistors, by cutting a groove in the form of an internal helix until the desired value of final resistance is obtained. Conventional end caps and leads are then pressed over the end of the cylindrical tube and the whole assembly is molded into an epoxy resin shell. This encapsulation is, of course, designed to secure the advantages of an insulated resistor, good for the usual V block test of 900 V rms for one minute, but additionally the unit is converted into a form virtually impervious to weather, humidity and salt spray conditions. This insulating covering is sufficiently thin to allow the unit to dissipate its full wattage rating without undue internal rise in temperature, but is also sufficiently thick to reduce the heat flow to satisfactory proportions under severe thermal shock conditions. Inspection of Figure 2 shows these various elements in a view of a cut section through a Vamistor.

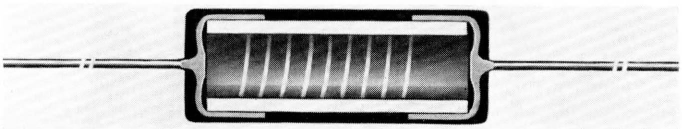


Figure 2—Sectional View of the Weston Vamistor.

Specifications and Performance

The design specification for the Vamistor is shown in Table 1. It should be emphasized that this specification does not spell out the limitations of the Vamistor, rather it represents a standard which can be realized at this time. It will be realized that for any design of equipment, two conditions will be encountered. Firstly, a design specification which will enumerate the limits which must not be exceeded, i.e., an inspection feature, and secondly, specifications of typical performance. In very many respects, the actual performance of the Vamistor far surpasses its design

TABLE 1—SPECIFICATION FOR WESTON VAMISTOR MODEL 9851

Characteristic	List	Requirement	Characteristic	List	Requirement
Resistance	Minimum (Ohms) Maximum (Megohms)	1,000 0.1	Moisture Resistance	Method 106, MIL-STD-202	½% Max.
Power Rating (Watts)	85° C Ambient Derates to Zero	½ Watt 150° C	Salt Water Immersion	0° C to +85° C 5 Cycles	½% Max.
Accuracy		1% or 5%	Effect of Solder	350° C Solder 3 Sec.	½% Max.
Temperature	Coef. (ppm/°C)	+50 Max. +25 Max. (Selected)	Insulation Resistance	V-Block 100 V. D-c	100 Megohms
Short Time Overload	2.5 Times—10 Min.	½% Max.	Dielectric Strength	V-Block 900 V. RMS 1 Min.	.05% Max.
Load Life	500 Hours 85° C	¾% Max.	Terminal Strength	5 Lb. Pull Test	½%
Temperature Cycle	−55° C to +85° C 5 Cycles	0.2% Max.	Physical Size	Body Length	¾ ± ⅛
Low Temperature	−65° C 24 Hrs.	½% Max.		Body Diameter	$\frac{5}{16} \pm \frac{1}{32}$

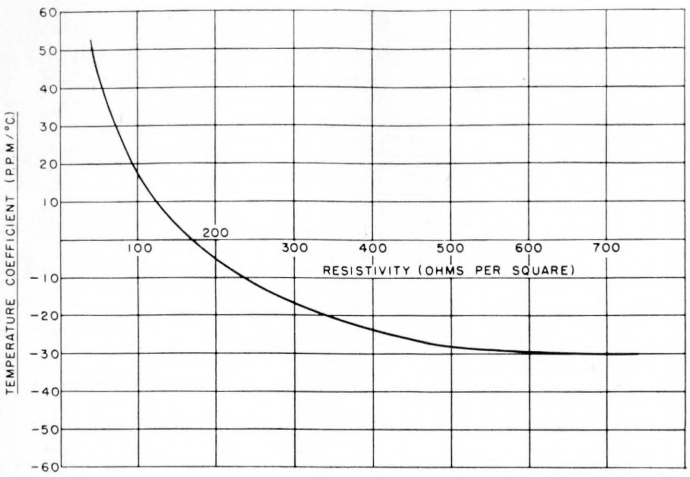


Figure 3—Resistivity Versus Temperature Coefficient.

and 0.1 megohm, respectively, at present.

Power Rating and Load Life

The current specification lists 85° C as the highest ambient temperature for full load dissipation. Latest results, however, indicate 105° C for this temperature as in Figure 4. The final ability of the unit to dissipate heat has proved most difficult to determine, e.g., a ½-watt unit has had no load applied at 170° C for 50 hours then 2 cycles of 0-150° at load and then double load, i.e., 1 watt in a 1,000-hour cycling load test at 70° C with one resulting failure out of twelve resistors (failure during this very severe test being defined as drift greater than 1%). With the intention of using the unit as a precision and not a power resistor, it is probable that a good deal of further testing will be required before the final limits can be firmly established.

Comparison of Vamistor Specification With Military Specification: Requirements

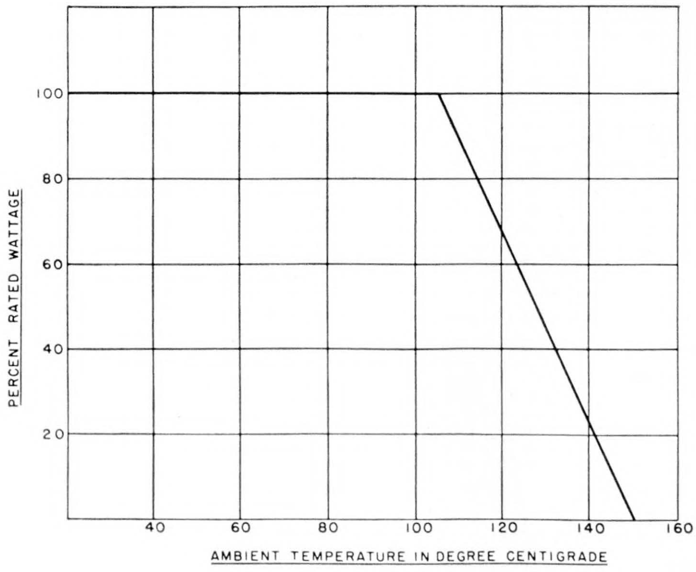
An index of quality of performance of a precision resistor can certainly be gained by study of its design specification relative to present military specification requirements. It is rather difficult to fully analyze such data in simple form since details of individual tests must

specification and comments will be made under their appropriate headings.

Resistance—Range and Temperature Coefficient

The deposited metal film can be deposited within the range 50-600 ohms per square. This has been found to give temperature coefficients of resistance within the range ±50 parts per million per degree centigrade. This resulting temperature coefficient of resistance is the sum of several effects. The inherent temperature coefficient of resistance of the metal alloy deposited is of positive magnitude. This metal is dispersed throughout the glaze film under a compressive stress at room temperature due to the relative thermal coefficients of expansion of the ceramic cylinder, glaze and metal film. As the ambient temperature rises, this stress level falls and acts in such a direction to reduce the resistivity of the film, i.e., the stress effect acts as a negative temperature coefficient of resistance. The over-all temperature coefficient of resistance is then the sum of these effects. This can be quite clearly seen in Figure 3, which shows how it is possible to have a negative temperature coefficient with a metal alloy. As the metal film's deposited thickness decreases, i.e., higher resistivity, the stress effect is larger and the over-all temperature coefficient goes negative. Conversely, as the film's thickness increases, the positive temperature coefficient of the metal plays an increasing effect in determining the final temperature coefficient. Units from the Pilot Plant are normally available in the ±50 ppm/°C range, but it will be seen from Figure 3 that if the metal film is deposited in the range 100-300 ohms per square, a resistor is obtained with temperature coefficients within the range ±25 ppm/°C. Control of the deposit in the Pilot Plant study has shown this reduced temperature coefficient possible and it is entirely probable that the specification will include this as a standard rather than a selected type in the near future. Deposition of the film is being limited to the range 100-300 ohms per square (see Figure 3) for this reason and as a result minimum and maximum values of the spiralled resistor are limited to 1,000 ohms

Figure 4—Derating Curve.



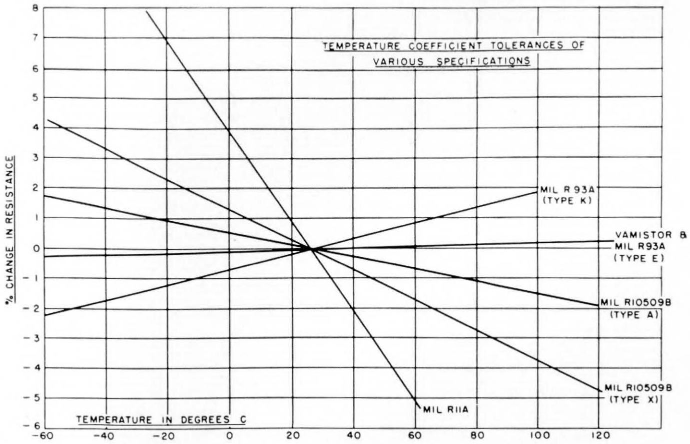


Figure 5—Per Cent Change in Resistance With Temperature.

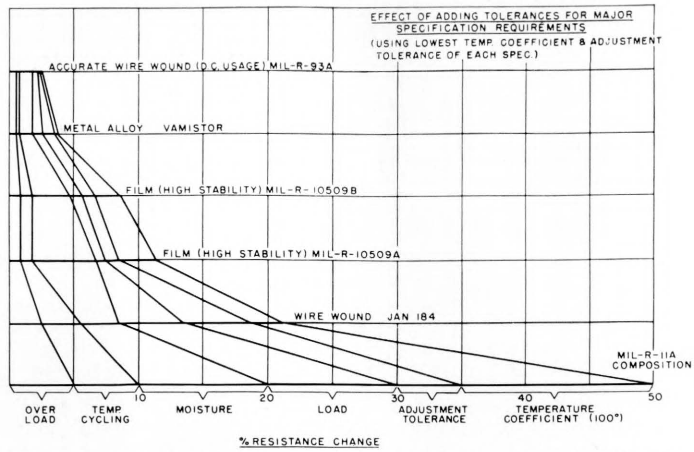


Figure 6—Total Per Cent Resistance Change Due to Major Specification Requirements.

be fully studied from their appropriate specifications. An attempt, however, has been made in Table 2 to list the specification requirements of the Vamistor specification, the accurate wire-wound specification MIL-R-93A and the film (high stability) specifications MIL-R-10509A and MIL-R-10509B. In each case, comparable sized resistors have been selected and their appropriate style numbers designated.

Specifications by themselves tend to serve as more of a basis for inspection of the maximum possible resistance changes of a given resistor under set conditions rather than demonstrating to a components engineer what are the limitations in use of a particular unit. Temperature coefficient, in particular, gives little appreciation of its true effect when stated in terms of numbers. Figure 5 shows what happens to the over-all value of the resistor with change in ambient temperature for various specification requirements. It will be seen that even for an 80° C variation, a composition resistor will change some 12% in resistance compared with 0.25% for a Vamistor. Inspection of Figure 5 often comes as something of a shock to a components engineer who buys a 1% tolerance resistor and unexpectedly realizes it could change 12% in the temperature range from −20° C to +60° C.

Temperature coefficient, however, is but one part of the change that may be expected to take place in the value of a resistor. Other departures from a stated resistance value can be caused by overload, temperature cycling, moisture, load and adjustment tolerance. Many additional factors may contribute, but the above represents a very large percentage of possible causes of change. It would, of course, be wholly unlikely in any given installation that the maximum percentage changes from all causes would be strictly additive. The question, then, of how much the value of a resistor could change would only be found by extensive statistical checks for the given installation. Nevertheless, information of considerable value may be obtained by adding together all the allowable major percentage changes in resistance that can occur in the various specifications. This has been done in Table 3 and the results are shown graphically in Figure 6. This chart shows, quite clearly, the steady decrease in the permissible percentage changes that occur with increase in the quality rating required by the specification and this figure can, in many ways, serve for determining an index of quality by locating the position of a given design specification in its correct place relative to existing military specifications.

On this basis, it will be seen that the Vamistor specification is superior in all respects to the performance requirements of MIL-R-10509B, MIL-R-10509A, JAN-184, MIL-R-11A and inferior to that of MIL-R-93A. Closer inspection of the Vamistor design specification versus MIL-R-93A reveals that the major difference is caused by the accuracy of adjustment 0.1% for MIL-R-93A compared to 1% for the Vamistor. It will be recalled that MIL-R-93A specification does include a range of adjustment tolerance from 0.1 to 1%, but the above comparisons were made on the basis of the highest quality unit in each specification. Under this condition, however, the MIL-R-93A Style RB-52 will be dissipating only 1/8 watt

Figure 7—Comparison of Average Resistance Per Cent Change With MIL-R-93A Limits.

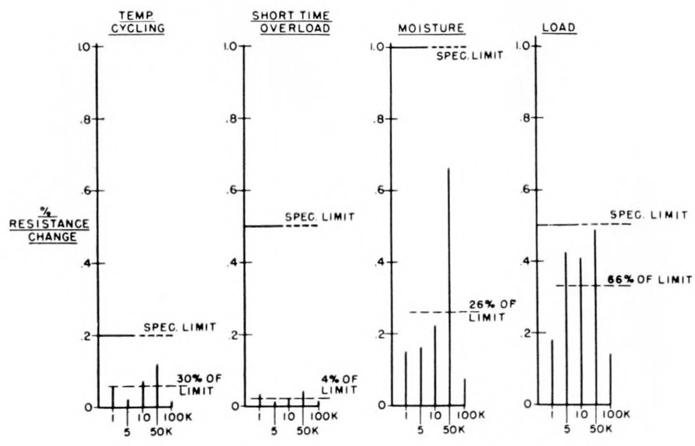


TABLE 2—SPECIFICATION REQUIREMENTS FOR PRECISION TYPE RESISTORS

Characteristic	Vamistor Model 9851	Wire Wound MIL-R-93A Style RB 52	Film MIL-R-10509A Style RN 25	Film MIL-R-10509B Style RN 70
Size in.	L .760—.800 D .285—.305	L .718—1.093 D .218— .531	L .875—1.00 D .265— .328	L .687—.843 D .218—.281
Power Rating Watts	½ (85° C)	¼ (85° C)	½ (80° C)	½ (70° C)
Resistance Minimum	1,000 Ohms	.1 Ohm	100 Ohms	10 Ohms
Maximum	.12 M Ohm	.12 M Ohm	4.92 M Ohms	.1 M Ohm (A), 5 M Ohms (B)
Tolerance %	1—5	0.1—1	1, 2, 5	1 and 5
Temperature Coefficient (ppm/°C)	±25 selected ±50 standard	±22 (Sym. E) −40 to ±155 (Sym. J) −50 to ±255 (Sym. K)	300 (Sym. R) 500 (Sym. X)	200 (Sym. A) 500 (Sym. B)
Load Life (% Change)				
1,000 hrs. at 40° C			1	1
500 hrs. at 85° C	¾	½		
Temperature Cycling (% Change) 5 Cycles from −55° C to ±85° C	.2	.2	1	1
Short Time Overload (% Change)				
100% Overload 10 Min.		½		
2½ Times Voltage 5 Sec.	½		¾	¾
Moisture Resistance (% Change) 10-24 hr. Cycles Full Load at 95% Humidity	½	1	5	3
Salt Water Immersion (% Change) 5 Cycles 0-85° C	½	½ (Room Temp.)	......	......
Low Temp. Exposure (% Change) 96 hrs. at −65° C	½	......	3	1
Soldering Effect (% Change)	½	......	½	½

TABLE 3—PERMISSIBLE PERCENTAGE RESISTANCE CHANGES IN SPECIFICATIONS

Specification	Overload	Temp. Cycling	Moisture	Load	Adjustment Tolerance	Temp. Coef. (for 100° C)	Total	
MIL-R-93A	.5	.2	1	.5	.1	.22	2.5	Wire Wound Accurate
Vamistor	.5	.2	.5	.75	1	.25	3.2	Metal Alloy
MIL-R-10509B	.75	1	3	1	1	2	8.7	Film (high stability)
MIL-R-10509A	.75	1	5	1	1	3	11.7	Film (high stability)
JAN-184	2.5	3	3	5	5	2.5	21	Wire Wound
MIL-R-11A	5	5	10	10	5	15	50	Composition

(Tightest adjustment tolerance and temperature coefficient requirements selected from each specification.)

TABLE 4—ACTUAL TEST RESULTS

GROUP OF 1K RESISTORS

Size: 0.780″ ±0.020″ ×0.295″ ±0.010″ O.D. Rating: 0.5 Watt Tolerance: ±1.0%	Delay (Min.)	MIL-R-93A Tolerance		Results of Tests							
				Deviation		Fails	Values, Percentage Change				
		%	Fails (2 Max.) Total	% Avg.	% Max.	No.	(a) R	(b) R	%	(c) R	%
Test Group #1—18-1K's Resistance measurement (a)	......	1.0	....	......	......	0	1002.6 999.1 999.4 1009.2 997.9	1002.0 999.0 999.4 1008.6 998.3	−.06 −.01 0.00 −.06 +.04	1001.9 999.0 999.4 1008.6 999.2	−.01 0.00 0.00 0.00 +.09
Visual and mechanical inspection temp. cycling: 25° C for 15 min.: 55° C (b) for 30 min.: 25° C for 15 min.: 85° C for 30 min.: T.C. calculated (must not exceed 50 ppm/°C)	60	0.2	....	.0567	+.23	1	996.5 993.7 1004.3 1003.3 1002.5	998.3 993.0 1004.2 1002.6 1002.5	+.18 −.07 −.01 −.07 0.00	999.7 992.9 1004.0 1002.7 1002.5	+.14 −.01 −.02 +.01 0.00

TABLE 4—ACTUAL TEST RESULTS (Cont.)

GROUP OF 1K RESISTORS (Cont.)

Size: 0.780″ ±0.020″ ×0.295″ ±0.010″ O.D. Rating: 0.5 Watt Tolerance: ±1.0%	Delay (Min.)	MIL-R-93A Tolerance		Results of Tests							
				Deviation		Fails	Values, Percentage Change				
		%	Fails (2 Max.) Total	% Avg.	% Max.	No.	(a) R	(b) R	%	(c) R	%
Short time overload (1 watt for 20 min.) (c)	30	0.5	....	.0339	+.18	0	1002.6	1002.6	0.00	1002.6	0.00
							992.6	994.9	+.23	996.7	+.18
							996.1	995.8	−.03	995.8	0.00
							992.7	991.9	−.08	991.9	0.00
							1002.8	1002.2	−.06	1002.3	+.01
							1000.5	1000.6	+.01	1000.6	0.00
							1007.7	1007.0	−.07	1007.6	+.06
			2				1004.9	1004.5	−.04	1005.3	+.08
Test Group #2A—6-1K's from GRP #1 Moisture resistance—temp. and humidity cycling as per PG-11 of MIL-R-93A (Std. JAN-I-6) 100% wattage load. 3 hrs. at 14° F and 15 min. vibration on 5 out of 10 days duration (b)	......	1.0	2	.15	.44	0	1002.0	1002.1	+.01		
							999.0	1003.4	+.44		
							999.4	1000.8	+.14		
							1008.7	1008.9	+.02		
							999.4	1001.2	+.18		
							1000.7	1001.9	+.12		
Terminal Pull—5 lbs.	......	NIL	0	......	......	0					
Test Group #2B—6-1K's from GRP #1 Moisture resistance—temp. and humidity cycling as per PG-11 of MIL-R-93A (Std. JAN-I-6) 100% wattage load. Duration—10 days (b)	......	1.0	2	.10	.16	0	993.0	993.1	+.01		
							1004.1	1004.8	+.07		
							1002.8	1003.0	+.02		
							1002.5	1004.1	+.16		
							1002.6	1003.9	+.13		
							998.1	1000.3	+.22		
Terminal pull—5 lbs.	......	NIL	0	......	......	0					
Test Group #3—6-1K's from GRP #1 Load life test: rated voltage applied for 1.5 hrs.—and off for 0.5 hr. intermittently. Temperature held at +85° C. Readings taken at 24, 100, 250, and 500 hr. intervals (b)	......	1.0	1	.188	.43	0	996.0	996.9	+.09		
							991.9	992.3	+.04		
							1002.3	1003.6	+.13		
							1000.7	1002.7	+.20		
							1007.7	1010.0	+.23		
							1005.3	1009.6	+.43		

GROUP OF 100K RESISTORS

Test Group #1—18-100K's Resistance measurement (a) visual and mechanical inspection temperature cycling: 25° C for 15 min.; (b) −55° C for 30 min.; 25° C for 15 min.; +85° C for 30 min.; TC calculated (must be less than 50 ppm/°C)	60	1.0	....	......	......	0	99940	99950	+.01	99950	0.0
	......	0.2	....	.012	+.04	0	99570	99570	0.0	99580	+.01
							100230	100250	+.02	100260	+.01
							99930	99930	0.0	99940	+.01
							100030	100040	+.01	100040	0.0
							99700	99710	+.01	99710	0.0
							100160	100170	+.01	100180	+.01
							100210	100220	+.01	100210	−.01
							100620	100660	+.04	100670	+.01
							100510	100520	+.01	100520	0.0
Short time overload (c) (1 watt for 20 min.)	30	0.5	....	.01	+.06	0	100510	100500	−.01	100560	+.06
							99670	99680	+.01	99670	−.01
							100700	100690	−.01	100690	0.0
							99896	99930	+.03	99920	−.01
							100280	100300	+.02	100330	+.03
							99870	99880	+.01	99880	0.0
							100180	100180	0.0	100180	0.0
			2				99630	99630	0.0	99630	0.0
Test Group #2A—6-100K's from GRP #1 Moisture resistance—temp. and humidity cycling as per PG-11 of MIL-R-93A (Std. JAN-I-6) 100% wattage load. 3 hrs. at 14° F + 15 min. vibration on 5 out of 10 days duration (b)	......	1.0	2	.073	−.27	0	99950	99920	−.03		
							99580	99600	+.02		
							100260	100290	+.03		
							99940	100000	+.06		
							100040	100070	+.03		
							99710	99440	−.27		
Terminal pull—5 lbs.	......	NIL	0	......	......	0					

TABLE 4—ACTUAL TEST RESULTS (Cont.)

GROUP OF 100K RESISTORS (Cont.)

Size: 0.780″ ±0.020″×0.295″ ±0.010″O.D. Rating: 0.5 Watt Tolerance: ±1.0%	Delay (Min.)	MIL-R-93A Tolerance		Results of Tests							
				Deviation		Fails	Values, Percentage Change				
		%	Fails (2 Max.) Total	% Avg.	% Max.	No.	(a) R	(b) R	%	(c) R	%
Test Group #2B—6-100K's from GRP #1 Moisture resistance—temp. and humidity cycling as per PG-11 of MIL-R-93A (Std. JAN-I-6) 100% wattage load duration 10 days (b)	......	1.0	2	.24	+.56	0	100180 100210 100670 100520 100560 99670	100290 100270 101230 100860 100860 99750	+.11 +.06 +.56 +.34 +.30 +.08		
Terminal pull—5 lbs.	......	NIL	0	......	......	0					
Test Group #3—6-100K's from GRP #1 Load life test: rated voltage applied for 1.5 hrs. and off 0.5 hr. intermittently. Temp. held at 85° C. Readings taken at 24, 100, 250 + 500 hrs. (b)	......	1.0	1	.14	+.34	0	100690 99920 100330 99880 100180 99630	100770 99990 100510 100220 100250 99720	+.08 +.07 +.18 +.34 +.07 +.09		

TABLE 5—COMPARISON OF AVERAGE TEST RESULTS WITH MIL-R-93A LIMITS
Test Averages %

Test	1K	5K	10K	50K	100K	Average	% Spec. Limit	Average % Spec. Limit
Temp. Cycling	.06	.02	.07	.12	.01	.06	.2	30
Short Time Overload	.03	.006	.02	.04	.01	.02	.5	4
Moisture	.15	.16	.22	.66	.07	.26	1	26
Load	.18	.42	.41	.48	.14	.33	.5	66

compared to ½ watt for the Vamistor. As pointed out previously, much remains to be done in exploring the full possibilities of the Vamistor and the question of possible improvement in adjustment tolerance will be related to further experience acquired in quantity production. It must be realized that probably the principal limitation in the use of wire-wound resistors is their restriction to d-c or very low frequency a-c signals only, due to the inherent high interlayer capacitance of the winding. The Vamistor, having the same construction as the film type resistor, can be used satisfactorily up to high radio frequencies. In summary, then, for d-c usage, the Vamistor design specification is slightly inferior to MIL-R-93A in its highest adjustment tolerance requirement (while dissipating four times the wattage). For a-c usage at radio frequencies, the Vamistor design specification is considerably superior to MIL-R-10509B, the present high-stability film specification when issued.

Typical Test Results

In general, it will be seen that the Specification MIL-R-93A sets the highest existing standard of performance for precision resistors. Tests were made during the Pilot Plant Study on a batch of 1, 5, 10, 50 and 100 kilohm Vamistors under the Vamistor specification of ½-watt dissipation. It is to be expected that tests on the units presently in production will show superior results. Table 4 gives detailed results of these tests on the extreme values of 1 and 100 kilohm Vamistors. Columns 3 and 4 in this table detail the requirements of MIL-R-93A. This latter specification, however, requires smaller wattage for this given size. Resistance changes are given in percent, both for the maximum change as well as the average change for the tests concluded. These average results for all the 1, 5, 10, 50 and 100 kilohm Vamistors are compared in Table 5 and Figure 7 to the MIL-R-93A specification requirement. The spread of this average value is very well within the requirement and represents a healthy grouping in the range of 4-66% of the specification limitation.

Future of Vamistor

It is to be anticipated that new styles will be developed and that the utility of existing and future styles will be extended by widening the resistance range available and reducing adjustment tolerance.

One interesting property of the dispersed film, not so far mentioned, is that of surface hardness and smoothness. It is thought that this property will prove to be of considerable use in the field of potentiometers requiring infinite resolution. These and other properties are now being carefully investigated.

E. N.—No. 115 —*R. C. Langford, Ph.D.*

EDITOR'S NOTE: This article is a reprint of a paper presented by Dr. R. C. Langford and Mr. J. G. Ruckelshaus, of Weston Electrical Instrument Corporation, on May 3, 1956, Electronic Components Symposium, Washington, D. C.

RUGGEDIZATION—ANOTHER WESTON FIRST IN EXPOSURE METERS

WESTON pioneered in the field of photographic exposure control, having designed and built the world's first photoelectric type exposure meter in 1932. During the past twenty-odd years, all Weston exposure meters were built with the precision of fine watches. To this precision, ruggedization has now been added. The Master III, Figure 1, is produced by the same master craftsmen who have made thousands of ruggedized meters for the military services. Ruggedization is not a catch-phrase, as it means instruments that will maintain accuracy in tanks rolling over rough terrain, in airplanes with guns in full operation, or in ships under intense artillery fire.

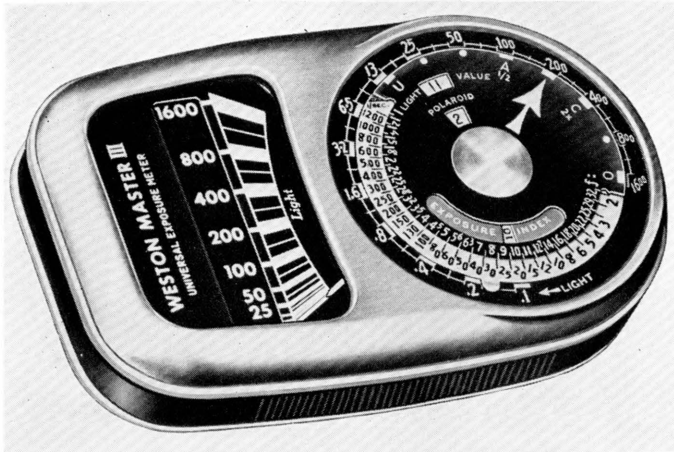


Figure 1—Weston Master III Universal Exposure Meter.

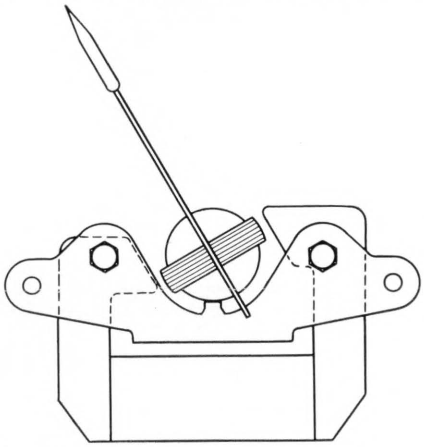


Figure 2—Microammeter Movement.

In the Master III, ruggedization is accomplished in two ways. First, the microammeter movement shown in Figure 2 is rubber-cushion mounted in the bakelite chassis. And second, the movable coil is provided with hardened and polished steel pivots and practically frictionless jewel bearings which are spring-backed, as shown in Figure 3. Under shock, the pivot presses the jewel against a light spring, and, if the shock is severe, the jewel and spring will be compressed until the shoulder of the shaft, which holds the pivot, strikes the washer in the jewel assembly. With this arrangement, the maximum pressure on the jewel and pivot is about 16 grams, which is considerably less than the load necessary to cause any deformation of either the pivot or jewel. These methods of absorbing mechanical shock have been tested in the laboratory and in the field and have been found very effective in providing the necessary protection to assure long life under adverse conditions.

Truly Universal

Webster defines "Universal" as "including or covering the whole, embracing a wide range of subjects." The Master III amply meets this definition for the following reasons:

1. It more than meets the American Standards Association (ASA) specifications for exposure meters.

2. It is calibrated to cover both the European and American systems of f/stops and exposure times.

3. It is calibrated for direct reading in Light Values for use with the new cameras with LVS shutters.

4. It is calibrated for direct reading in Polaroid-Land camera numbers.

5. It can be used with all still and motion picture cameras.

6. It can be used with any color or black and white film rated from 0.1 to 3,200 Exposure Index or Weston Speed.

7. It can be used to measure reflected light, or incident light when the Invercone is attached.

8. It has a high scale and a low scale to enable measurements of extremely bright light and very dim light.

9. It has a calculator which is extremely easy to use and yet universal enough to solve photographic problems in the same manner that a slide rule solves mathematical problems.

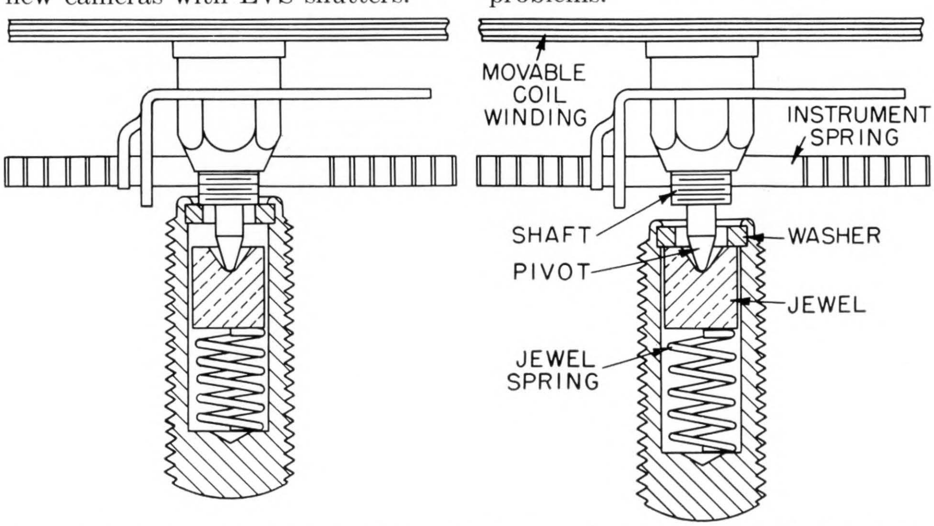


Figure 3—Spring-back Jewel Showing Depressed Position on the Left and Normal Position on the Right.

Newly Designed Control Dial

The Master III is the result of over twenty years' experience in the design and construction of exposure meters. The exposure control dial, which converts the meter readings into photographic information, is one of the most important considerations when designing an exposure meter. Many exposure meters contain too few film speed values, f/stops and exposure times which give the impression of simplicity, but unfortunately only lead to frustration when the user discovers that many of the camera markings are not on the calculator. We believe that an exposure meter should be usable with all cameras and that it is better to have a few calibration values that may not be required by some photographers than to not have values that other photographers may need. We also appreciate that many photographers have difficulty in reading small figures and therefore a great deal of time was spent on the problem of getting larger figures on the control dial without sacrificing the scope of usefulness or the small size of the over-all meter. A glance at the dial, or even better, a comparison with former models, will show we succeeded in increasing the readability very substantially and, in addition, the Light Values and Polaroid-Land camera scales were added. This was accomplished by doing several things.

1. The push-button type of indexing release, to alter film speed settings, was eliminated and a different type of indexing was designed. This allowed the use of a larger diameter control dial.

2. The use of fractional values for exposure times was eliminated in accordance with standard camera practice. This meant that by merely having 25 instead of 1/25, the numbers could be substantially larger. But this also meant that there would be duplicate numbers having different values. For example, 25 means 1/25 second and also 25 seconds. This ambiguity was solved by having black figures on a light background for fractional values and light figures on a black background for whole numbers.

By means of these two changes in design, nothing has been sacrificed and the figures are approximately 100 percent greater in area and much more readable than those on the majority of cameras.

To further increase the readability of the Master III, the meter scale has been made bolder than on prior models. The scale divisions and numerical values are considerably heavier.

Film speeds are designated as "Exposure Indexes" on the meter to comply with the ASA specification and our new Film Rating booklet contains both the Weston System and Exposure Index ratings. The Weston Sensitometric Laboratories will continue to test and furnish film ratings as in the past. Actually, we test and rate films in the Weston Ratings which includes development in the recommended manufacturer's developer and interpretation of the resulting characteristic curve according to our practice for many years, and now we also test and rate them in Exposure Index Values according to the specifications of the American Standards Association. Either system can be used with confidence.

Importance of Acceptance Angle

So far, we have been concerned mainly with the general characteristics of the exposure meter from the photographer's viewpoint. Perhaps some of the technical design considerations may be of interest.

The acceptance angle of an exposure meter is of utmost importance to both the photographer and the manufacturer. All that any exposure meter can do is to indicate the average brightness of the area included in the acceptance angle. This is important to the photographer for the simple reason that, if the acceptance angle is large, the meter indication will be the result of the average brightness of a large area and this may be substantially different from the brightness of the center of interest. To the manufacturer, it means added parts, as shown in Figure 4. A small acceptance angle reduces the light flux which reaches the photoelectric cell. This results in a low photoelectric current, which in turn requires an extremely sensitive microammeter movement. A sensitive microammeter needs fine windings on the movable coil, low spring torque, very careful inspection of jewels and pivots and high operation skill in the over-all assembly. It is evident, therefore, that the cost of building an exposure meter is governed to a large extent by the acceptance angle.

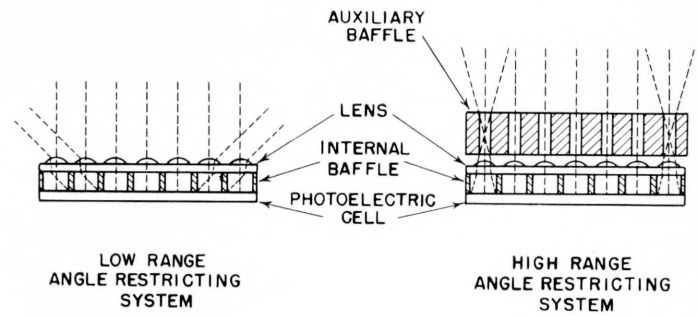


Figure 4—Arrangement of Light Restricting Means to Control Acceptance Angle.

The acceptance angles of the high and low ranges of the Master III are shown in Figure 5. It will be seen that the high range acceptance angle is considerably smaller than most camera lenses and this high selectivity has proved to be a real advantage in outdoor photography. The low range acceptance angle is greater than most camera lenses and has been chosen as a means for obtaining sensitivity to low brightness levels. This sacrifice in acceptance angle to obtain sensitivity is predicated on the fact that where low brightness levels are encountered, such as in indoor photography, it is possible to take close-up readings and thus cancel out the effect of the large acceptance angle and gain the advantage of being able to measure low brightness levels.

Many exposure meters on the market have acceptance angles which

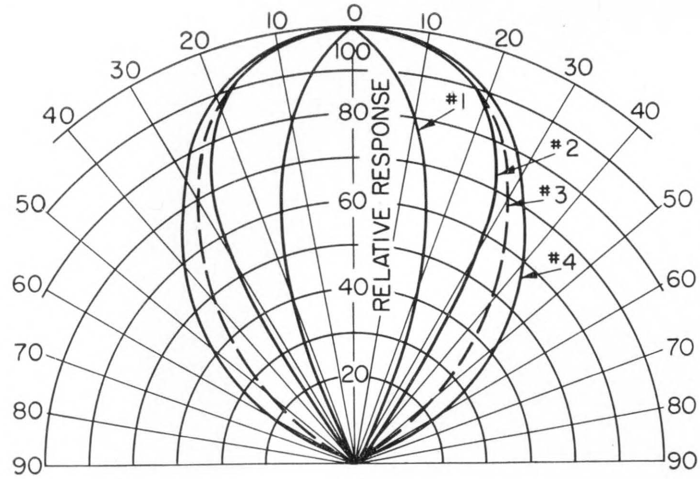


Figure 5—Acceptance Angle Curves.
No. 1. High Range of Weston Master III.
No. 2. Low Range of Weston Master III.
No. 3. High Range of Foreign Competitor Meter.
No. 4. Low Range of Foreign Competitor Meter.

are entirely too large and therefore cause the photographer to obtain erroneous exposures. This is particularly true of almost all foreign exposure meters sold in the United States. Figure 5, which shows the acceptance angles of the high and low ranges of the Master III, also includes the acceptance angle curves of a typical foreign meter. Note that both the high and low range acceptance angles are considerably greater than even the low range of the Master III. The small acceptance angle of the high range of the Master III allows the photographer to obtain the average brightness of discrete areas without the danger of including dark areas which will result in over-exposure, or of light areas which will result in underexposure. The ASA specification on Acceptance Limits specifies three classes of acceptance. The Master III high range is rated Class A, the low range Class B, and the majority of foreign meters fall in Class C or are below the specified limit.

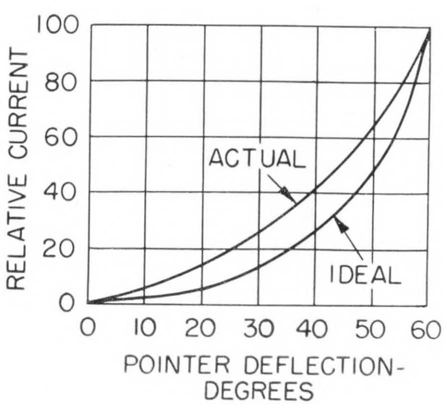


Figure 6—Microammeter Movement Characteristics.

Microammeter and Photoelectric Cell

The microammeter, shown in Figure 2, is connected directly to the photoelectric cell, which is of the barrier-layer type, and is used to measure the current from the photoelectric cell. Since there is a definite relationship between the photoelectric cell current and the amount of light on it, the meter scale can be calibrated in light values. The relationship between Brightness and Exposure for any photographic film is shown by the following equation:

$$B = \frac{KA^2}{ST}$$

where

B = Brightness in Candles per Square Foot

K = Calculator Constant, which ASA specifies shall be between 1.00 and 1.35. (Master III = 1.00)

A = Relative Aperture or f/stop

S = Exposure Index of Film

T = Exposure Time in Seconds

For any given film speed and exposure time, then, $B = KA^2$. Hence the ideal exposure meter scale is one in which the deflection is proportional to A^2. This means that the meter scale should be uniformly divided so that each cardinal division will represent a 100 percent step in exposure. This ideal is substantially attained in the Master III, as can be seen on the meter scale shown in Figure 7, since the spacing between 1,600 and 800, 800 and 400, etc., is practically uniform down to 50, below which the low range scale should be used. The attainment of this ideal requires a microammeter having the characteristics shown by the dotted line in Figure 6. This ideal is practically unattainable as the loss in magnetic flux necessary to obtain this non-linearity of response results in a microammeter, which, with ample spring torque, requires more power than the photoelectric cell assembly will deliver. The solid curve shows the actual attainment. Actually, the non-linearity of the photoelectric cell helps some but it is mainly the non-linearity of the microammeter which allows the accomplishment of the meter scales shown in Figure 7.

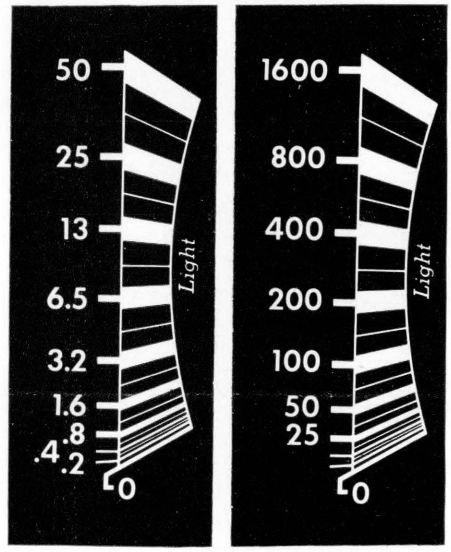


Figure 7—High and Low Light Meter Scales.

To summarize, the Weston Master III is the culmination of over two decades of exposure meter design and craftsmanship by the world's largest producer of electrical measuring instruments and represents the ultimate in accuracy, sturdiness and ability to solve photographic exposure problems.

E. N.—No. 116 —*A. T. Williams.*

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The Editor

"Westonia"

E. F. WESTON, our Board Chairman, broke into conversation at the lunch table where we were discussing new plastics and someone had remarked on the apparent antiquity of Bakelite.® We asked Dr. Weston when the first Bakelite appeared in the Weston manufacturing plant.

"It stems from the difficulty we were having with a molded shellac composition disc used to retain the actuating coil in one of the iron vane voltmeters a little after the turn of the century. It was miserable stuff and while it made good phonograph records it simply wouldn't stand any heat. My father remembered that he had met a Dr. Baekeland at the Chemists Club in New York who was playing with a new plastic. You will remember that Dr. Baekeland invented Velox photographic printing paper and sold it to Eastman and had started a private chemical laboratory up in Yonkers.

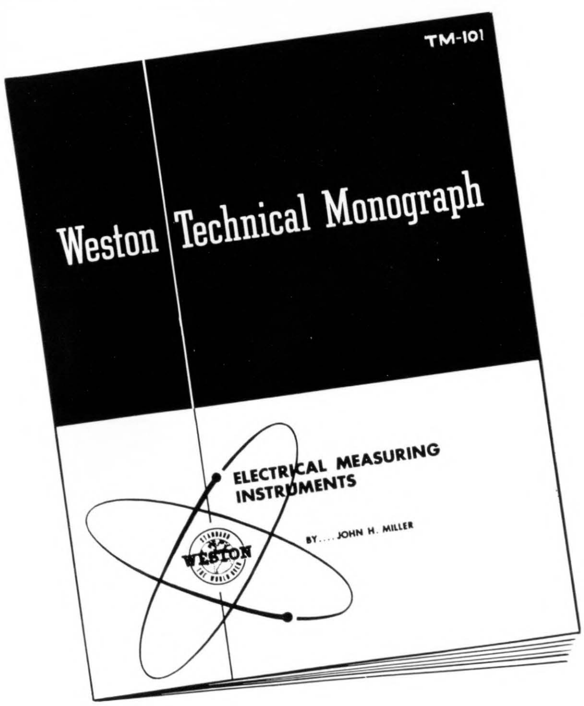
"A date was made and Father and I traveled up there. Dr. Baekeland showed us the reaction of phenol and formaldehyde which, when heated in the open air, suddenly foamed all over the place into a hard, brittle sponge. Dr. Baekeland had discovered that by starting the reaction under pressure, he could stop it part way and get a syrup, which could later be further treated under heat and pressure to form a solid resin.

"We explained our need for a good molded insulation material. Dr. Baekeland referred us to the Boonton Rubber Company, which was experimenting with molding this new material. Mr. Richard W. Seabury, who was operating the rubber business at that time, foresaw the eventual end of profits in the rubber reclaiming process and was casting about for something to keep his plant operating. He knew Dr. Baekeland personally and was well acquainted with his work on Bakelite, so he obtained a license to develop molding mixtures and mold Bakelite parts. Mr. Seabury devised various Bakelite molding mixtures, including some made with dyed wood flour, and molded the material experimentally. He made the first piece of molded Bakelite ever used in industry. Based on his knowledge and experience, Mr. Seabury stated that he could mold the pieces we required to within the tolerances (namely, $+0$ to $-.002''$) provided the molds could be made with sufficient accuracy.

"So we made the tools in the Weston Tool Shop! The Boonton Rubber people molded very satisfactory pieces for us which were within the limits and, more importantly, which did not warp when they got hot.

"The material was such an advance on the shellac composition which was the only alternate then available, that it seemed a perfect answer, and shortly thereafter, we made arrangements with Dr. Baekeland for a license covering molding this new material under his patents. Mr. Seabury had License #1 and we were given License #2.

"Some time later, Dr. Baekeland licensed a chemical manufacturer to make molding mixtures which soon became an article of commerce. After many trials, this company produced the double dyed wood flour mixture which we have been using ever since and, of course, although this material has been called by various names and numbers, it is still essentially what was produced for some of these very first items."



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A broad cross section of the field is presented including many of the recent instruments incorporating the use of vacuum tubes as well as Cathode-Ray tubes. Some of the titles of the subjects covered are "Galvanometers," "Moving-Coil Permanent-Magnet Instruments," "Absolute Measurements," "Laboratory Instruments," and many others.

Individual copies of this 20-page monograph are available on request. Please address the Editor of WESTON ENGINEERING NOTES requesting a copy of Weston Technical Monograph TM-101.

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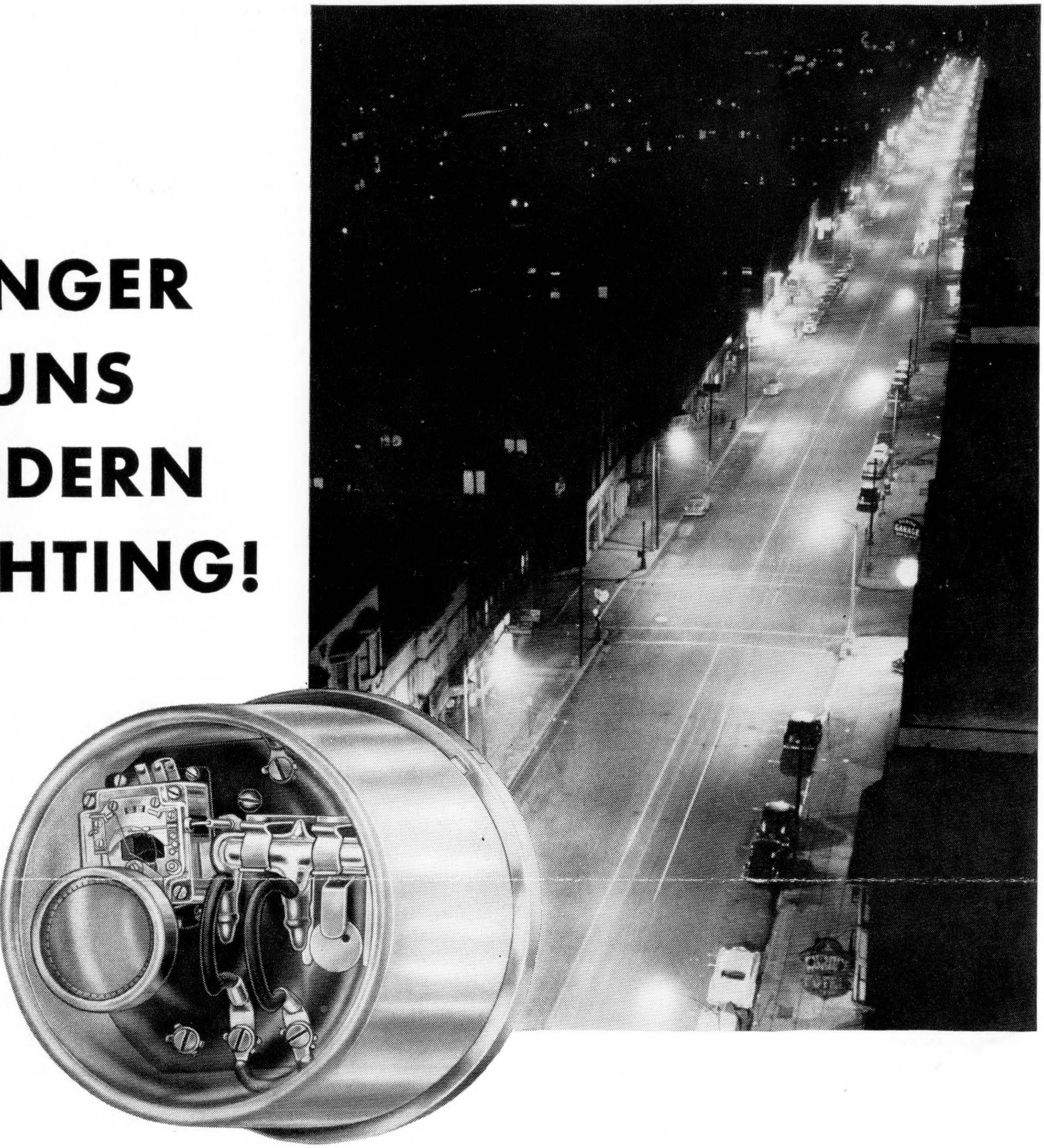

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