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High Temperature Metallized-Paper Capacitors

By the Research Department, Aerovox Corporation

METALLIZED paper capacitors have become part of our accepted way of life. Just about one year ago, a symposium was held in Washington on metallized paper capacitors.* Since that time, the number of metallized paper capacitors manufactured has increased by a factor of 10-15 and the demand by a factor of almost 30. From all signs this demand will grow and, at present, there is no indication as to the ultimate requirements of the electronic industry for metallized paper capacitors.

Like all electronic components, metallized paper capacitors must be capable of operating at higher temperatures. This must be achieved with a simultaneous improvement in performance and reliability.

The utility of present type metallized paper capacitors at temperatures in excess of their rating of 70°C is limited by the fact that such capacitors must be operated at voltages lower than their rated voltage. The decrease in the permissible operating voltage with an increase in temperature is such that at a temperature of 85°C there is little advantage in the use of metallized paper capacitors over conventional type capacitors, except for the self-healing characteristic.

Foreword

The material contained herein is based on papers and discussions presented at the National Electronics Conference, Chicago, Illinois, on October 24, 1951, by Mr. Louis Kahn, Director of Research for the Aerovox Corporation.

Figure 1 shows the permissible operating voltage for conventional wax or oil impregnated metallized paper capacitors.

As a result of improved techniques, it has been possible to use the same derating curve for both wax and oil impregnated capacitors. It should be noted, however, that at 95°C the capacitors cannot be operated at more than 50% of the nominal value.

The decrease in the permissible operating voltage is determined by the fact that as the temperature increases the deterioration of the capacitor properties, which occurs whenever a fault takes place, is greatly accelerated.

A brief review of the construction of such capacitors will show why this takes place. The capacitors are designed to operate at dielectric stresses very close to the breakdown point of the insulation. For voltages of 200 volts and lower and with a single layer of dielectric, it has been found that a micro-crystalline wax has been the most suitable type of impregnant. For higher voltages, that is, ratings of 400 volts and 600 volts, it has been possible to use liquid impregnants, such as mineral oil as is now being used for the impregnation of conventional type paper capacitors. It is significant to note that the wax is a solid over the normal operating range.

Since metallized paper capacitors are operated just below the breakdown voltage of the dielectric, occasional breakdowns or faults of the dielectric will occur at rated voltage or at the permissible operating voltage when the capacitors are operated at elevated temperatures. Whenever a fault occurs and is cleared by the energy stored in the capacitor or available from the external circuit, a certain deterioration of the dielectric occurrs, and this deterioration generally shows up as an eventual decrease in the insulation resistance of the capacitor. This decrease in insulation resistance is, of course, limited to the immediate vicinity of the fault. In the process of faulting and clearing, the electrode material

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*Symposium on Metallized Paper Capactors in Washington, D. C. November 29, 1950.

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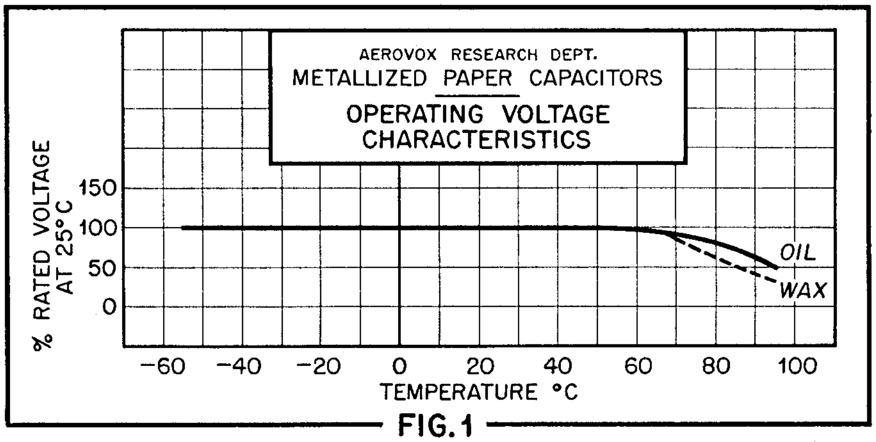

FIG. 1

is actually molten and, in some cases, may become detached from the film itself. In addition, there will also be present a certain amount of carbon particles which may be produced at the point of the fault. There will be present, therefore, a number of conducting particles. These conducting particles in a material, such as wax, which normally is solid at the operating temperature, will be immobile. However, in liquid impregnants, these materials can and will align themselves in an electric field, producing a relatively low resistance path between electrodes. If the capacitor is operated above the melting point of the wax; we have essentially the same condition that exists with any liquid impregnant, although it should be remembered that the viscosity of the wax at temperatures above its melting point can be considerably lower than that of mineral oil.

In addition to the above, the dielectric strength of the impregnant becomes lower at the elevated temperatures. It is the above conditions which limit the utility of metallized paper capacitors at high temperatures.

Research on the causes of low insulation resistance of metallized paper capacitors has resulted in considerable improvement in the performance of metallized paper capacitors at elevated temperatures. Nevertheless, still higher operating temperatures were required, and the only avenue of development was to use an entirely new impregnant.

It became apparent, therefore, that the limiting factor in the high temperature operation of metallized paper capacitors was primarily the impregnant used. The nature of the metallized paper itself limits the types of impregnants available.

For use in metallized paper capacitors, the impregnant should have the following characteristics:

1. Chemical Inertness (with respect to the other components of the capacitor)
2. Low Viscosity for Impregnation
3. High Dielectric Constant
4. Low Power Factor
5. High Insulation Resistance

Chemical inertness, of course, is of the greatest importance in this type of capacitor, since the amount of metal in electrodes is so small that even extremely low reaction rates between the impregnant and the electrode film on the surface of the paper will result in a very rapid deterioration and eventual destruction of the continuous metallic film on the surface of the paper. It should be remembered that this film is approximately 50 millimicrons thick. This requirement has limited the available impregnants, until the present, to mineral oils and mineral waxes, or other materials of a similar nature

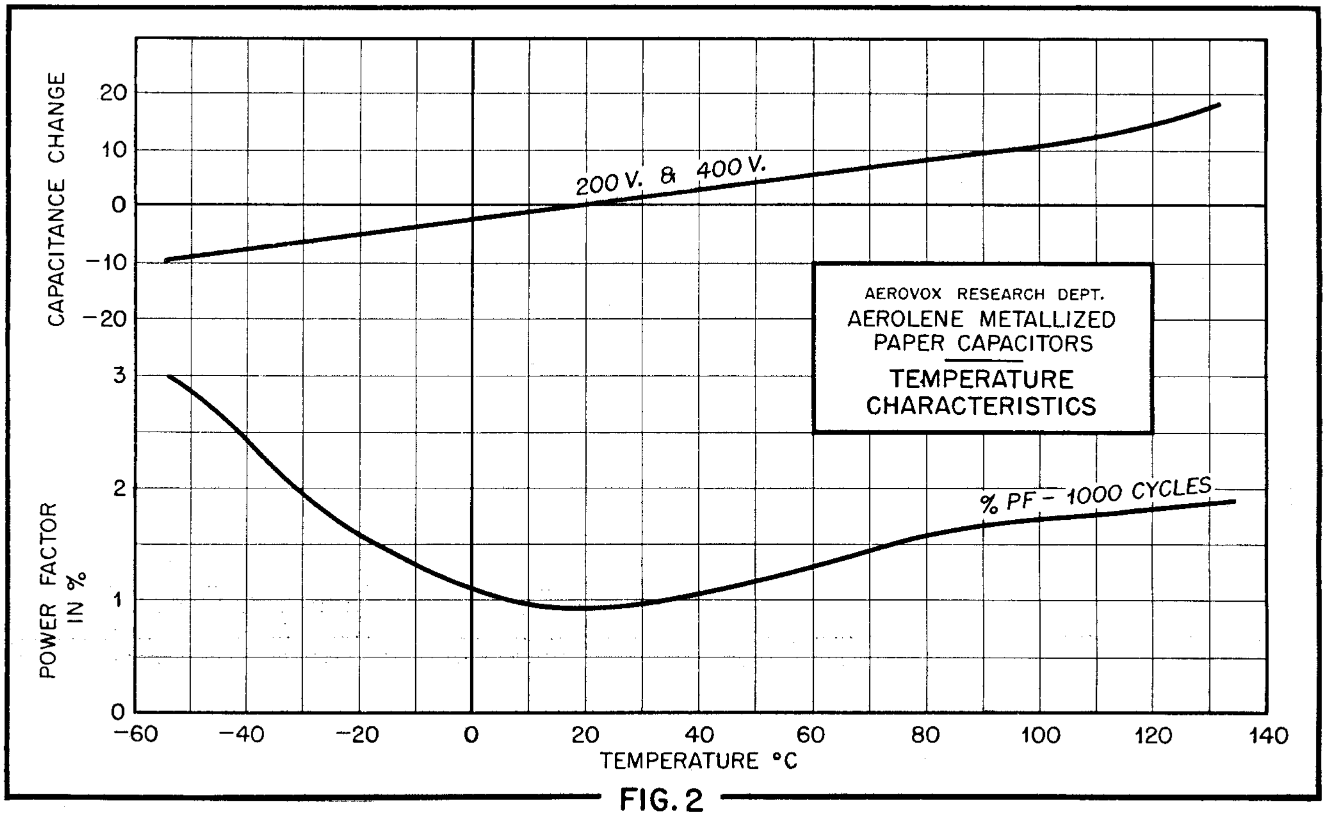

FIG. 2

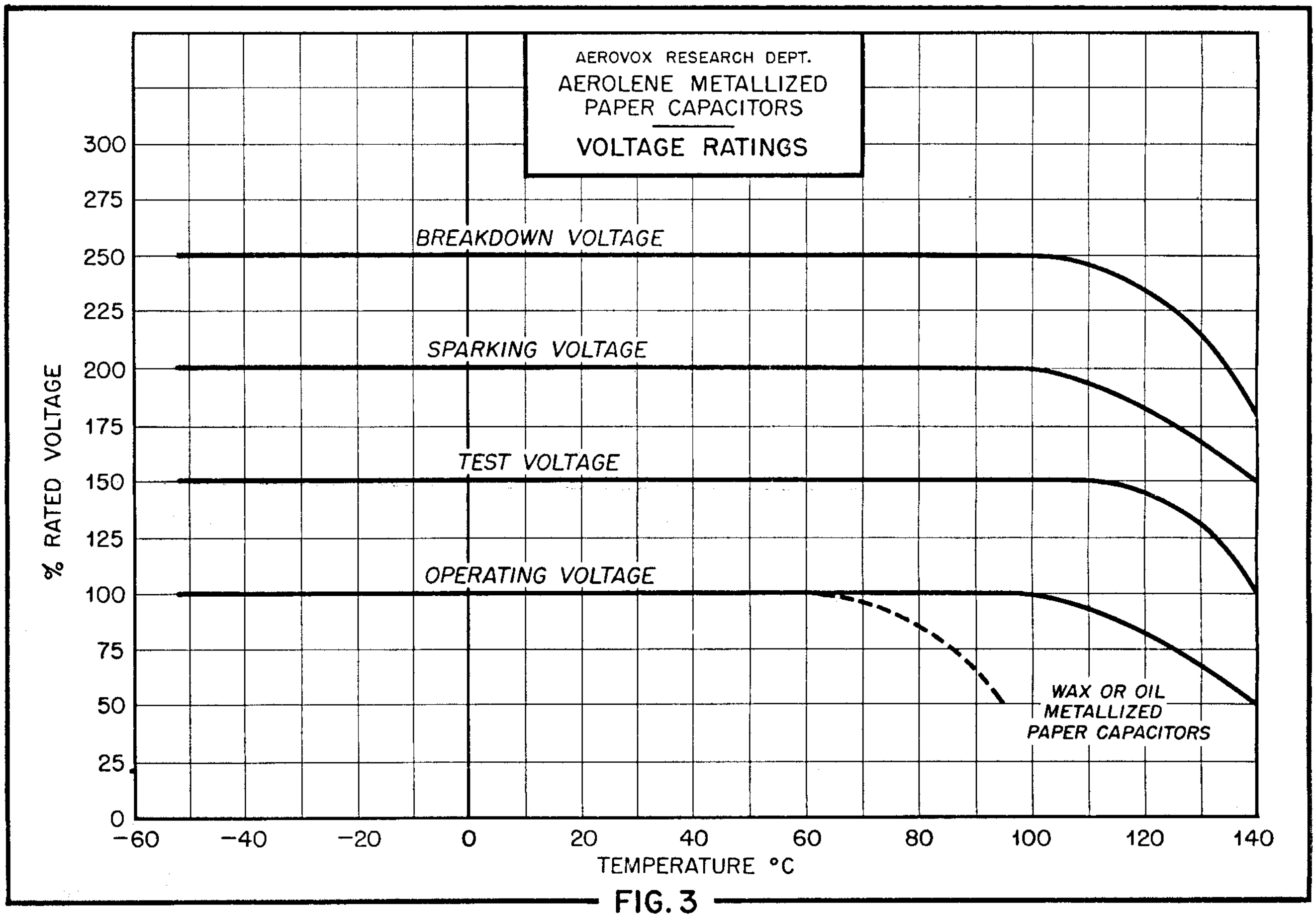

FIG. 3

with dielectric constants of 2.2-2.6. It has been impossible to use any of the high dielectric constant materials, such as chlorinated naphthalene with a dielectric constant of 5.28-6.14, or the chlorinated diphenyls with a dielectric constant of 4.9 for metallized paper capacitors.

Moreover, it has been extremely difficult to find mineral waxes having the necessary physical properties as well as the electrical properties for use as satisfactory impregnants. The best mineral waxes available so-far have had melting points in the vicinity of 70°-75°C, while present-day operating requirements require that capacitors be capable of operating at temperatures up to 125°C. Such impregnants must also be sufficiently plastic at the low temperature end of the operating range to prevent formation of voids that may be caused by shrinkage of the impregnating medium. Moreover, the impregnant must be of a low enough viscosity so that capacitors can be readily impregnated. This is of the greatest importance in metallized paper capacitors, since a large percentage of the end area is completely sealed off by the necessary metallic spray used for making connections to each turn of the capacitor winding.

The ideal impregnant for metallized paper capacitors would be, therefore, some material which would have a dielectric constant in the vicinity of 5, although higher values would not be undesirable; a power factor of such value that the completed capacitors would have power factors of less than 1%; insulation resistance of such order that finished capacitors would have insulation resistances of the order of 2,000 meg. mfd. at 25°C and in excess of 1.0 meg. mfd. at 125°C. Also, the material should be a solid after it has become a part of the capacitor and should be solid for all temperatures up to and including the maximum operating temperature. Too much stress cannot be placed on the chemical stability or the composition of the products caused by an electrical discharge within a capacitor, which occurs during the clearing of a fault. The material must also be of such chemical nature that it will not disturb the lacquer film that is placed on the paper prior to its metallizing.

An analysis of available impregnants indicated that the material which came closest to meeting the above requirements was Aerolene, a co-polymer of a polyester and styrene-monomer. There are other materials available but none have dielectric constants as high, although they may have other properties which for special application were found extremely suitable.

CHEMISTRY

Aerolene is a specially modified thermosetting resin of the unsaturated polyester type. The three groups of compounds commonly used in the preparation of polyester resins are: (1) dibasic acids, such as maleic, fumaric, itaconic, and phthalic, (2) alcohols and glycols, such as allyl alcohol, ethylene glycol and propylene glycol, and (3) unsaturated hydrocarbons, such as styrene and cyclopentadiene.

The polyester prepared by the condensation of acids and alcohols must contain at least one unsaturated compound. This may be one of the acids, such as maleic acid or one of the hydroxy compounds, such as allyl alcohol. This polyester is then capable of polymerizing to form cross-linked three-dimensional structures. To modify the properties of the polyester and, also, to act as a solvent vehicle for it, unsaturated hydrocarbon liquid compounds are mixed with the polyester to form the commercial resins. The polyester resins are polymerized by heat, ultra-violet light, peroxides or hydroperoxides or combination of these catalysts, to convert the liquid resins into a solid infusible mass.

TABLE I — Energy (Watt Seconds) To Clear Faults

CAP. MFD.	300 VOLTS	200 VOLTS	100 VOLTS	50 VOLTS	25 VOLTS
6	0.216	0.03	0.003	0.0015	0.000165
3	0.113	0.032	0.0028	0.00075	0.000140
1	0.04	0.015	0.0021	0.00045	0.000312
0.5	0.02	0.008	0.0016	0.00040	fault not cleared
0.25	0.01	0.004	0.00095	0.00024	fault not cleared

These resins differ from phenolic and amine thermosetting resins in that they do not produce water or other volatile by-products during polymerization thus, allowing polymerization without the use of high pressures. The fact that there are no by-products such as water, are of course extremely important when any material is used as a capacitor dielectric.

The material is a liquid having a relatively low viscosity at room temperatures and can be maintained liquid under proper conditions of handling and storage for an indefinite period of time. The liquid has fairly good wetting properties and can be used for the impregnation of metallized paper capacitors without difficulty. Its chemical stability, both as a liquid and as a co-polymer, has been proven over the past several years by the large number of conventional type tubular capacitors that have been manufactured and used.

Aerolene, after polymerization, has a dielectric constant of 3.8; a power factor of 0.5%; and a volume resistivity of 10^8 meg. cm. The above values are at 25°C. At 85°C the dielectric constant is 4.4; the power factor is increased to 2.5%; and the insulation resistance is 10^5 meg. cm. After impregnation, the dielectric constant of paper impregnated with Aerolene is 5.1; power factor ranges from 0.5% at 25°C to 3% at 125°C; and insulation resistance is of the order of 2,000 meg. mfd. at 25°C and 2-3 meg. mfd. at 125°C.

Figure 2 shows the characteristics of Aerolene impregnated metallized paper capacitors over its operating range of -55°C to 125°C.

It should be noted that capacitors impregnated in Aerolene meet very closely the requirements as outlined above. However, the material does have one characteristic which may limit its utility to some extent. It will be noted that the capacitance increases slightly with an increase in temperature, and 85°C is approximately 7% higher than at 25°C, and that at 125°C has reached a value of 115% of room temperature values.

Because of the higher dielectric constant of Aerolene, there is approximately a 10% reduction in the volume of metallized paper capacitor sections when impregnated with Aerolene compared to metallized paper capacitors impregnated with wax. Although this reduction in size is not great, it is an appreciable amount, if the smaller unit will fit into a space the larger unit will not.

OPERATING VOLTAGE

The rating of a metallized paper capacitor is not the same as the rating of a conventional type of paper capacitor. It is desirable, therefore, to review briefly the basis for rating of metallized paper capacitors.

Unlike the conventional unit, in which only a single voltage is given for rating purposes, the metallized paper capacitor actually has four voltages which must be considered in its rating. These are: (1) the test voltage, (2) the sparking voltage, (3) the breakdown voltage and (4) the operating voltage.

Curves on Figure 3 show the maximum values of these voltages and their dependence upon temperature.

It should be pointed out again, at this point, that the rated working voltage of the capacitor is such that some sparking may occur during the normal operation of the capacitor. However, it has been found that if the capacitors are operated at approximately 75% of their working voltage that the possibility of sparking has been practically eliminated, and that such capacitors can operate for extremely long periods of time without any signs of sparking or fault. Under these conditions such capaci-

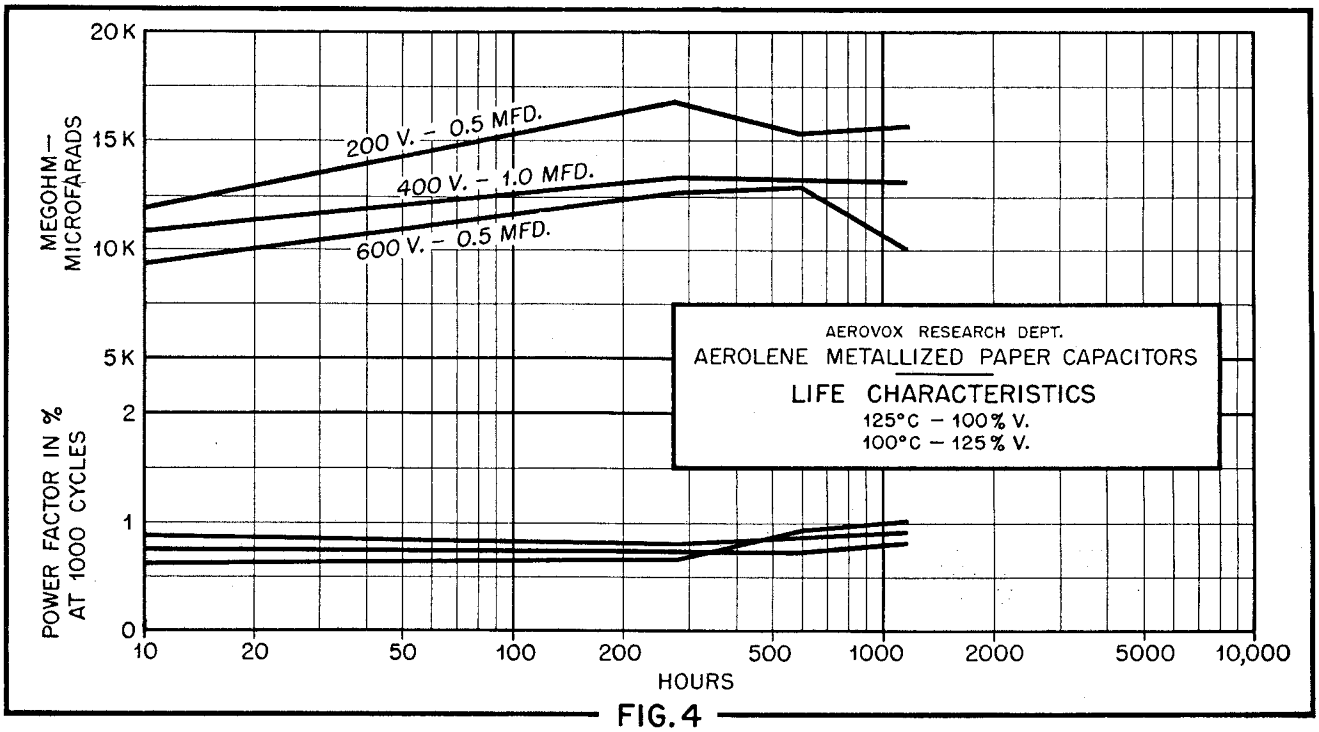

FIG. 4

tors become the equivalent to conventional paper capacitors with the additional advantage that if a fault should occur such faults will be cleared and will, therefore, not cause failure of the system.

The energy to clear a fault has not changed appreciably, although an increase was expected because of the nature of the impregnant. An attempt was made to measure this difference, but the experimental errors were greater than the differences.

It may be of interest to note the magnitude of the energy required to clear faults in metallized paper capacitors. Table I shows the energy measured to clear intentional faults. The energy was measured by discharging a capacitor into a fault and measuring the voltage before and after the clearing. The energy was computed from the voltage and the capacitance of the storage capacitors. The storage capacitors were wound with polystyrene film to reduce absorption and residual charge effects to a minimum.

In obtaining the above data, no energy was supplied to the system after the capacitors were charged.

It is of interest to note that the energy to clear a fault is extremely small, and that there is a minimum voltage which must be exceeded for a satisfactory clearing. Energy in excess of the minimum requirements is dissipated in the fault, probably by carbonization of the paper and impregnant, as well as by the larger area of metal molten. The minimum value of storage capacity and voltages are limited by the amount of metal molten and the time available for the fault clearance.

The time required to clear these faults was of the order of one microsecond.

Figure 4 shows the change in power factor and insulation resistance of several groups of capacitors on life test at 100°C and 125°C at 125% and 100% of rated voltage, respectively. This is a somewhat accelerated test, since it is run at 125% of the operating voltage at the test temperature.

Only one set of three curves for the 125°C test are shown, since the points for the 100°C test fall on the curves of the 125°C test and were omitted to prevent confusion in reading the data.

The rise in insulation resistance with time is probably due to a continued polymerization of the impregnant. This change is accompanied by a slight decrease in power factor. No measurable change in capacitance has been noted in any of these tests.

To date, life tests on Aerolene impregnated metallized paper capacitors have run over 10,000 hours at 85°C with the following results as described in Table II above.

TABLE II — Life Test Data

UNIT No.	UNITS ON TEST		INITIAL			HOURS ON TEST	FINAL			% CHANGE		
	START	END	CAP	PF	IR		CAP	PF	IR	CAP	PF	IR
906	19	18	0.00448	0.885	>100 K	10,146	0.00471	0.912	815 K	+5.2	+3.0	—
930	36	34	0.2682	0.802	20 K	4,978	0.2702	1.15	29 K	+0.76	+23	+46

CAP in microfarads; PF in %; IR in megohms
Test Voltage - Test No. 906 — 125% Rated Voltage, Test No. 930 — 125% Rated Voltage
Test Temperature — 85°C

APPLICATION

Since the characteristics of metallized paper differ from the characteristics of the foil type, the application of these capacitors must be studied and made in light of their characteristics. These differences in characteristics have been reported* previously and every possible attempt has been made to screen all applications. This, of course, has limited the possible usage of metallized paper capacitors.

The use of Aerolene as an impregnant has eliminated some of the differences between metallized paper capacitors and the foil units. This has broadened the field of application considerably. However, the experience with metallized paper capacitors in this country is still small and caution should be exercised in their use. Specifically, the use of Aerolene has decreased the probability of temporary faulting by a factor of at least 5 and, possibly, 10. At the same time, the voltage limits for sparking and breakdown have increased, although the permissible limits have not been increased proportionally in order to increase the margin of safety.

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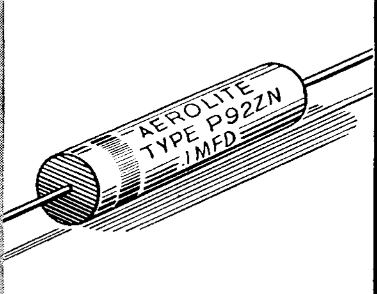
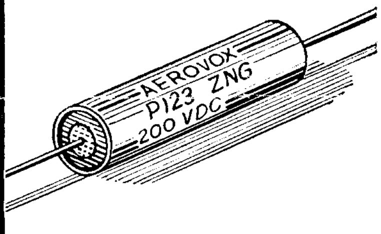
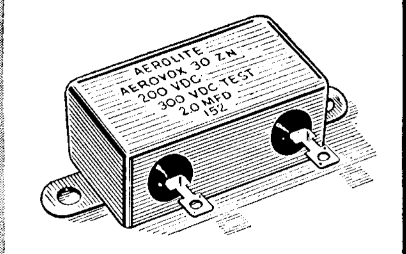
high-temperature metallized-paper capacitors



Series P92ZN Aerolene-impregnated metallized-paper capacitors are modified plastic-tubular, duranite-end-sealed units in paper cases. Operating temperatures of —30°C. to +100°C. 200, 400 and 600 v. D.C. 0.01 to 2.0 mfd.

Series P123ZNG Aerolene-impregnated metallized-paper capacitors housed in tubular metal cases with vitrified ceramic terminal seal. Operating temperature range of —55°C. to +100°C. at full rating: to +125°C. at 75% of voltage rating. 200, 400 and 600 v.D.C. .0005 to 2.0 mfd.

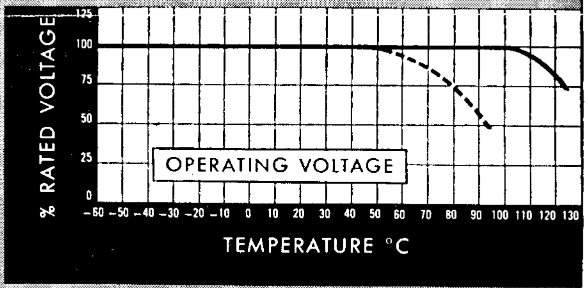




Series P30ZN Aerolene-impregnated metallized-paper capacitors housed in "bathtub" metal cases with vitrified or glass terminal seals. Operating temperature range of —55°C. to +100°C. at full rating; to +125°C. at 75% of voltage rating. 3.0 mfd. to 15.0 mfd. for 150 V.D.C. units. 2.5 mfd. or less for 300 V.D.C. units.

Once again, Aerovox is privileged to blaze the capacitor-development trail. For these high-temperature metallized-paper capacitors are ~~definitely Aerovox "firsts" in concep~~*~~tion~~*, *production* and *application.*

Their truly phenomenal acceptance is due to (1) The *Space Factor,* especially when *miniaturization* is a prime consideration; (2) *Reliability,* particularly in meeting voltage peaks or surges, by taking advantage of their self-healing characteristics; and (3) *Wide Operating Range,* from sub-zero to elevated temperatures.



Let us quote on your metallized-paper capacitor needs. Or if you are not already familiar with metallized-paper advantages, our engineers will gladly show you how they can fit your functions and circuits.

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