Monsanto

FROM (NAME & LOCATION): M. F. BABER - ST. LOUIS

DATE: JUNE 3, 1970 CC

SUBJECT: CAPACITOR INDUSTRY INFORMATION

REFERENCE

TO :

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You will find attached selected background information on the capacitor industry which may be useful in future thinking and planning.

Attachment 1 breaks out the domestic industry by type of capacitor; and presents sales forecasts, descriptions and kinds of materials used for each type.

Attachment 2 was prepared as a rough indication of the total potential for dielectric films and impregnants in paper-film capacitors. It was estimated that in 1975 approximately $100 M of paper and film will be consumed in domestically produced capacitors. Not all these capacitors will be impregnated. However, if they were, they would consume about $10 M of impregnants (Aroclor, mineral oil, etc.) in 1975.

Much of the information in the other attachments comes from the 1960 book on capacitors by Drummer and Nordenberg. I have been unable to locate more recent information of this type.

Mike

MICHAEL F. BABER

MS

Attachments

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Attachment 1

CAPACITORS BY TYPE

SALES AND MATERIALS OF DESIGN

I. SALES AND PROJECTED GROWTH RATE:

		Estimated[1] 1969 U.S. Sales $ M	Estimated Annual[2] Growth Rate 1969 - 1975 $ Sales	Units
1.	Power Line Factor Correction (Aroclor)	$ 35	10%	10%
2.	Lighting Ballast (Aroclor)	25	7%	7%
3.	Aroclor Motor Run, etc. with Paper and/or Plastic Film	25	5%	5%
4.	Paper Dielectric (non-Aroclor) - A.C.	22	(8%)[3]	(9%)
5.	Paper Dielectric (non-Aroclor) - D.C.	13	(8%)	(9%)
6.	Plastic Film Dielectric	43	(1%)	(1%)
7.	Metallized Paper and Film	49	(4%)	(4%)
8.	Dual Dielectric	5	0%	0%
9.	Tantalum Electrolytic	104	10%	12%
10.	Aluminum Electrolytic	96	(7%)	(6%)
11.	Mica Dielectric	24	4%	4%
12.	Ceramic Dielectric	43	2%	(1%)
13.	Monolithic Ceramic	36	2%	(1%)
14.	Other Fixed Dielectrics	14	-[4]	-
15.	Variable Capacitors, All types.	16	(1%)	2%
	TOTAL	$550	2%	-

(1) Source: 1.-3., revised rough estimates based on information from PGB and capacitor company visits; subject to further revision.
4.-15., Electronic Industries Association

(2) Source: 1.-3., MFB rough estimate, does not imply growth of Aroclor consumption
4.-15., Stanford Research Institute report

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(3) Parenthesis represent decline in sales.

(4) Unknown growth rate.

II. CAPACITOR DESIGN AND MATERIALS:

This section presents for each type of capacitor -

a. Normal design structure

b. Normal electrode material

c. Dielectric materials

d. Other important materials used, excluding the case or encapsulating outer coating.

1. Power Line Factor Correction

a. Design - Roll of foil, polypropylene film and paper, impregnated with Aroclor.

b. Electrode - Aluminum (Al)*

c. Dielectric - polypropylene film, paper, Aroclor

2. Lighting Ballast

a. Design - Roll of foil and paper, usually impregnated with Aroclor. Metallized film is being considered.

b. Electrode - Al

c. Dielectric - paper - Aroclor

3. Aroclor Motor Run, Etc., with Paper and/or Plastic Film

a. Design - Presently roll of foil and paper impregnated with Aroclor. Expect conversion from paper to polypropylene film - paper dielectric soon. Within a few years expect redesign to use of metallized film, perhaps with an impregnant.

*Aluminum (Al) foil is used except where specified otherwise.

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b. Electrode - Al

c. Dielectric - Paper and/or polypropylene foil, presently impregnated with Aroclor.

4. & 5. Paper Dielectric (Non-Aroclor)

a. Design - Roll of foil and paper, impregnated.

b. Electrode - Al

c. Dielectric impregnant - Castor oil, mineral oil, polyisobutylene, silicone fluids, mineral wax, chlorinated naphthalene, dibutyl sebacate.

6. Plastic Film Dielectric

a. Design - Roll of foil and film frequently impregnated. Metallized film will see increasing use.

b. Electrode - Al

c. Dielectric film - polystyrene, polyester (Mylar), Teflon, crosslinked polyethylene, polycarbonate, polyimide, polypropylene, cellulose acetate.

d. Impregnants - Silicone fluids, polystyrene, mineral oil and others used to fill pin holes and improve dielectric properties of the film.

7. Metallized Paper and Film

a. Design - Roll of metallized paper or film, usually impregnated (see 4.c.)

b. Electrode - Al coating

c. Dielectric - impregnated paper or film (mostly Mylar)

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8. Dual Dielectric

a. Design - Roll of foil and two dielectrics, primarily paper-plastic film or plastic film-plastic film. (When paper-polypropylene film dielectrics for Aroclor type capacitors become popular, they will show up in this category, except for power line factor and lighting ballast types).

b. Electrode - Al, usually

c. Dielectric - Paper and plastic films shown in 6.c.

d. Impregnants - When used, they will be those in 5.c. and 6.d.

9. Tantalum Electrolytic

a. Design - Roll of tantalum foil or tantalum slugs, separated from a silver cathode by an electrolyte.

b. Electrode - Sintered tantalum slugs, plain or etched tantalum foil; silver cathode in non-foil design.

c. Dielectric - Ta_2O_5 film on foil or slug

d. Electrolyte - Sulfuric acid, lithium chloride, succinic acid, boric acid, or a solid electrolyte of MnO_2.

10. Aluminum Electrolytic

a. Design - Roll of oxide coated aluminum foil.

b. Electrode - Plain or etched aluminum foil, or aluminum-sprayed aluminum gauze.

c. Dielectric - Al_2O_3 film on foil

d. Electrolyte - Aqueous solution of ammonium borate, boric acid and glycol.

11. Mica Dielectric

a. Design - Stacked sheets of mica with electrodes in between.

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b. Electrode - Silver coating or aluminum foil.

c. Dielectric - Mica sheet or chip.

d. Other - Sometimes impregnated with wax to separate molded case from electrode. Frequently encapsulated in epoxy or phenolic resins.

12.&13. Ceramic Dielectric (Including Monolithic)

a. Design - Ceramic tubes, disks or plates, coated on both sides with silver.

b. Electrode - Silver coating.

c. Dielectric - Steatite, titanium dioxides, magnesium ortho-titanate, barium titanate, mixed titanate, fused quartz, bentonite film, other metal oxides.

d. Other - Frequently encapsulated in epoxy or phenolic resin.

14. Other Fixed Dielectrics

a. Design - Various

b. Electrode - Various

c. Dielectric - Various materials including air, vacuum, gases, vitreous enamel, glass, and magnesium silicate.

15. Variable capacitors, All Types

a. Design - Fixed stator plate and movable rotor plates which can be moved to change capacitance of the unit.

b. Electrode - Various

c. Dielectric - Various, including air, vacuum, gases, mineral oil, mica, ceramics, glass, polystyrene film, teflon film.

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Attachment 2

FILM/PAPER CAPACITOR REQUIREMENTS

FOR FILM, PAPER AND INPREGNANTS

(Rough Estimate)

	Estimated U.S. Sales $ M		Potential Consumption of[2] Film/Paper and of Impregnant M Pound	
	1969	1975	1969	1975
Aroclor Types				
Power Line Factor	$ 35	$ 61	11.2	19.8
Lighting Ballast	25	37	7.0	10.5
Motor Run, Etc.	25	34	7.0	9.5
Sub-Total	$ 85	$132	25.2	39.8
			$ 6.0 M of Impregnant[3]	
			$59.0 M of Film and Paper[4]	
Other Paper and Film Capacitors				
Paper Dielectric-A.C.	$ 22	$ 13	6.2	3.6
Paper Dielectric-D.C.	13	8	3.6	2.2
Plastic Film Diel.[1]	43	40	12.0	11.2
Metallized Paper[1] & Film	49	38	13.7	10.6
Dual Dielectric[1]	5	5	1.4	1.4
Sub-Total	$132	$104	36.9	29.0
			$ 4.4 M of Impregnant[3]	
			$44.0 M of Film and Paper[4]	

(1) Estimated sales for 1975 are probably low as a large percentage of Aroclor type capacitors will have plastic, metallized and dual dielectrics (with or without Aroclor).

(2) Depending upon technological developments, the types of capacitors represented by this table could have dielectrics primarily of paper or primarily of film. They could all be impregnated or none could be impregnated. This column gives estimated combined consumption of film and paper. This is identical to consumption of impregnants, if all these capacitors happen to be impregnated (which is unlikely). Assume 0.32 lb. of impregnant and 0.32 lb. of film per $ value for power factor capacitors, and 0.28 lb. of impregnant and 0.28 lb. of film per $ value for other capacitors.

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(3) Assume average price of impregnants at 15¢/pound.

(4) Assume average price of film and paper at $1.50/pound.

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Table 4-4—Capacitor Quality Factors*

Capacitor type	Insulation resistance	Dielectric strength	Dielectric absorption	Power factor	Factor of merit "Q"
1. Air	Very high	Low	Very low	Very low	Very high
2. Vacuum or gas	Very high	High	Very low	Very low	Very high
3. Mica	High	High	Low	Low	High
4. Ceramic	High	High	Low	Low	High
5. Paper	Average	Average	Average	Average	Average
6. Plastic	High	High	Low	Low	High
7. Aluminum oxide†	Very low	Low	High	High	Low
8. Tantalum oxide†	Low	Very low	High	High	Low

E.C.H. (ELECTRONIC COMPONENTS HANDBOOK)

* From Convair Design Manual.
† Ceramic-type capacitors.

Table 4-3—Capacitor Ratings

Description	Style	Min cap	Max cap	Max working volts
Paper	CN	1000 mmf	0.2 mf	1000
Paper	CP	0.001 mf	20 m	12500
Mica	CB	10 mmf	3900 mmf	300
Mica	CM	5 mmf	0.1 mf	35000
Ceramic	CV	1.5 mmf	125 mmf	500
Ceramic	CC	0.5 mmf	1300 mmf	500
Ceramic	CK	100 mmf	10,000 mmf	500
Glass	CY	5 mmf	5100 mmf	500
Air	CT	3.5 mmf	143 mmf	†
Tantalum	CW	0.5 mf	320 mf	630
Electrolytic, AC	CJ	21 mf	552 mf	125
Aluminum, Electrolytic	CE	4 mf	2000 mf	450
	*	0.01 mf	0.25 mf	†
	#	0.01 mf	2.0 mf	†

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* Paper, high-voltage, suppression.
# Paper, feed-through, suppression.
† Not specified.

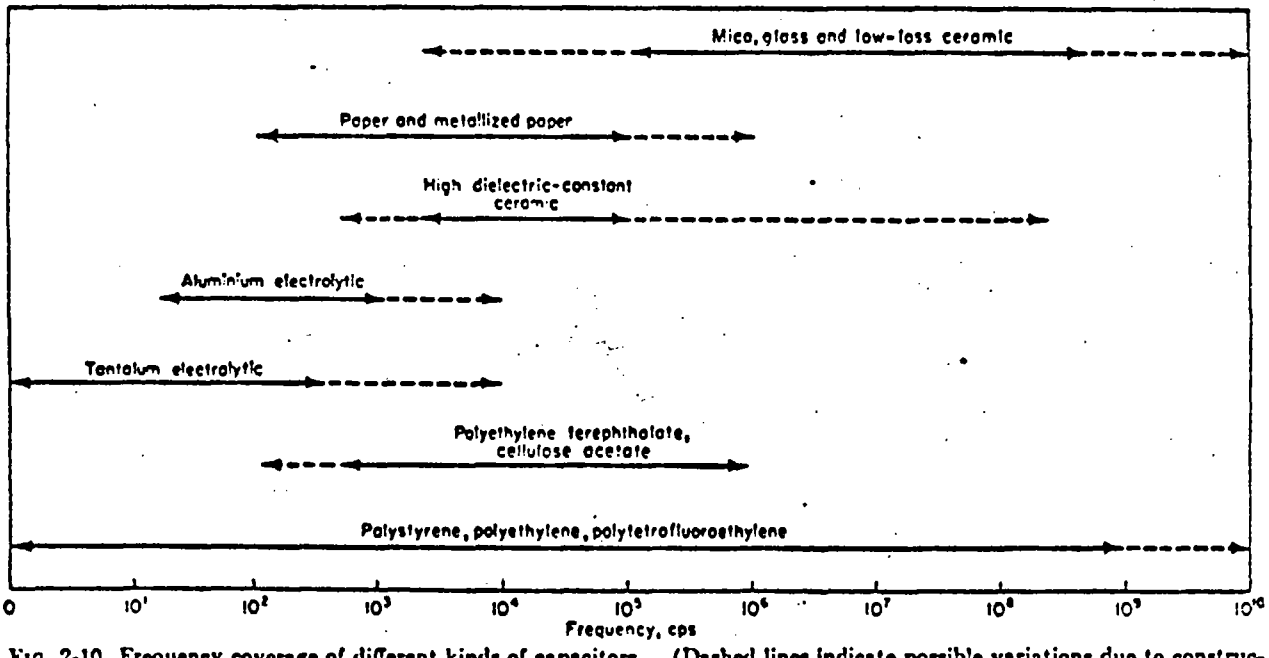

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FIG. 2-10. Frequency coverage of different kinds of capacitors. (Dashed lines indicate possible variations due to construction techniques, capacitance value, etc.)

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TABLE 3-9. SUMMARY OF SOME OF THE IMPORTANT CHARACTERISTICS OF FIXED CAPACITORS (1960)

Type of capacitor (military specification)	Closest tolerance in specification	Power factor (at 1 Kc/sec and 25°C) or Q (at 1 Mc/sec and 25°C)	Temperature coefficient (ppm/°C) characteristics where applicable	Insulation resistance (min at end of life test, megohms)	Length of life test MIL (spec)	Maximum capacitance variation after life tests	Maximum operating temperature for long life
Impregnated paper (MIL-C-25)	±10%	0.004–0.01	•	30% of original specified req.	250 hr max amb & 90 to 100°C of rtd. volt. at 40°C depend on impregnant & watt-second group	10%	85°C or 125°C‡ depending on impregnant
Metalized paper (MIL-C-18312)	±10%	0.005–0.015	•	½ of original specified req.	1000 hr at rtd. volts d-c	10%	85°C or 125°C‡
Molded mica capacitors (MIL-C-5)	±2%	0.001–0.005	B—not specified C ± 200 ppm/°C D ± 100 ppm/°C E + 100 ppm/°C − 20 ppm/C° F + 70 ppm/°C − 0 ppm/°C	7,500	1,000 hr max amb 150% of rtd. voltage	3% or 0.5 pf, whichever is greater	85°C 125°C or 150°C‡
Glass dielectric (MIL-C-11272)	±2%	0.001	140 ± 25 ppm/°C	10,000	1,000 hr at 85°C at 150% of rtd. voltage	2% or 1 pf, whichever is greater	85°C or 125°C‡
Vitreous enamel (none)	•	0.001	115 ± 25 ppm/°C	•	•	•	85°C
Ceramic temp. compensating (MIL-C-20)	±1%	1,000 min	+100 −200 0 −330 −30 −420 −80 −750 −150	1,000	1,000 hr 750 volts d-c +250 volts a-c (peak to peak, not to exceed 100 cycles)	3% or 0.5 pf, whichever is greater	85°C
Ceramic general-purpose (MIL-C-11015)	+100 − 20	0.01 to 0.03 varies with temp., etc.	−1,500 varies non-linear	3,000	1,000 2x rtd. volts d-c	•	85°C or 150°C‡
Mica, button types (MIL-C-10950)	±2%	0.001–0.005	B—not specified D ±100 ppm/°C	7,500 or 50,000 (depends on type of seal)	250 hr & 1,000 hr at 750 volts for 85°C & 125°C units, respectively	3% or 0.5 pf, whichever is greater	85°C or 125°C‡
Polystyrene film (MIL-C-19978)	±5%	4,000 min	−120 ±30 ppm/°C	60% of original specified req.	250 hr 115% of rtd. voltage at 85°C	6% for values <0.05, 3% for values >0.05	65°C (85°C)†
Polytetrafluoroethylene (MIL-C-19928)	±5%	5,000 min	•	60% of original specified req.	250 hr at 115% of rtd. voltage at 170°C	5%	170°C (200°C)†
Polyethylene terephthalate (MIL-C-11978)	±5%	0.01 varies with temperature & frequency	Varies with temperature	60% of original specified req.	250 hr at 50% of rtd. voltage at 125°C	5%	125°C (150°C)†
Aluminum electrolytic (MIL-C-62)	−10 + 150 (up to 50 volts) −10 + 100 (up to 350 volts) −10 + 50 (over 350)	0.02–0.35 (at 120 cps)	•	•	1,000 hr at rtd. voltage	10%	65°C or 85°C‡
Tantalum electrolytic (MIL-C-3965)	±2%	0.02–0.2	•	•	2,000 hr at rtd. voltage		85°C, 125°C or 175°C‡
Tantalum solid-electrolyte (MIL-C-21720)	±10%	0.04–0.06 (at 120 cps)	+600 ppm/°C	•	1,000 hr at rtd. voltage	10%	85°C
Precision-type air dielectric (none)	±0.01	0.00001	+10	•	•	•	25°C

• Not applicable.
† Capacitors may be operated up to these temperatures with proper voltage derating and reduction in life expectancy.
‡ Different maximum operating temperatures specified for different characteristics.

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TABLE 3-11. SUMMARY OF SOME OF THE IMPORTANT CHARACTERISTICS OF VARIABLE CAPACITORS (1960)

Type	Capacitance function, law*	Approximate capacitance swing, pf	Power factor at 1 kc/sec and 25°C	Q at 1 Mc/sec and 25°C	Approximate oper. volts d-c at sea-level pressure	Temp. coeff., ppm/°C	Max oper. temp. for long life	Remarks
Single unit, precision	SLC	100–1,500	0.00001	—	1,000	+10 (best)	—	
Single unit, general-purpose	SLC and SLF	15–100 and 350–550	0.001	—	750	+120	—	
Multigang, general-purpose	SLC and SLF	15–100 and 350–550	0.001	—	750	+120	—	
Multigang, miniature, general-purpose	SLC	300–350	0.001	—	500	+150	—	
Trimmers, air-diel. vane type	SLC	3.5–145	—	250 min.	C1:850 C2:1,150 C3:1,400	+50–150	85°C	Covered by mil. spec. MIL-C-92
Trimmers, glass-diel. piston type	SLC	0.5–30	—	500 min.	500	±100	125°C	Covered by mil. spec. MIL-C-14409
Trimmers, ceramic dielectric	SLC	7–45	—	500 min.	500	Char. T-C *A* NPO *B* N300 *C* N500 *D* N650		Covered by mil. spec. MIL-C-81
Trimmers, mica compression	Non-linear	15–3,000	0.001	—	250–500	Poor	—	

* See Chap. 14.

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Table 4-5.—Common Capacitor Applications

Description	CM	CP	CN	CB	CK	CW	CE	CT	CC	CV	CJ	CY
	Mica, molded or potted -- MIL-C-5A	Paper, hermetically sealed in metallic case -- MIL-C-25A	Paper, nonmetallic case -- MIL-C-91A	Mica, button type -- MIL-C-10950A	Ceramic, general purpose -- MIL-C-11015A	Electrolytic, tantalum -- MIL-C-18211 (Navy); MIL-C-25102 (USAF) and MIL-C-14000 (SigC)	Electrolytic, d-c -- JAN-C-62	Air, trimmer -- JAN-C-92	Ceramic, temperature compensating -- JAN-C-20A	Ceramic, variable -- JAN-C-81	Electrolytic, a-c -- MIL-C-3871	Glass -- MIL-C-11272A
Common applications												
Blocking	X	X	X									X
Buffer	X	X										
Bypass	X	X	X	X	X	X	X					X
Coupling	X	X		X	X			X	X	X		X
Filtering	X	X	X		X	X	X					
Tuning	X			X				X	X	X		X
Motor starting											X	
Temperature compensation									X			

X Indicates uses mentioned in the pertinent MIL or JAN specification.

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Dielectric constant K	
Vacuum	1.0
Dry air	1.00059
Polystyrene	2.5
Polytetrafluoroethylene (Teflon*)	2.0
Polyethylene terephthalate (Mylar*)	3.0
Impregnated paper	4.0-6.0
Mica	6.8
Tantalum oxide	25.0†
Aluminum oxide	7.0
Ceramic (magnesium titanate, etc.)	Up to 20
Ceramic (titania)	80-100
Ceramic (high-K‡)	1,000 and upward

* Registered trademark of E. I. du Pont de Nemours & Company.

† Approximate value, with general acceptance.

‡ The high dielectric constant in high-K ceramic capacitors comes from the fact that the electric charges in the molecular structure of the material are very loosely bound and can move almost freely under the polarizing voltage, resulting in high total capacity.

Table 4-1—Dielectric Constants of Typical Insulating Materials at 25 C

Material	K	Power factor (percent)
Vacuum	1.0	0
Air	1.0001	0 +
Teflon	2.0	0.02
Polystyrene	2.5	0.015
Mylar	3.0	0.5
Polyethylene	3.3	0.1
Lucite (or Plexiglass)	3.5	6.
Textolite	4.	0.2 to 4.
Fused quartz	4.4	0.02
Pyrex	4.7	0.05
Kraft paper	2-6	0.5 to 1.0
Cellulose acetate	4-6	2.0
Steatite	6.3	0.08
Lead glass	6.6	0.06
Mica	6.8	0.02
Tantalum oxide	11.0	10.0
Titanium dioxide	120. +	0.07 +
Mangnesium ortho-titanate	2,000. +	2. +
Barium titanate	6,000. +	2.5 to 3.

C.C.H.

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TABLE . PROPERTIES OF SOME CAPACITOR DIELECTRIC ATERIALS

Material	Power factor (at 25°C)		Dielectric constant (K) at 25°C, 60 cps	Capacitance at 85°C relative to 25°C, 60 cps, %	Insulation resistance, (ohm-farads) 500 volts d-c		Dielectric absorption 1 min after 2-sec discharge, %	Operating temp range, °C	Remarks
	60 cps	1 kc/sec			25°C	85°C			
Paper (Kraft Cap tissue) with:									
Mineral oil	0.002	0.0025	2.23	102	15,000	100	2.0	−55 to 105	Maximum frequency of operation approx. 1 Mc/sec
Castor oil	0.005	0.007	4.7	96	1,500	50	2.5	−25 to 65	
Silicon oil	0.003	0.0035	2.6	101	20,000	150	1.0	−60 to 125	
Polyisobutylene	0.002	0.003	2.2	101	20,000	150	1.0	−55 to 125	
Chlorinated naphthalene	0.004	0.005	5.2	93	4,000	50	2.5	−20 to 55	
Chlorinated diphenyl	0.0025	0.003	4.9	96	10,000	100	2.5	−55 to 85	
Polyethylene terephthalate	0.0025	0.001	2.8	101	100,000	10,000	0.25	−70 to 150	Losses are high, between 1 and 10 Mc/sec
Above with silicone fluid	0.0025	0.0015	3.0	102	20,000	2,000	2.0	−60 to 150	
Polytetrafluorethylene (cast film)	0.001	0.0005	2.05	99	1,000,000	100,000	0.02	−90 to 200	Maximum freq. of operation, approx. 10,000 Mc/sec
Above with silicone fluid	0.001	0.0005	2.1	98	20,000	20,000	2.5	−60 to 200	
Cellulose acetate	0.009	0.015	3.8	105	15,000	200	1.5	−70 to 125	
Above with silicone fluid	0.01	0.016	3.8	101	8,000	100	2.5	−60 to 125	
Polystyrene	0.001	0.0005	2.6	99	1,000,000	100,000	0.02	−70 to 85	Maximum freq. of operation, approx. 10,000 Mc/sec
Polyethylene	0.001	0.0005	2.25	96	100,000	1,000	0.02	−70 to 85	
Mica (ruby)	0.0025	0.0000	5.5	100	100,000	1,000	0.7	−60 to 160	Maximum freq. of operation, approx. 10,000 Mc/sec

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TABLE 2-2. PROPERTIES OF SOME CAPACITOR DIELECTRIC MATERIALS (*Continued*)

Material	Loss (at room temperature)			Dielectric constant (over operating frequency range)	Dielectric strength, volts per mil (breakdown)	Temperature limits, °C		Remarks
	Limiting frequency of operation		Power factor (loss angle tan δ)			Approx. min	Approx. max	
	Approx. min	Approx. max						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Glass (soft lead-soda)	200 cps	10,000 Mc/sec	0.001	6.5–6.8	<500	No limit	+200	
Glass (hard, borosilicate)	100 cps	10,000 Mc/sec	0.001	4.0	<500	No limit	+200	
Quartz (fused)	100 cps	>10,000 Mc/sec	0.0002	3.8	1,000	No limit	+300	
Ceramic (Low-dielectric-constant types) Magnesium silicate	100 cps*	10,000 Mc/sec	0.001	5.4–7.0	200–300	No limit	+150	
Ceramic (Medium-dielectric-constant types) Titania Rutile (TiO_2)	500 cps*	5,000 Mc/sec	0.001	70–90	100–150	No limit	+125	
Ceramic (High-dielectric-constant types) Titanate	1,000 cps*	1,000 Mc/sec	0.01	Approx. 1,000–over 7,000	100	−100	+120	Characteristics dependent on temperature. Sharp max in dielectric constant at 120°C. Dielectric constant depends on volts. Below 120°C hysteresis occurs and loss dependent on volts. Other high-K materials exist with different peaks

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* Can be direct current, but slow capacitance change is possible.

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FIXED AND VARIABLE CAPACITORS

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FIXED CAPACITORS NOW AND IN '69

Better control over dielectric thickness has led to increased capacitance and giant-step improvements in the basic property of volumetric efficiency. And more advances in this basic property are on the way.

BOB KOEPER, Senior Editor

Manufacturer forecasts of improved capacitor capabilities during the coming 12 months are no more than extensions of the last 2 years' developments, a recent EDN survey shows. Many capacitor builders declined to forecast, but among those who did, most predicted comparable performance from smaller physical size, a trend that has already placed capacitors in the micro class.

Both current and anticipated improvements in volumetric efficiency can be linked in part to the growing demand for capacitors in hybrid circuits. This demand will result in more R&D money to further reduce the thickness of dielectric materials; but, because handling becomes more difficult as thickness decreases, the use of deposited dielectrics is expected to advance.

Other forecasts for the coming year include:

- Improvements in reliability brought about by new materials that include polymer films and new coating material for making unglassed, uncased capacitors.
- Packaging of film capacitors for specific applications and cost improvements.
- 200°C "Teflon".
- High voltage- and current-handling capacitors for SCR applications.
- Higher K and more stability while still maintaining a high Q.
- "X" characteristic capacitors with a ±15-percent temperature coefficient.

Now for the Present

EDN's Basic Property Charts on the following pages reflect what has taken place in capacitors in the past 2 years. Manufacturers' views on the reasons for these improvements are recapped by major dielectric categories used on the charts. Much of what is manufactured is not in the strict sense off-the-shelf, and a much larger number of components is available to the designer who is familiar with trade-offs available among such variables as size, stability and price. Designers should be aware of the broad range of characteristics available to get the best component for an application. The Basic Property Charts furnish a handy reference for comparing dielectric characteristics.

Electrolytics

In the aluminum electrolytic capacitor, a semisolid, leakproof, nonaqueous electrolyte makes lower-cost seal construction capacitors extremely reliable, electrically stable and naturally seepageproof. A second development extends the operating temperature of large computer-grade aluminum electrolytics to 125°C without derating. This extension results from the new semisolid electrolyte and an improved anodizing process. These 125°C units now are available in values from 100 to 200,000 μF over a voltage range from 3 to 100V.

Also attributed to electrolyte developments is the extended temperature range for aluminum electrolytics, which now spans from −80 to 150°C. And the 125°C voltage rating has been increased from 50 to 80 percent of the 85°C value.

All tantalum-type capacitors have increased in volumetric efficiency by a factor of almost 2:1. Top capacitance value of foil units increased from 580 to 8700 μF and for solids from 680 to 1000 μF.

Paper Film

While the charts reflect little change in paper capacitors, paper-"Mylar" types have seen an increase of more than a factor of 6 in the maximum capacitance values available (from 30 to 200 μF). Also, the maximum CV product is up from 750 to 120,000, and the maximum dc working voltage has increased from 15 to 125 kV.

Film

Many of the film capacitor advances are directly related to improvements in basic dielectrics stemming from the use of ultraclean rooms for manufacturing plastic films. Resulting thinner dielectrics have, for example, made possible a 100-μF metallized polycarbonate capacitor. Two years ago EDN reported this type of capacitor available only to 10 μF. Reduced film thicknesses also have resulted in 50V rated metal-

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Reprinted from the November 11, 1968 Issue of EDN Magazine, A Cahners Publication

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lized polycarbonate lines with a 45-percent volume reduction over that of 100V lines. Similar results, with 33-percent volume reduction, have occurred in "Mylar" units. Because very thin metallized "Mylar" is not yet available, current 50V units are 100V devices with voltage derating for 125°C operation.

Four dielectrics have been added to the film category. They are polypropylene, polyethylene, "Kapton" and "Metfilm A". Polyethylene raises the film-type capacitor to a new high of 400 μF, while "Kapton" (a Du Pont trademark) offers a high-voltage temperature-stable device (negative temperature coefficient) over a temperature range from −80 to 200°C. "Metfilm A" (a Sprague trademark) is a metallized acetate capacitor that offers high volumetric efficiency.

Special Types

One addition has been made to the special-type category. "Amplifilm" (an Amp, Inc. trademark) is a line of wafer capacitors with a maximum capacitance range to 1 μF at 5000V, dropping to 0.15 μF at 15 kV.

Other specials repeated from 2 years ago include synthetic resin capacitors made by impregnating a foil electrode of aluminum (or tin) with a dielectric resin. This capacitor's temperature coefficient is nonlinear, but stays within ±35 ppm/°C between 20°C and 125°C.

"Parylene", a thin-film development by Union Carbide, is a plastic suitable for deposition that yields a good dielectric film.

Tantalum oxide (nonelectrolytic) capacitors are available to 0.033 μF and 125V. Except for the fact that they are slightly polar, they can be compared to stable miniature ceramic capacitors.

Glass Ceramic

The greatest advances in glass ceramic capacitors have been in volumetric efficiency. General-purpose ceramic capacitors, for example, have experienced a change from 1300 to 55,000 $(\frac{\mu F\text{-}V}{in^3})$—an improvement factor of 42. This improvement is attributed to new capability of producing uniform, reliable ceramic-dielectric materials in very thin form. Porcelain, too, has seen big improvements. In one case the use of a very stable dielectric has shrunk the physical size of a traditional MIL-11272B device by 1 to 2 orders of magnitude. A 1000- pF device with a "Q" of 10,000 at 1 MHz and a 90 ppm TC was packaged in a 0.1-in square. This high-temperature porcelain dielectric is reported to have a higher K than glass or traditional porcelains, giving increased packaging density without sacrificing stability.

Added to this glass-ceramic category are monolithic ceramic, high K glass and fixed composition types. Monolithic units have great volumetric efficiency and a linear temperature coefficient and find their widest use in the manufacture of hybrid circuits. Their frequency and temperature characteristics make them attractive where previously only mica could be used. High K glass offers the size advantage of ceramic capacitors but with glass capacitor performance. In chip form these glass K capacitors will be offered for use in hybrid circuitry in a range from 270 pF to 2 μF.

Mica

Receiving types now have a new low working voltage rating of 50V and a temperature range that extends from −55 to 150°C. The upper level of working voltage for mica transmitting types has increased, by a factor of 2, to 100 kV.

Reconstituted mica paper has been added. These units operate at unusually high temperatures. Their capacitance and dissipation factor change comparatively little over a wide temperature range. Insulation resistance is comparatively good at all temperatures and their resistance to radiation is very good.

Vacuum

Probably the biggest reported change in vacuum capacitors is extension of their lower operating temperature. Two years ago the low temperature reported was −35°C. Now it is −100°C. Volumetric efficiency for this type of capacitor also shows a marked increase. □

Acknowledgments

EDN is indebted to the following capacitor manufacturers for taking time to provide comments and for their help in updating the basic property charts of fixed capacitors:

American Lava Corp., Chattanooga, Tenn.; American Technical Ceramics, Huntington Station, N.Y.; Amp, Inc./Capitron Div., Harrisburg, Pa.; Cambion, Cambridge, Mass.; Centralab, Milwaukee, Wis.; Chicago Condenser Corp., Chicago, Ill.; Component Research Co., Santa Monica, Calif.; Components, Inc./Semcor Div., Phoenix, Ariz.; Cornell-Dubilier Electronics/Div. of Federal Pacific Electric Co., Newark, N.J.; Corning Electronics, Corning, N.Y.; Dickson Electronics Corp., Scottsdale, Ariz.; Electro Motive Mfg. Co., Inc., Willimantic, Conn.; Erie Technological Products, Inc., Erie, Pa.; General Laboratory Assn., Inc., Norwich, N.Y.; ITT Jennings, San Jose, Calif.; JFD Electronics Co./Components Div., Brooklyn, N.Y.; Marshall Industries/Capacitor Div. Monrovia, Calif.; Maxwell Laboratories, Inc., San Diego, Calif.; Mepco, Inc., Morristown, N.J.; Monolithic Dielectrics, Inc., Burbank, Calif.; Ohmite Mfg. Co., Skokie, Ill.; Plastic Capacitors, Inc., Chicago, Ill.; Potter Co. CFT Div., Wesson, Miss.; P. R. Mallory Co./Div. of Radio Material Co., Chicago, Ill.; RF Interonics, L.I., N.Y.; Solar Mfg. Corp., Los Angeles, Calif.; Sprague Electric Co., North Adams, Mass.; Stackpole Carbon Co., St. Mary's, Pa.; STM Corp., Oakland, Calif.; Texas Instruments Incorporated, Dallas, Tex.; U.S. Capacitor Corp., Burbank, Calif.; Varadyne, Inc., Santa Monica, Calif.; Vitramon, Inc., Bridgeport, Conn.

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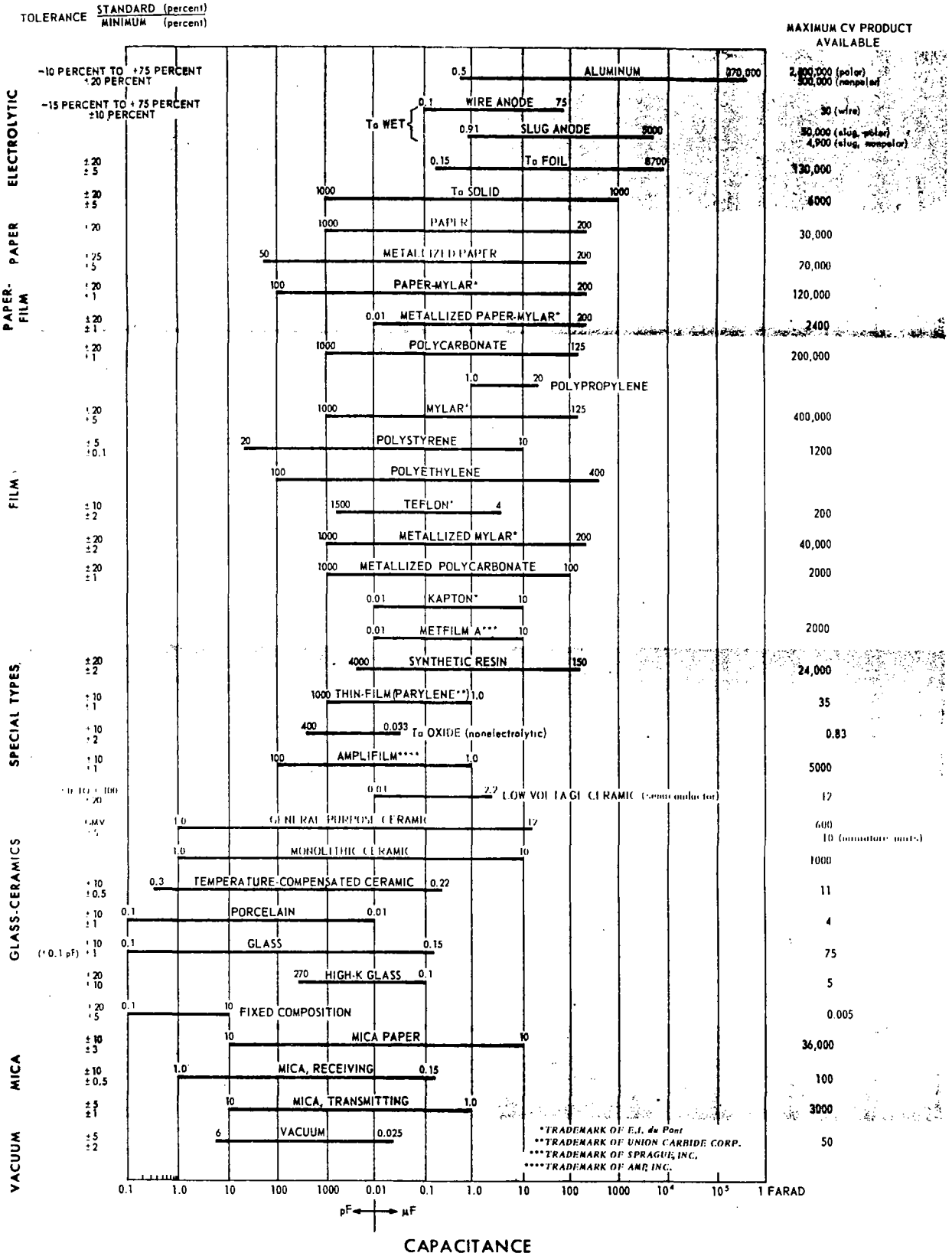
Basic Property Charts of Fixed Capacitors



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Ranges **of capacitance** for commercially available fixed capacitors. Shown are capacitance ranges for each dielectric, along with standard and minimum tolerances commercially available. Maximum CV product (microfarad-volts) indicates maximum voltage available for a certain capacitance value, and vice versa.

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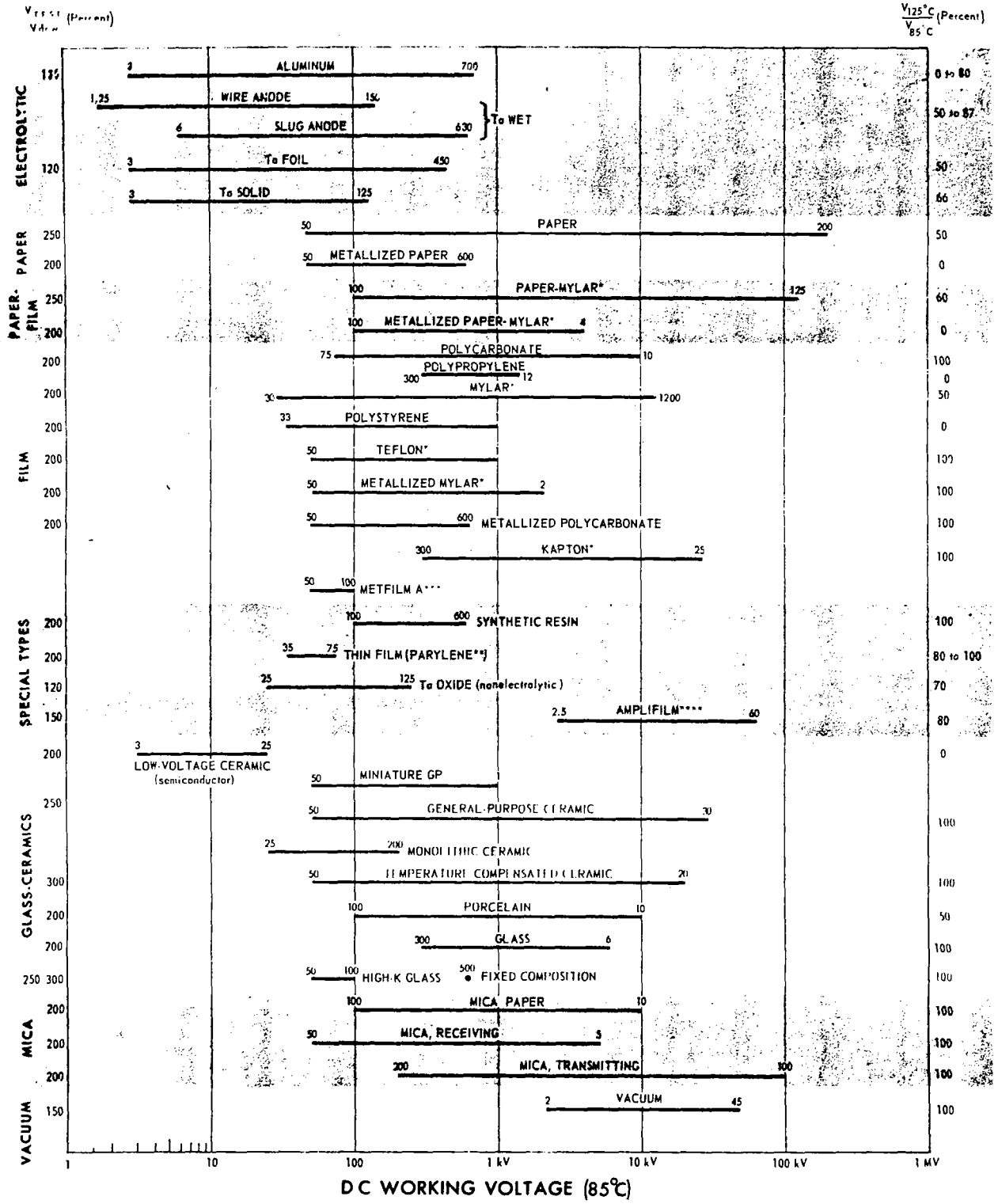

Voltage ratings (at 85°C) of commercial fixed capacitors. Voltage rating at 125°C is indicated as percentage of 85°C value. As a guide for operation under transient voltages, chart shows test voltage as percentage of Vdcw. If you expect transients in your circuit, refer to the manufacturer's test voltage. AC voltage ratings under 200V rms depend almost exclusively on ac current ratings, which are limited by Joule-effect and dielectric losses. At frequencies greater than 400 Hz, the corona start voltage, peak voltage and type of dielectric system must be considered in addition to ac current ratings. To obtain approximate value of the maximum capacitance available at each dc working voltage, refer to the maximum CV product listed in the capacitance chart.

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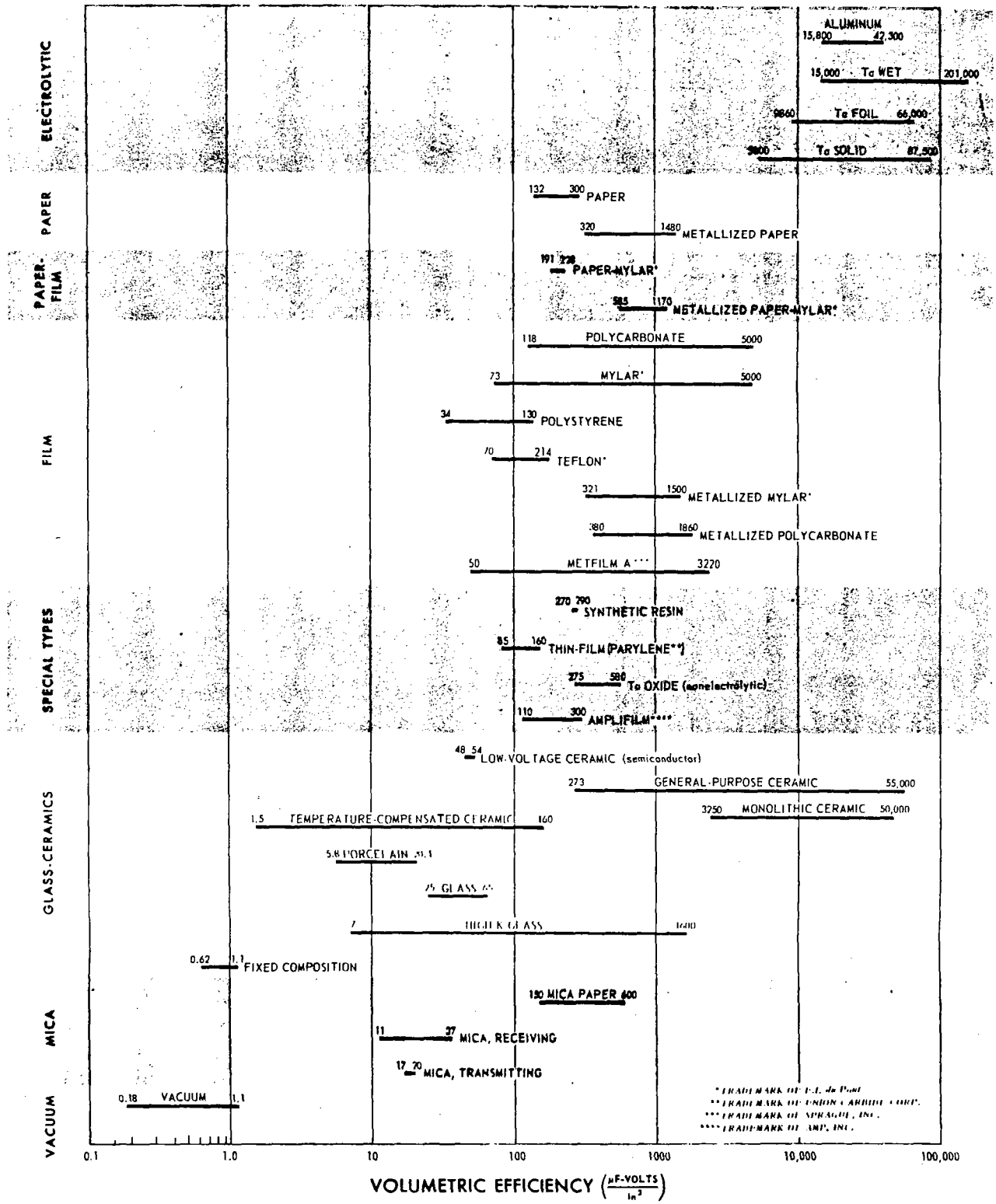

Volumetric efficiency expressed in microfarad-volts per cu in. The values as shown here have been computed by considering only the capacitor case without leads. Cylindrical units pack more microfarad-volts than rectangular ones, although rectangular units can be stacked more compactly in a circuit. Miniature capacitors have lower volumetric efficiency than the large capacitors because there are two factors that take a proportionately larger share of volume in miniature units. These factors are encapsulation and margin (unused dielectric extending beyond the electrodes to prevent voltage breakdown around edge).

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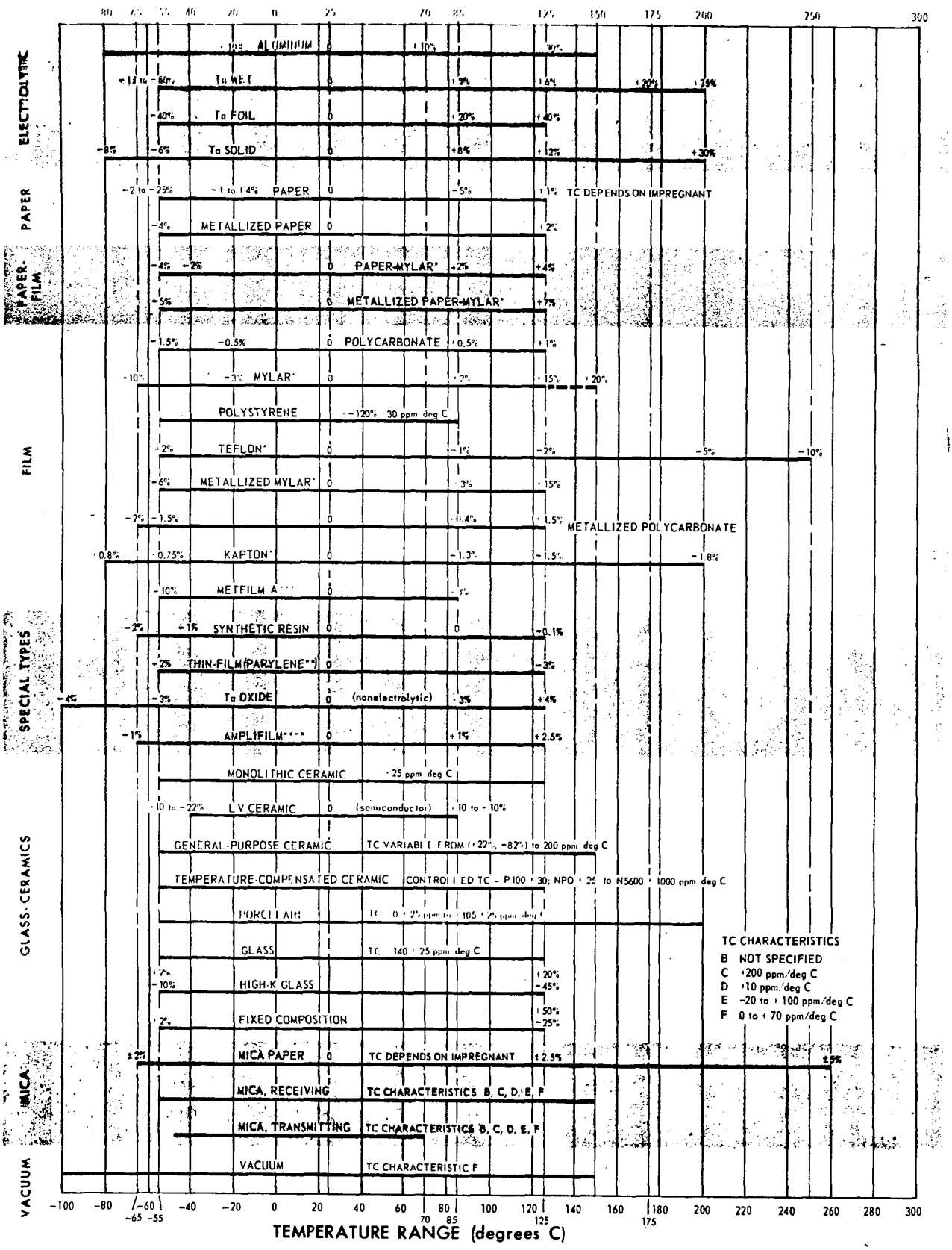

Temperature ranges of commercial capacitors, and effect of temperature on capacitance and voltage. When capacitance variation is nonlinear, its change at each important temperature is referred to capacitance at 25°C. Polystyrene, TC ceramics and glass exhibit linear and predictable temperature coefficients.

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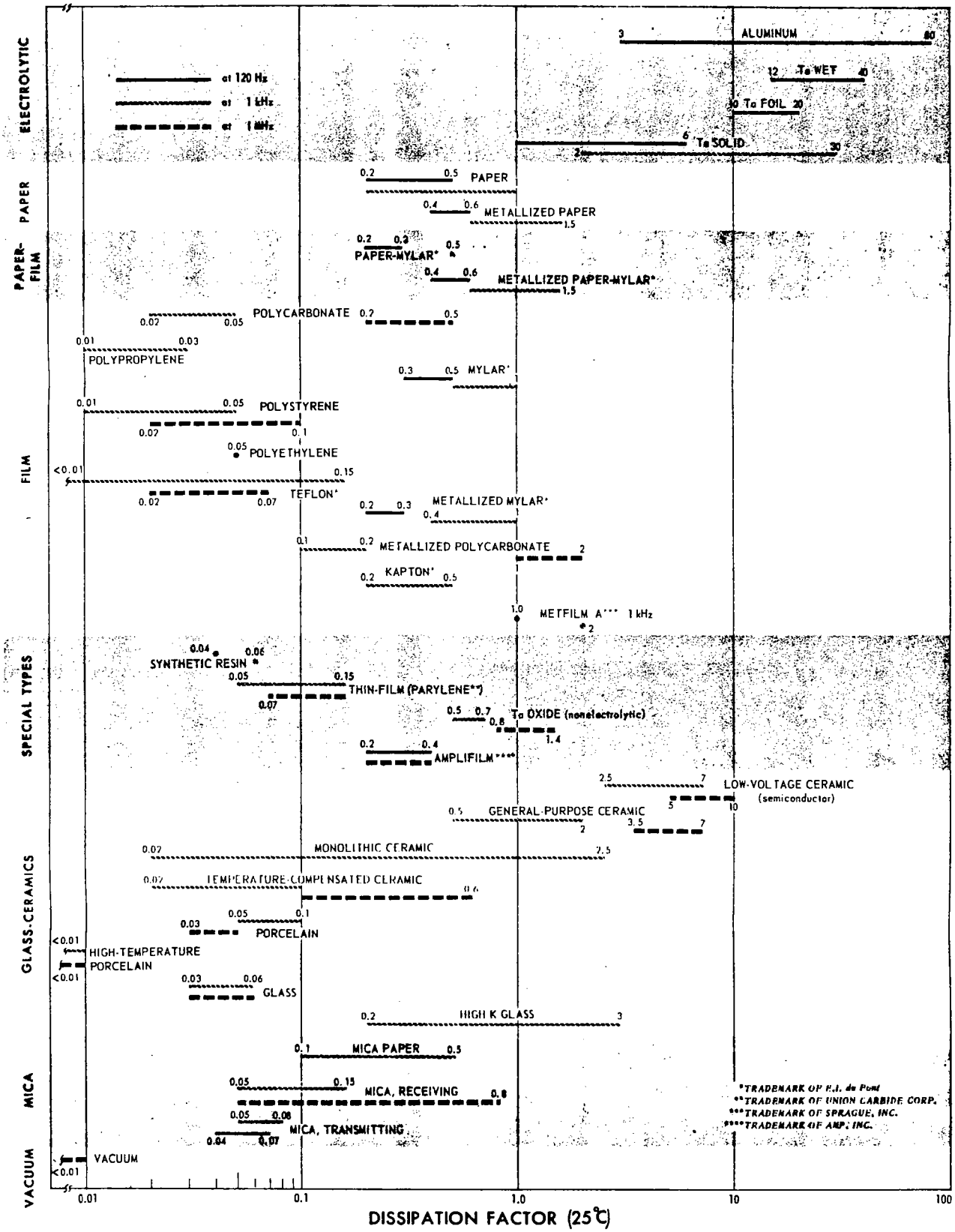

Power factor at 25°C, expressed in percentage. Most dielectrics exhibit an increase in their losses with increases in both frequency and temperature. Such changes are smaller for polystyrene, ceramics, glass and micas. Data are available typically at 120 Hz (for filtering), at 1 kHz and 1 MHz. At temperatures above 10 KHz, both the capacitance value and form factor greatly influence the dissipation factor.

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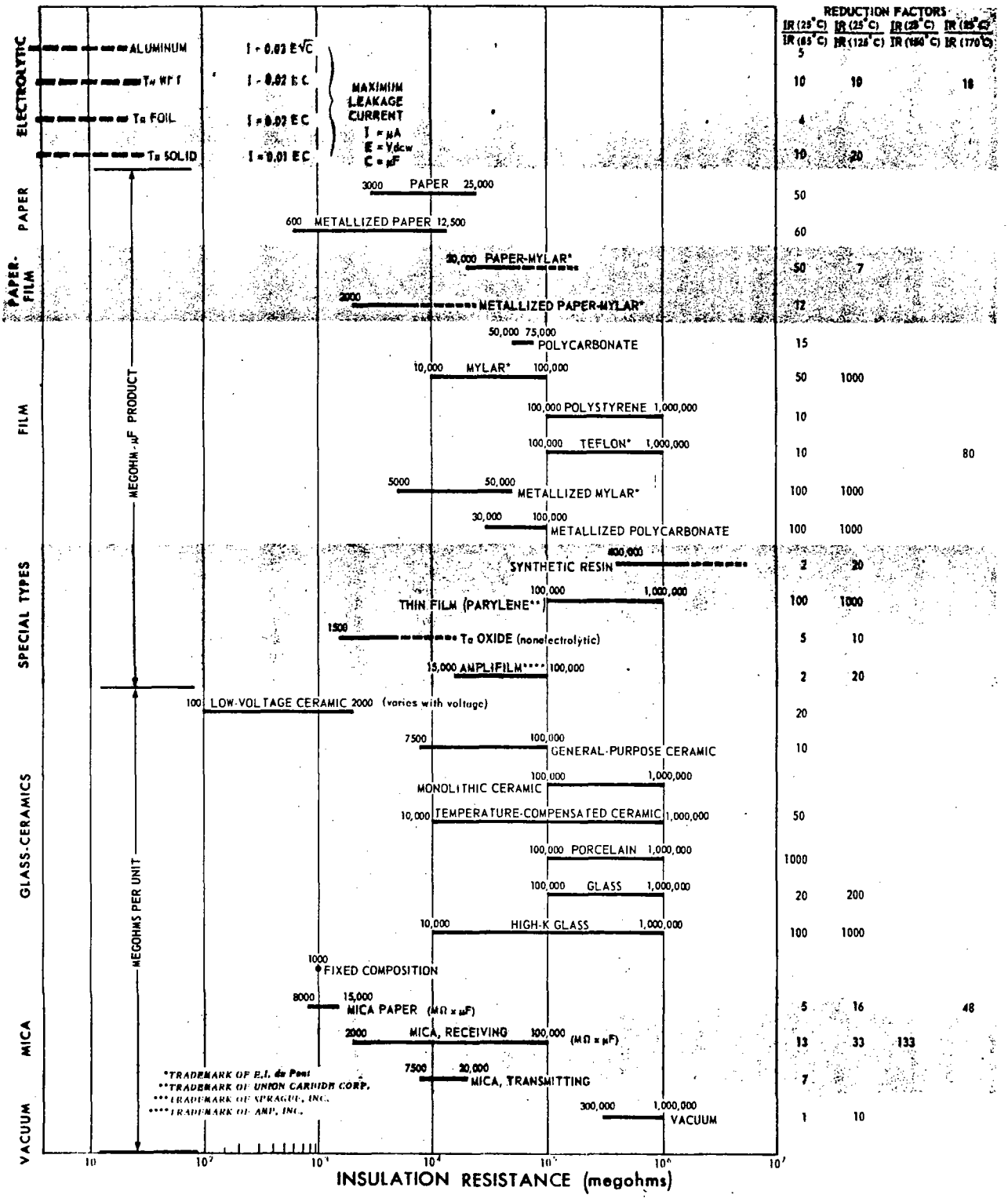

Insulation resistance at 25°C. This resistance appears in parallel with the capacitance. Its value is expressed directly in megohms per unit for ceramic, glass and mica capacitors unless noted. Insulation resistance (IR) of rolled capacitors (paper and films) is calculated by dividing megohm-microfarad product by capacitance of unit. Electrolytic capacitors are specified in terms of their leakage current, because the resistance of an electrolyte is nonlinear. Insulation resistance decreases for all dielectrics as temperature increases. Chart shows reduction factor for the key temperatures, referred to insulation resistance value at 25°C. When IR is used as a quality indicator rather than a circuit requirement, the 25°C measurement loses much of its value and the 125°C measurement becomes the better indicator.

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