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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A HETERODYNE FREQUENCY METER FOR 10 TO 3,000 MEGACYCLES

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● TO MEASURE FREQUENCIES, power from an unknown source can be absorbed in a calibrated resonant circuit and made to operate an indicator. The indicator can be an incandescent lamp, a glow tube or a galvanometer preceded by a detector. This simple and straightforward method requires appreciable power and is

limited to frequencies for which resonant circuits are available.

In a heterodyne frequency meter, the power required from the unknown source to produce beat notes with a calibrated oscillator is smaller by several orders of magnitude, and the frequency range that can be covered with a single oscillator, spanning a two to one range, extends continuously over several decades.

If the unknown frequency is lower than the lowest frequency of the heterodyne oscillator, harmonics of the unknown are used to produce beats with the oscillator fundamental. If the unknown is higher than the highest frequency of the heterodyne oscillator, harmonics of the oscillator are used. In either case the harmonics are produced in a non-linear element of the heterodyne frequency meter.

Experience has shown that harmonics up to the twentieth order can be used in an instrument of this type with a corresponding spacing of 5% between frequencies which

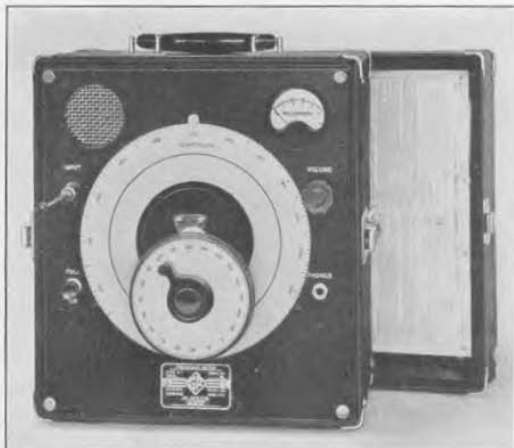


FIGURE 1. View of the Type 720-A Heterodyne Frequency Meter with cover removed.



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produce adjacent beats. It follows that the calibrated oscillator should have a range of approximately 100 to 200 megacycles if unknown frequencies up to 3,000 megacycles are to be measured.

The chief obstacle to producing a heterodyne frequency meter for this range has been the erratic performance of oscillators using conventional tuned circuits. Sliding contacts produce erratic variations in frequency and amplitude, while changes in tubes and supply voltages have much greater effects than at lower frequencies. The newly developed Butterfly Circuit,* however, has made it possible to avoid most of these difficulties. With the new TYPE 720-A Heterodyne Frequency Meter, which uses the Butterfly Circuit, a frequency of 3000 Mc can be measured as conveniently and as accurately as those in the broadcast range. The low-frequency limit for normal use is about 10 Mc, but lower frequencies can be measured if more than 1 volt at the unknown frequency is available at the detector input.

The TYPE 720-A Heterodyne Frequency Meter is a portable battery-operated instrument of small size and light weight, with unusually high sensitivity. The panel view of the new instrument is shown in Figure 1. A complete set of operating instructions is mounted

*E. Karplus, "The Butterfly Circuit," *General Radio Experimenter*, Volume XIX, No. 5, October, 1944.

in the removable cover. The functional elements of the instrument are a calibrated oscillator, a detector, and an audio amplifier as shown in the schematic diagram of Figure 2. An internal view of the instrument is shown in Figure 3.

Oscillator

The frequency of the heterodyne oscillator is continuously variable between 100 and 200 megacycles. The frequency-determining element is a tuned circuit of the butterfly type, with rotor plates shaped to give an approximately logarithmic frequency distribution. The rotor is mounted in ball bearings. No sliding contacts are used, and no current flows through the bearings. Smooth adjustment of frequency and stability of calibration are therefore assured.

The main dial of the frequency meter is calibrated directly in megacycles. The scale is 15" long and approximately logarithmic. The gear ratio between the tuned circuit and the vernier dial is over 200:1. Over most of the frequency range one-half turn of the vernier dial corresponds to 1% variation in frequency, and one division of the vernier dial to a frequency change of 100 parts per million. Unknown frequencies are measured by producing beats with the calibrated heterodyne oscillator. Beats may be produced between the fundamentals of the unknown source and the

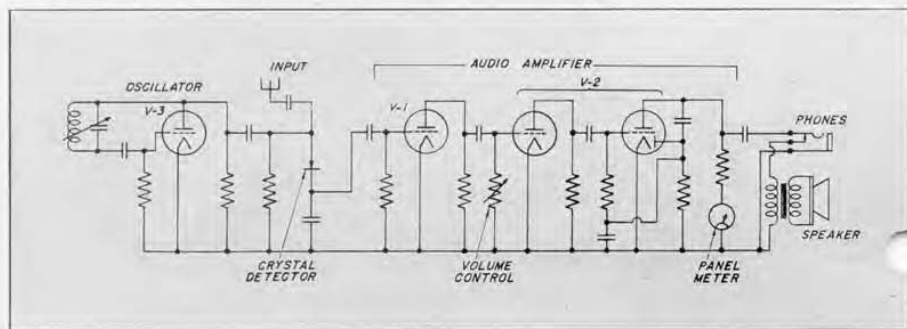


FIGURE 2. Schematic circuit diagram of the heterodyne frequency meter.

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heterodyne oscillator, between harmonics of the unknown frequency and the heterodyne fundamental, between the unknown fundamental and harmonics of the heterodyne oscillator, or between harmonics of both the unknown source and the heterodyne oscillator.

Detector

The detector, in which the harmonics of the known and unknown frequencies and their beats or difference frequencies are produced, is a standard 1N21B-type crystal detector, consisting of a silicon crystal and a tungsten wire, mounted in a small ceramic cartridge. The detector cartridge is located near the antenna input terminal and is held in place by a ring-shaped spring. A spare detector is furnished with the instrument, but, since the cartridge used has standard dimensions, different makes and types of detectors can be substituted.

Adequate input to the detector is usually obtained if the instrument is placed in the vicinity of the oscillator whose frequency is to be measured. An input antenna of adjustable length is permanently mounted on the front panel. This adjustment is used to improve signal strength when working with frequencies above 1000 Mc. For frequencies below 100 Mc, it may be necessary to connect an additional wire to the "input" terminal.

Amplifier

The three-stage audio amplifier has an effective band width of 50 kc and is connected to produce a deflection of the panel meter when a strong signal is impressed on the detector. This feature is particularly useful when the frequency under measurement is not sufficiently stable to produce a steady audible beat. Audible beats are simultaneously heard in the small dynamic speaker mounted on the front panel. Weak beat notes are

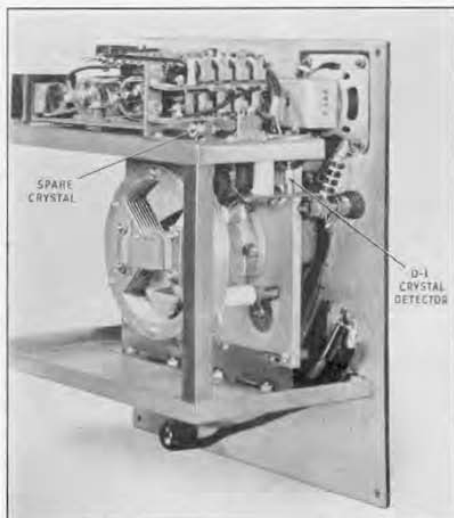


FIGURE 3. Interior view showing the butterfly-type tuned circuit and the location of the working and spare crystals.

best observed with a pair of headphones plugged into the PHONES jack.

Power Supply

One Burgess TYPE 6TA60 Battery is used to supply 90 volts to the plates and 1.5 volts to the filaments of the three vacuum tubes used. All necessary connections are made by a battery plug attached to a short cable. The filament and plate loads are well balanced, and the battery will give long service in intermittent use. Since the heating up time of the tubes is very short, the instrument can be turned off if appreciable time elapses between measurements. The instrument can also be operated from a rectifier power supply, and a compact a-c power unit to fit the battery compartment will be available later.

Making Frequency Measurements

The process of making frequency measurements by the heterodyne method consists fundamentally of three



steps. The first is to establish a beat note between the unknown source and the heterodyne oscillator. The second step is to determine the order of the beat observed, and the third step is to determine the frequency of the heterodyne oscillator.

With the TYPE 720-A Heterodyne Frequency Meter the last step consists merely in reading the directly-calibrated main dial of the instrument. The accuracy thus obtained is 0.1%. If higher accuracies are desired, the true frequency of the heterodyne oscillator can be measured in terms of a more accurate low-frequency standard. The TYPE 720-A then is merely a convenient stepping stone between the high unknown frequency and the low standard frequency, which are too far apart to produce beat notes by themselves. The best procedure to establish beat notes and to determine their order depends on whether the unknown frequency is in the range of the fundamental oscillator frequency or above or below. In general, if the "unknown" frequency is known approximately, a single beat is sufficient to determine the frequency accurately. On the other hand, if the approximate value is not known, it will be necessary to note successive beats until their pattern can be determined.

Frequencies between 100 and 200 Mc. When the frequency to be measured lies within the fundamental

range of the TYPE 720-A Heterodyne Frequency Meter, the unknown frequency is read directly from the main dial when a strong beat is obtained. In addition to this beat note, other weaker beat notes may be heard. For example, if a fundamental frequency of 150 Mc is measured, a strong beat will be obtained at a dial setting of 150.0 Mc, and weaker beats may be heard at dial settings of 100 and 112.5 Mc. These weaker beats are produced between the 2d and 3d harmonics of the unknown frequency and the 3d and 4th harmonics of the TYPE 720-A Oscillator, respectively; $2 \times 150 \text{ Mc} = 3 \times 100 \text{ Mc}$ and $3 \times 150 \text{ Mc} = 4 \times 112.5 \text{ Mc}$.

Frequencies over 200 Mc. For frequencies which lie above 200 Mc the procedure is to start at the high end of the frequency range and to note the successive settings of strong harmonic beats as the frequency of the heterodyne oscillator is progressively reduced. If the frequency at which one beat occurs is divided by the frequency difference between it and a successive beat, the result must be an integer and is the harmonic number of the successive beat. *Example:* A high frequency is measured and strong beats are obtained at 200.0 and 160.0 Mc. Subtracting the second beat from the first gives $200.0 - 160.0 = 40.0$. Dividing the first beat by this difference gives $200.0 / 40.0 = 5$, which is the harmonic number of the second

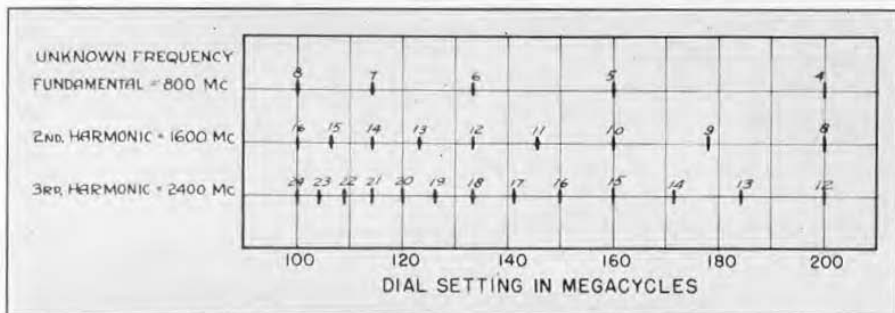


FIGURE 4. Chart showing pattern of harmonic beats for an unknown frequency of 800 megacycles.





beat. Hence, the unknown frequency is $5 \times 160.0 = 800.0$ Mc.

In many cases it will be possible to produce beats between harmonics of the unknown frequency and harmonics of the heterodyne oscillator. These beats will usually be much weaker than the beats produced between the unknown fundamental and the heterodyne harmonics. The chart of Figure 4 gives the possible beats up to the 3d harmonic of the unknown used in the example above.

Frequencies under 100 Mc. For frequencies which lie below 100 Mc, the procedure is to start at the low end of the frequency range and to note the successive settings of beats as the frequency of the heterodyne oscillator is progressively increased. The frequency difference between two successive beat settings is equal to the unknown frequency. *Example:* A low frequency is measured and beats are observed at 105.0, 120.0 and 135.0 Mc. The frequency difference between successive

beats is 15.0 Mc, which is the frequency being measured.

Wavelength. The wavelength in centimeters is obtained with sufficient accuracy by dividing 3×10^{10} by frequency. In most applications electromagnetic waves are characterized by their frequency, but in some problems the use of wavelength may be more convenient. It has been shown in the paragraph entitled "Frequencies over 200 Mc" above, for instance, how an unknown frequency over 200 Mc can be determined from the two frequencies of the heterodyne oscillator which produce successive beat notes. If all frequencies are converted into wavelength, the wavelength of the unknown is simply the difference between the two wavelengths which produced the successive beat notes. *Example:* 160 and 200 Mc in the example above correspond to 187.5 and 150 cm. The difference of 37.5 cm corresponds to 800 Mc.

— EDUARD KARPLUS

SPECIFICATIONS

Frequency Range: The fundamental frequency range is from 100 to 200 Mc. This range is covered in a single band with approximately logarithmic frequency distribution. By harmonic methods, frequencies between 10 Mc and 3000 Mc can be measured.

Calibration: The main dial is calibrated in frequency, each division corresponding to 1 Mc. The vernier dial is geared to the tuning unit to make one-half turn of the dial correspond to 1% change in frequency over the major part of the tuning range. The vernier dial carries 200 uniform divisions.

Accuracy: The overall accuracy of measurement is 0.1%. Changes in tubes or battery voltages and variations of temperature and humidity over the range of laboratory conditions normally encountered do not affect the accuracy of the instrument.

Detector: One cartridge-type crystal detector (1N21-B) is used and is supplied with the instrument.

Vacuum Tubes: The following tubes are used and are supplied with the instrument:

- 1—TYPE 1N5GT
- 1—TYPE 1D8GT
- 1—TYPE 95B

Battery: A single-block Burgess TYPE 6TA60 Battery is used and is supplied with the instrument. The power required is approximately 80 volts, 6 ma and 1.4 volts, 250 ma.

Case: The TYPE 720-A Heterodyne Frequency Meter is mounted in a shielded carrying case of durable airplane luggage construction.

Spare Parts: One 1N21-B-type detector is supplied as a spare in addition to the one in the instrument.

Accessories: Headphones which can be plugged in on the front panel and stored in the cover of the instrument are recommended.

Dimensions: Overall, (width) $12\frac{1}{2}$ " \times (height) $13\frac{1}{2}$ " \times (depth) $10\frac{1}{2}$ ". Panel, (width) $10\frac{3}{4}$ " \times (height) $11\frac{3}{4}$ ".

Net Weight: Including battery, $27\frac{3}{4}$ pounds.

Type		Code Word	Price
720-A	Heterodyne Frequency Meter	FANCY	\$250.00

This instrument is manufactured and sold under (1) patents of the American Telephone and Telegraph Company, and (2) U. S. Patent No. 2,367,681.





HOW HUMIDITY AFFECTS INSULATION

PART I—D. C. PHENOMENA

The present increasing use of electrical equipment in tropical climates has made necessary a better understanding of the behavior of insulation under extreme conditions of humidity. General statements such as "At 100% relative humidity and a frequency of 60 cycles, increases as much as 50% in capacitance, of a millionfold in conductivity, and up to a dissipation factor of 1.0, are quite possible for such porous materials as filled and laminated thermo-setting plastics, many thermoplastics and natural fibers like cotton, wool, and silk"¹ are quite inadequate. How long does it take to produce these changes; how much less is the effect at lower humidities; what happens at other frequencies; are there any really good insulators that are unaffected? It is the object of this article to give some sort of answer to each of these questions and to make a beginning at sorting out present commercial insulating materials according to their resistance to moisture.

Electrical Properties

The electrical property most affected by moisture is insulation resistance. This is made up of two parts, surface resistance and volume resistance, which exhibit vastly different behavior, especially with respect to time. Volume resistivity is an inherent property of a material, which is at a maximum under dry conditions, and decreases rapidly as water is absorbed. Surface resistivity is infinite for a clean dry surface, but decreases very rapidly as any foreign conducting material adheres to the surface. Water adheres to the surface of most insulators and is absorbed by them under

conditions of immersion or high relative humidity. This water film, even though pure initially, becomes ionized from carbon dioxide in the atmosphere, from solution of salts on the surface or in the water on immersion, and from slight solution of the insulating material itself.

The relative importance of these two modes of conduction, surface and volume, depends greatly on the shape of the sample under test. For the slab of insulation shown in Figure 1 the surface and volume resistances are, respectively,

$$S = \sigma \frac{l}{2(w+t)} \quad \text{and} \quad R = \rho \frac{l}{wt}$$

where σ = surface resistivity (independent of units)

ρ = volume resistivity

Since the ratio of surface to volume resistance

$$\frac{S}{R} = \frac{\sigma}{\rho} \frac{wt}{2(w+t)}$$

is independent of path length, it can be minimized by making the slab as thin as possible. The samples used for studying insulation resistance are between $\frac{1}{16}$ and $\frac{1}{8}$ inch thick and have bar electrodes so placed that the surface area is usually a square, so that surface resistivity is approximately twice the insulation resistance (volume resistance being assumed negligible). The electrodes are attached by a center bolt through a hole in the specimen or by two end bolts.² Resistance is measured on a TYPE 544-BS8 Megohm Bridge,³ on which, at 500 volts, a resistance of 10 MM Ω can be distinguished from infinite resistance. The sample is mounted on the metal top of a glass desiccator jar. The terminals

²ASTM D257-38, Insulation Resistance of Electrical Insulating Materials, Figures 1 and 2.

³This model has a resistance range 10 times greater than that of the standard bridge.

¹R. F. Field, "The Effect of Humidity on Electrical Measurements," *General Radio Experimenter*, Vol. XVIII, No. 11, April, 1944, p. 5.



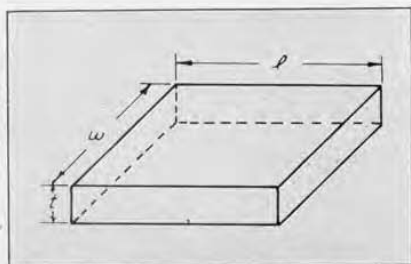


FIGURE 1. Dimension sketch of test slab of insulation.

are mounted on TYPE 133-UL Binding Post Assemblies with the metal top connected to the guard terminal of the bridge. Except for a few of the poorest materials, the insulation resistance of the sample when dry is greater than 10 MMΩ.

Effect of 100% Relative Humidity

When any sample is placed in an atmosphere of 100% relative humidity,⁴ an ionized conducting film of water forms within a few seconds. Within one minute its resistance drops to a value about a decade above its final equilibrium value in the manner shown in Figure 2 for four materials which either have no volume absorption or a negligible amount within the time indicated. The quantity plotted is surface resistivity. For some materials the equilibrium value is steadily approached, while for others there is a minimum value and a slow rise. These different forms result from the divergent effects produced by the applied voltage in sweeping ions to the electrodes and in forming new ions by collision, a process which results in a voltage coefficient of resistance. When the bridge voltage is not applied continuously but only momentarily for a reading, the measured resistance is decreased, but returns to its larger value when the voltage is main-

⁴Obtained by filling the base of the desiccator jar with water and having a cover on for four hours previously.

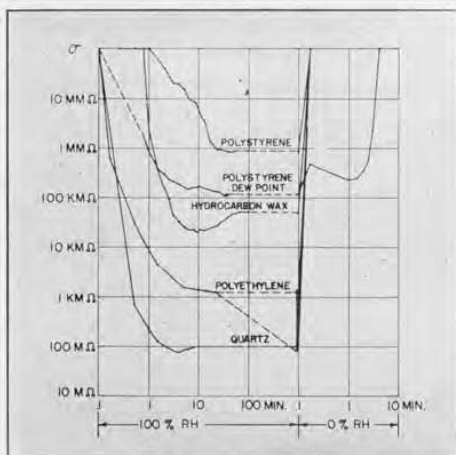
tained. Thompson and Mathes⁵ have reported a similar effect. This behavior is shown by polyethylene for which the voltage was removed for 16 hours with a tenfold decrease in resistance when the voltage was reapplied. But within 15 minutes its resistance was up to the earlier value, showing that the water film did not change with time. If, however, dew point condensation is produced by initial cooling of the sample, the water film is both more conducting and thicker, as shown by the two curves for polystyrene. Proof that the film is thicker will appear in the next paragraph.

Recovery at 0% Relative Humidity

The degree of permanence of the water film is demonstrated by transferring the sample to an atmosphere of 0% RH.⁶ For the materials of Figure 4 the initial resistance is recovered within 10 seconds.⁷ Even this short recovery time

⁵B. H. Thompson, K. N. Mathes, "Electrolytic Corrosion—Methods of Evaluating Insulating Materials used in Tropical Service", AIEE Transactions, Vol. 64, June 1945, p. 297.

FIGURE 2. Plot of surface resistivity vs. time for four materials having negligible volume absorption within the time indicated. The left-hand portion of the plot shows the surface resistivity under the condition of 100% relative humidity for time up to 1000 minutes, where the time scale repeats for the right-hand portion, which shows the recovery time at 0% relative humidity.



is probably set more by the natural diffusion rate of water vapor outward to the silica gel than by any specific property of these materials. For the thick film produced on polystyrene by dew point condensation, the rapid rise in resistance is halted after a few seconds because the relative humidity immediately surrounding the specimen is no longer 0%. The film is redistributed, and only after one minute does resistance start to rise again to regain its initial resistance after 4 minutes. The use of forced ventilation, even at a room humidity of 30% RH, removes the film in 10 seconds.

This shape of the recovery curve, in which there is a rapid rise, a slow drop during redistribution and a final rise to initial value, seems to be characteristic of those materials having no volume absorption within the time of the measurements, when by various means the film is made sufficiently thick. Curves for two grades of mica-filled phenolic are given in Figure 3. Sample A recovers within 10 seconds after an exposure of 90 minutes to 100% RH but requires 14

⁶Obtained by filling the base of the desiccator jar with silica gel and having a cover on for four hours previously.

⁷The bridge is preset at infinite resistance and the time to return to balance is measured by a stop watch.

FIGURE 4. (left) Plot showing how relative humidity affects the exposure curve for polyethylene.

FIGURE 5. (right) Equilibrium surface resistivity for polyethylene as a function of relative humidity. The exponential relationship is characteristic of all insulating materials.

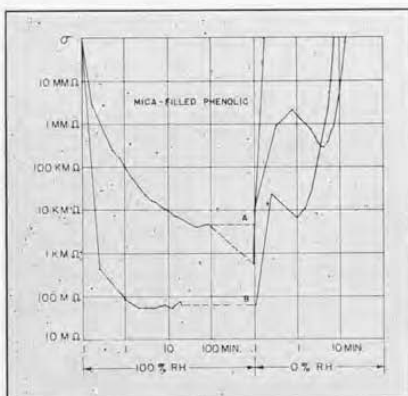
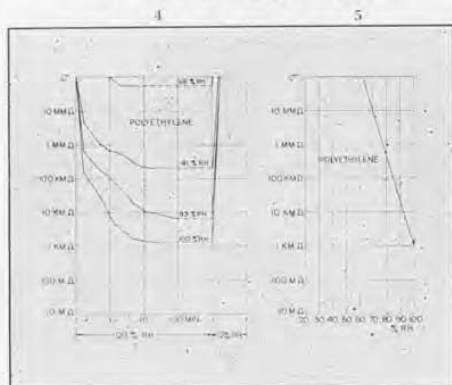


FIGURE 3. Exposure and recovery curves for 2 grades of mica-filled phenolic. Apparently, small differences in surface finish result in large differences in surface resistivity.

minutes after a 16-hour exposure. Sample B shows a much lower surface resistivity and the typical recovery curve after only 20 minutes exposure to 100% RH. Forced ventilation removes the films from both materials in 10 seconds. Several other materials show this effect, as shown in Table I, which will be discussed later. The exact shape of the recovery curve can extend from that of vinyl chloride acetate, which rises above 10 MMΩ before the drop, to that of quartz after dew point condensation, which remains at its 100% RH value for 2 minutes before the final rise to initial value.

Effect of Other Relative Humidities

When materials are placed in humidities less than 100% RH, their equilibrium resistances are higher and the water films presumably thinner. Curves obtained for polyethylene are shown in Figure 4.⁸ The relation between the equilibrium surface resistivity and relative humidity is exponential, as shown in Figure 5, where the plot of the loga-

⁸Definite humidities are obtained by placing saturated solutions of various salts in the desiccator jar. The salts used are as follows:

%RH	32	43	52	66	81	93
Salt	CaCl ₂	K ₂ CO ₃	Na ₂ Cr ₂ O ₇	NaNO ₂	(NH ₄) ₂ SO ₄	NaSO ₄



ritms of resistivity against percent relative humidity is a straight line. This agrees quite well with the work done by Curtis in 1915⁹ on the available insulation of that day. His plots were nearly linear from 100% RH down to about 50% RH and then flattened to a constant value of resistance defined by the volume resistivity of the sample. The greater sensitivity of his apparatus allowed him to measure 100 kMMΩ and to carry the observations down to 0% RH. Surface resistivity at any relative humidity, H%, is best defined by stating the surface resistivity, σ_{100} at 100% RH and the change in relative humidity h which changes the resistivity by one decade. Then

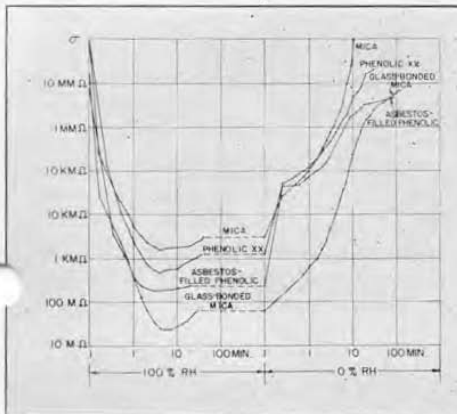
$$\log \sigma = \frac{100 - H}{h} - \log \sigma_{100} \quad (3)$$

Effect of Volume Absorption

Volume absorption of water into the body of an insulator provides both a volume conductance and a storage of water, which on drying out must pass out through the surface. Long before enough water has been absorbed to re-

⁹H. L. Curtis, "Insulating Properties of Solid Dielectrics", Bulletin of Bureau of Standards, Vol. II, No. 3, May 1915, pp. 359-420.

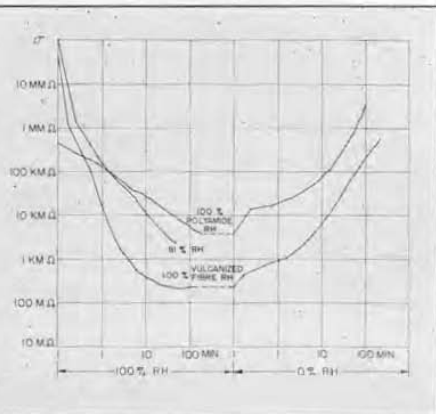
FIGURE 6. Exposure and recovery curves for four materials having appreciable volume absorption. Such materials show, in general, a smoother recovery curve, extending over a time comparable to the exposure time.



duce volume resistance to a value at all comparable to surface resistance, the shape of the recovery curve is changed, because the absorbed water tends to maintain the surface film. Surface resistivities for four materials having appreciable volume absorption are shown in Figure 6. Their recovery curves rise slowly and require more than 10 minutes to attain initial values. Something more than amount of water absorbed determines the rate of recovery, since the laminated paper and asbestos-filled phenolics absorb much more water than glass-bonded mica or sheet mica. This may be the molecular force which holds the water film to the surface.

For high rates of volume absorption of water volume resistance at 100% RH becomes comparable with surface resistance before the equilibrium value of surface resistance is attained. The resistance-time curve then continues downward at a rate dependent upon the rate of water absorption. This effect will first appear in the curves for the lower humidities, because the rate of water absorption is probably independent of relative humidity so long as a surface film exists, while the surface resistance in-

FIGURE 7. Exposure and recovery curves for two materials having so large a volume absorption that an equilibrium value of surface resistivity cannot be observed.





creases with lowered humidity. These distinctions are shown in Figure 7. The surface resistivity of vulcanized fibre at 100% RH is so low that equilibrium is attained at 90 minutes before volume resistance can have an effect, while at 81% RH volume resistance becomes comparable to surface resistance within 10 minutes, prevents equilibrium, and causes insulation resistance to decrease directly with time. Polyamide has a relatively high surface resistivity, so that even at 100% RH its volume resistance becomes comparable to surface resistance within 10 minutes and prevents any equilibrium value being attained.

On continued exposure to high humidity extending over days and weeks rather than hours, volume conductivity steadily increases in proportion to the water absorbed and in most materials dominates over surface conductivity even at 100% RH. Kline¹⁰ has given a list of the times necessary to reach saturation for 22 materials. The values extend from 2 days to 2 years. They depend both on the structure of the material and the shape of the sample, particularly the ratio of surface to volume. Scheer¹¹ has measured the insulation resistance of several insulators over a period of 30 days and finds that resistance equilibrium is usually attained within that time. It is important to note that of the total decrease (6 to 7 decades) in insulation resistance from the initial dry value surface resistance accounts for the major part, which is usually sufficient to render useless any instrument in which the material is used. Volume resistance only accounts for the last one or two decades, but

makes the reduction permanent to the extent that the recovery time will be at least as long as the exposure time.

Collected Data

Some 40 materials are arranged in Table I in the order of decreasing surface resistivity after exposure to 100% RH, ranging from greater than 20 MMΩ to 30 MΩ. The position of certain materials is most surprising and may not be typical. All samples were washed in grain alcohol to remove dirt, but some grease and other substances may remain. At least they were as clean as they would be in actual use. Only one sample of a kind was tested so that there is no measure of the magnitude of normal variations. However, the results are repeatable on the same specimen within 50%. Where more than one sample of a kind is given, they are known to differ or are made by different manufacturers. It is known that very small amounts of plasticizer can greatly change the surface behavior and none of the samples was furnished for this particular test.

The slope of the straight line plot of surface resistivity against relative humidity is given in the second column, and in the third column the relative humidity at which the surface resistivity is 20 MMΩ. Since for most of the materials this value of relative humidity is greater than 50% RH, it is easy to see why relative humidities less than 50% RH are considered to have little effect on insulation and also why that value is a good standard room humidity. Materials with volume absorption may be conditioned at that humidity without having any appreciable surface resistance.

The last three columns give the recovery times in minutes after 1 hour and 16 hours exposure to 100% RH and

¹⁰G. M. Kline, A. R. Martin, W. A. Crouse, "Sorptions of Water by Plastics", Proceedings of American Society for Testing Materials, 1940, pp. 1273-1282.

¹¹F. H. Scheer, "Study of Moisture Proofing Treatment for Phenolic Boards," Company Report 1943-4, Colonial Radio Corp.





Material	σ	%RH per decade change of σ	%RH for 20 MM Ω	Recovery time in minutes after 100% RH for		
				1 hr	16 hrs	Dew point condensa- tion
	MM Ω					
Hydrocarbon wax, modified	>20		100	.0	.0	
Cellulose acetate butyrate	>20		100	.0	.0	.0
Silicone rubber	10			.13		
Polytetrafluoroethylene	3.6			.17	.17	
	kM Ω					
Polystyrene (sheet)	840		93	.13	.13	4*
Polydichlorostyrene 2-5	29	7	79	.17		
Hydrocarbon wax	20	13	56	.17		
Ethyl cellulose	13	9	70	.33	.5	
Cellulose acetate	7.0	6	77	1.0	6	
Polyvinyl chloride acetate	5.7	12	58	6*		
Polystyrene (plasticized)	5.0	4	83	.17	62*	
Phenolic, mica-filled	5.0	9	66	.17	13*	
Aniline formaldehyde	4.2	4	82	.17	20*	
Polyamide	3.8	14	48	200		
Porcelain, glazed	3.7	15	42	2.5*		
Glass (high K)	3.4	10	59	17*	20*	
Mica	3.0	12	50	11		
Polystyrene (molded)	2.4	10	58	.17	.17	
Polystyrene (plasticized)	2.4	8	64	.11	.17	
Steatite (L-3)	1.6			.17	.75	
Quartz	1.4					
Polyethylene	1.3	9	63	.17	.17	
Phenolic, XX	1.3	16	45	80		
Phenolic, asbestos filled	1.2	9	61	1.5*	100*	
	M Ω					
Phenolic, XXXP	660	15	25	300		
Steatite (L-1)	640			.5	1	
Phenolic, LE	500	18	16	400		
Phenolic, mica-filled	320	8	58	40*		
Steatite (L-4)	280			.33		4*
Polydichlorostyrene 3-4	240	6	71	.33	5.3*	
Phenolic, cellulose filled	240	10	49	400		
Aniline formaldehyde, glass matte	240	9	50	14	1000	
Phenolic, C	220	16	20	300		
Vulcanized Fibre	220		0	6000		
Aniline formaldehyde, glass cloth	200	12	57	3		
Quartz	190					
Phenol formaldehyde (plasti- cized)	100	12	34	25		
Glass (sintered)	90					
Glass bonded mica	64	18	31	400		
Melamine, glass cloth	38	14	14	300		
Phenolic, mica filled	30	11	32	7*		

after dew point condensation. Any time up to 0.25 minute (15 seconds) indicates no volume absorption. Any longer time which is starred (*) refers to the shape of recovery curve characteristic of non-porous materials, for which forced ventilation will give a recovery time of less than 0.25 minute. Other large times indicate volume absorption under the condition noted.

Many interesting facts may be gleaned from this table. The high position of cellulose acetate-butyrate is surprising when it is realized that this material will absorb about 1% of water in 24 hours at 100% RH. This water must be kept in unconnected pockets to prevent conduction. A sample with 4% of water still has a resistance greater than 10 MM Ω . Eventually the water in the



isolated pockets joins and provides normal volume resistance. Glass, quartz, steatite and mica are well down in the list and probably would be lower if their surfaces had been made perfectly clean by high temperature baking. Silicone rubber is third from the top and illustrates the valuable water-repellent property of all silicone resins. Treatment of materials containing silicon, such as glass and quartz, by the special silicone resins which produce a molecular layer several hundred molecules thick makes the treated surface completely water-

repellent, even under hot salt spray and salt water immersion. A similar treatment of steatite affords great improvement, but is not always entirely successful. A non-porous ceramic properly treated with silicone resin is unaffected by moisture and is as nearly a perfect insulator as exists at present. It is quite possible that certain plastics, especially the silicone resins, will also meet this specification.

—ROBERT F. FIELD

Part II on A. C. Phenomena will appear in an early issue.

MISCELLANY

● At Oregon State College on June 10, the honorary degree of Doctor of Engineering was conferred upon Melville Eastham, founder and former president of the General Radio Company, now Chief Engineer in charge of research and development.

● A PAPER entitled "Wartime Problems of a Manufacturer of Engineering Products" was delivered by A. E. Thiessen, Vice President of the General

Radio Company, before the Cedar Rapids, Iowa, Section of the Institute of Radio Engineers on April 19, and at a meeting of the Chicago Section on April 20.

On April 27, Horatio W. Lamson, of the General Radio Engineering Staff, addressed the Boston Section of the Institute of Chemical Engineers on the subject of "Time and Time Measurement."

GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39

MASSACHUSETTS

TELEPHONE: TROWBRIDGE 4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WORTH 2-5837



CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WABASH 3820

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
TEL.—HOLLYWOOD 6321



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