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METALLIZED PAPER CAPACITORS

By WILLIAM M. BAILEY
Vice-President and Chief Engineer
Cornell-Dubilier Electric Corp.
New Bedford, Mass.

PART I

Use of metallized paper in place of the conventional alternate layers of paper and metal foil has resulted in a new type of paper capacitor that offers distinct advantages in size and weight reduction for many applications. In addition, the new capacitor has a unique self-healing characteristic that provides high reliability for its size.

This article will review briefly the methods used for making metallized paper capacitors and analyze their performance characteristics one by one. Limitations and advantages will be emphasized equally in comparison with conventional paper capacitors, to provide the required facts for choosing intelligently between the two types.

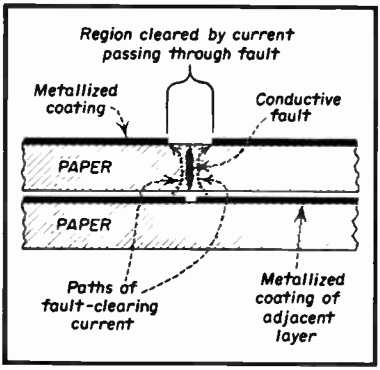

Fig. 1. Self-healing action in metallized paper capacitor.

Basic Concept. The electrodes of a metallized paper capacitor are an extremely thin metal layer that has been evaporated directly onto the insulating paper as shown in Fig. 1. This metal layer is so thin that the energy stored in the capacitor is usually sufficient itself, in case of a breakdown, to melt out or vaporize the metal layer in the vicinity of a dielectric fault. This self-healing action separates the fault in the paper from the metal electrodes by a sufficiently long insulating path to withstand the operating voltage.

The energy required to insulate a fault should be small enough to prevent excessive deterioration of the dielectric near the breakdown point. This necessary condition for self-healing is achieved when the thickness of the metal layer is about one-hundredth the thickness of the usual aluminum foil. Such a thin conducting layer cannot be handled as a self-supporting foil, but can readily be applied directly to the surface of the insulating paper by an evaporation process.

Obtaining Optimum Self-Healing. The effectiveness of a fault-clearing burn-out is dependent on the type of metal deposited on the paper, the specific resistance of the metallic layer, the thickness of the layer, and the structure of the layer. The lower the heat of evaporation, melting point, and boiling temperature, the smaller will be the energy required to get a clean and sufficiently large burn-out of the metal electrode around a fault.

As the metallized layer is made thinner, its electric resistance increases, the burn-out arc quenches itself faster, and the burn-out area is reduced. Thickening the deposited metallic layer, on the other hand, increases the possibility of mechanical destruction of the dielectric. Thicker electrodes also reduce the burn-out area, because with the greater mass of metal per surface unit the energy available for evaporation boils out less area of metal. There is thus an optimum thickness of metallic layer for a given metal.

For aluminum and zinc, the two metals most widely used for the metallic layer, the optimum thickness is about three-millionths of an inch. Such thin layers of metal cannot carry the high concentration of current that exists in the vicinity of a flaw: in this region, then, the metallic layer acts as a fuse

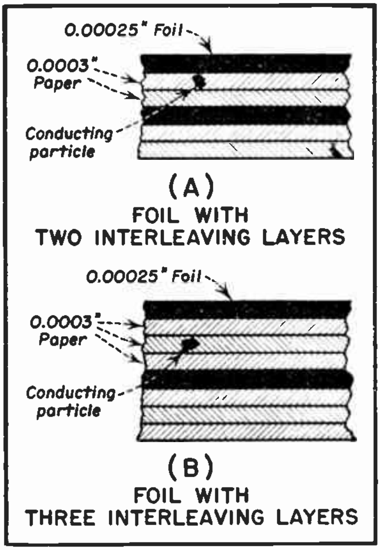

Fig. 2. Conducting particles in capacitor paper makes it essential to use a minimum of two interleaving layers between the foil electrodes of conventional paper capacitors.

and either oxidizes, vaporizes, or melts into isolated globules to insulate the area of the fault from the electrode.

The foil in ordinary paper capacitors is about 250 millionths of an inch thick. This foil can carry the short-circuit current produced by a fault, hence ordinary paper capacitors stay short-circuited permanently once a fault develops.

How Conventional Paper Capacitors Fail. Breakdown in a foil-paper capacitor may be **thermal** due to excess heat causing deterioration of the dielectric at the hottest spot, or **electric** due to sudden application of a voltage exceeding the breakdown electric field strength at some weak point in the dielectric. In either case, ionization takes place in the residual gas between the layers or in the insulating paper itself. This action builds up rapidly due to further ionization by collision of electrons, producing an avalanche of ions and electrons that destroys the dielectric mechanically. With no dielectric at the location of the breakdown, the metallic electrodes virtually are connected together and short-circuit the conventional foil-paper capacitor. It must then be discarded.

Faults in Capacitor Paper. In the manufacture of capacitor paper it is impossible to avoid small holes in the paper, and equally impossible to avoid inclusion of small conducting particles. In winding a conventional paper capacitor made with only a single paper layer, it would therefore, be short-circuited the instant a conducting particle was reached. For this reason, conventional units require at least two layers of paper insulation, as in Fig. 2A. For the lower voltage ratings two layers are sufficient because there is slight probability of two faults in the paper coinciding with each other. For higher voltage ratings more inter-leaving layers of paper are needed, as in Fig. 2B.

The smallest number of layers with which a standard foil-paper capacitor can be wound is six, as shown in Fig. 3A, since there are two foil layers and each requires two paper layers. The corresponding metallized construction, in Fig. 3B, requires only two layers, which greatly simplifies manufacturing problems. There is even a type of metallized paper construction, using a comb-shaped pattern of metallized coating, that requires only a single layer and provides the ultimate simplicity in capacitor winding.

In figuring the voltage rating of a conventional paper capacitor, one of the sheets of paper cannot be considered as insulation because of the conducting flaws in the paper. Thus, a unit with two layers of paper is considered as only one layer from a voltage breakdown standpoint; likewise, three layers count as two, and four as three. This makes the conventional paper capacitor much bulkier than it would be if a perfect insulating dielectric were obtainable.

The extra layer of paper is eliminated in metallized paper capacitors not by getting a more perfect insulating paper, but instead by isolating each flaw in the paper automatically during manufacture.

Making Metallized Paper Capacitors. A brief review of methods used in preparing, winding, impregnating, and housing metallized paper capacitors will aid in understanding the special features of these capacitors. This background information, equivalent to that obtained by a trip through the Cornell-Dubilier factory in New Bedford, Mass., will greatly assist in choosing between conventional and metallized paper capacitors for each particular application.

Lacquering the Paper. Though the surface of highly satinized capacitor paper appears smooth to the naked eye, it is by no means even. Under examination in an electron microscope, the paper is seen to have fibers, crags, and valleys amounting to a thickness variation of almost half the nominal thickness, as in Fig. 4A. If metal were evaporated onto such a surface, the metal vapors would penetrate the depressions and pores of the paper, producing sharp points that would reduce both the ionization voltage and breakdown strength of the capacitor. For this reason, an insulating coating such as lacquer is applied to the capacitor paper before it is metallized. The lacquer fills the depressions, as in Fig. 4B, leaving a smooth surface on which metal can be deposited.

Metallizing the Paper. Zinc and

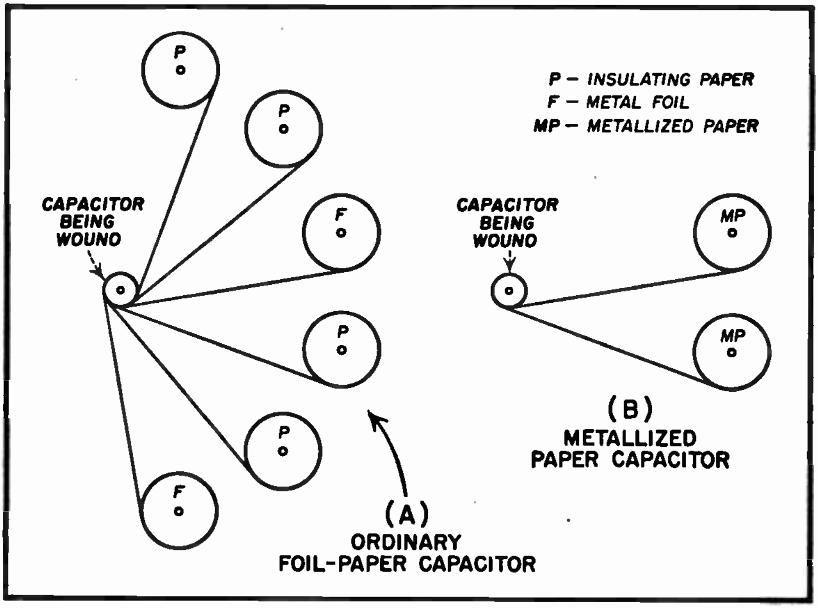

Fig. 3. Comparison of winding machines required for the two types.

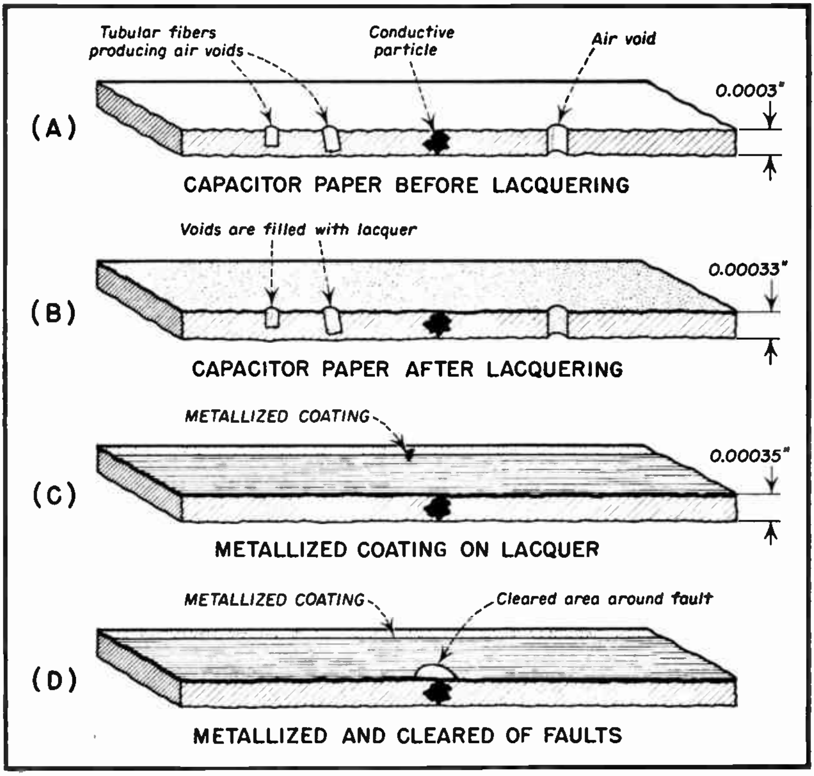

Fig. 4. Steps in making metallized capacitor paper.

aluminum are the two metals most widely used for metallized layers. Both are deposited by evaporation of molten metal as the paper is moved past in a large vacuum chamber. Zinc, which boils at about 500°F., can be evaporated from an electrically heated crucible inside the chamber, using relatively simple equipment. Aluminum with its higher melting point and higher corrosive action in the molten state cannot be evaporated from crucibles: instead, it must be evaporated off a tungsten heating wire in the chamber under carefully controlled conditions.

The metallizing process is a batch process, wherein usually one roll is coated at a time. The vacuum chamber is heavy steel with external controls by which the process can be controlled once started. The lacquered paper roll and the aluminum are properly placed therein, the chamber is sealed and pumped down, the electric heating element inside is energized to evaporate the metal, and the electric motor is started that moves the paper past the evaporated metal cloud at precisely the correct speed to give the desired thickness of metal deposit on one side of the paper, as in Fig. 4C.

One disadvantage of zinc is its vulnerability to moisture, which eats away the zinc coating and reduces the capacitance correspondingly during use. Sealing against moisture is thus extremely important when the coating is zinc.

Another drawback of zinc is its higher electrical resistance than aluminum, which results in a slightly higher power factor. This is of little or no consequence in telephone work, but may be important in other applications. In Europe, however, zinc is widely used as the metallized coating for practically all applications, and performance is claimed to be entirely satisfactory there.

Aluminum is the metal used for the coating in most metallized paper units on the market in this country. The speed of the paper and the rate of evaporation of the metal in the vacuum chamber are carefully controlled to produce a metallized layer about 3 millionths of an inch thick, which gives the optimum compromise for the various factors affecting performance characteristics.

Margins. Metallizing is applied to relatively wide rolls of paper for economic reasons, and the coated rolls are subsequently slit to the desired widths. Once the paper is in the final width, the metallized coating must be removed from one margin of each small roll to provide insulation against shorts when the capacitors are wound. The metallized paper is run over one metal contact roll to another roll that is insulated except for the width of the desired margin, and the foil in this marginal area is burned off by applying a voltage of appropriate value to the two metal rolls. The metallized layer is burned off by the high current density resulting from the voltage. An alternative procedure, used chiefly with zinc, involves masking the blank paper during the evaporation process to leave the required insulating margins.

Preliminary Fault-Clearing. Before the metallized paper is slit into the final widths, it is usually run between two metal rolls between which a voltage is applied. This removes the metallized coating from the vicinity of each fault one by one, as in Fig. 4D. If all the faults were left for simultaneous clearing after winding, much heavier fault-clearing currents would be needed and there would be danger of damaging disruptive discharges.

Winding. Metallized paper capacitors are generally made with noninductive construction. This is achieved by winding the units from two rolls of metallized paper with the insulating margins at opposite ends, as shown in Fig. 5.

Use of two metallized layers with oppositely positioned margins provides each end with an insulating margin as well as electrode extensions so that opposite electrodes project at opposite ends.

Comb-Pattern Printing. Another type of metallized paper capacitor construction requires only a single layer of metallized paper, giving easier winding and still more compact construction. Instead of providing an insulating margin along one side of the strip of metallized paper, the foil is burned off in a comb-shaped pattern as shown in Fig. 6 to separate the metallized layer into two sections. The pattern is so designed that the length of each rectangular cycle of the pattern is equal to the circumference of the turn on the capacitor at its position in the roll. Thus, the width of each rectangular pulse of pattern increases by 2 π times

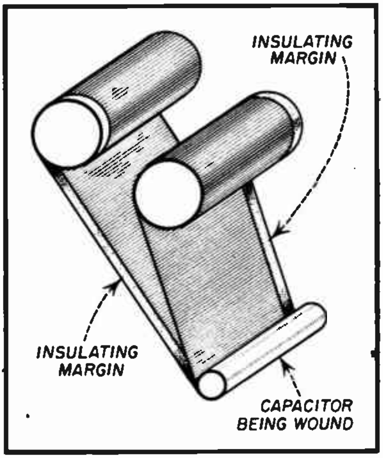

Fig. 5. Two-layer winding arrangement used in metallized paper capacitors.

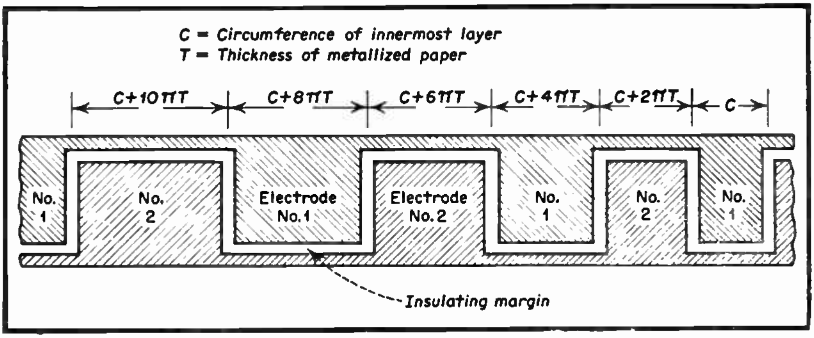

Fig. 6. Comb-pattern arrangement giving single thickness of paper between electrodes.

the thickness of the paper (about 6.28 times 0.00035 inch for standard metallized aluminum paper). When this condition is met, the rectangular pulses are directly over each other on succeeding turns, with alternate pulses connected to opposite ends of the roll. The ends of the finished roll can then be sprayed with molten copper for connecting purposes just as mentioned below with two-layer construction.

The comb-shaped pattern-printing technique was developed by Hunt in England, and is widely used there. In the United States it is used chiefly for low-voltage capacitors with small capacitance values.

Burning of the comb-shaped pattern requires a separate burning wheel for each size of capacitor. The circumference of the pattern wheel must equal the total length of paper in the capacitor, and the embossed pattern on the wheel must be precisely machined to meet the requirement that the rectangular pulses exactly overlay on all wound layers.

Higher voltage ratings are obtained with comb-pattern metallized capacitors by spreading out the metallized rectangles as in Fig. 7, so there is one full turn of insulating paper between adjacent pulses. This gives in effect two layers of paper between the electrodes, even though only a single strip is wound as before.

Molten Spraying of Ends. After metallized paper capacitors are wound, molten copper is sprayed over each end through a masking arrangement that leaves an uncoated strip across the diameter of each end for entrance of the impregnant. The insulating margin on one edge of each sheet of metallized paper is wide enough so that the molten spray cannot penetrate enough to reach the electrode of opposite polarity. The copper coating is next tinned by spraying molten solder on it, to facilitate later soldering of terminal leads. **END PART I.**

(*PART II will follow in May Issue*)

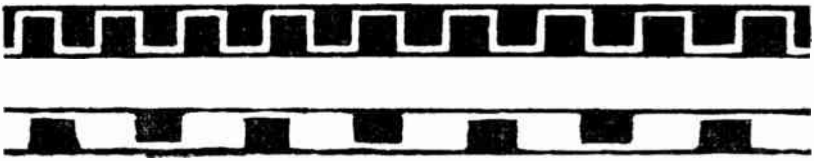

Fig. 7. Actual-size reproductions of comb-pattern metallized paper. The black portions of the pattern are the metallized part of the paper strip. Upper pattern is used where only one thickness of paper is needed between the electrodes, while lower pattern is for higher-voltage capacitors requiring two thicknesses of insulating paper.

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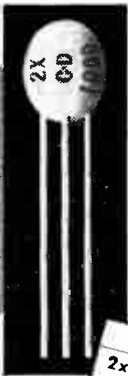

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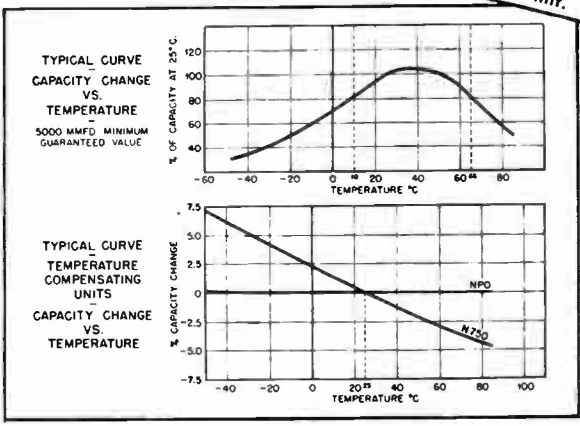
2x10,000 mmf.	8TM5DS1C



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FOR SALE—Model 180 wire recorder, complete with two removable take-up drums and about 8 hours of wire, used very little, good condition. Will sell cheap. Melvin E. Barnette, Box 154, Pendleton, S. C.

FOR SALE—Recently purchased Hammarlund Super-Pro SP400-X, complete. Best offer. Vincent Pellettieri, 5523 - 31 Ave., Woodside, L. I., N. Y.

FOR SALE—Store, Radio-Television-Appliance, Sales-Service. Complete, tools, equip., stock, parts, tubes, 2,000 customers. Also 3 room apt., steam heat - hot water, $40 rental, est. 19 yrs. M. Funk, 114 Ralph Ave., Brooklyn 21, N. Y.

WANTED—One or more tape-type decoding machines with tape puller and stylus in good cond., motor or spring drive. Please quote price and all particulars. Metropolitan Radio Service, 4387 Elston Ave., Chicago, Ill.

FOR SALE OR TRADE—Rider Manuals, 1 through 13, complete, $160, or will take laboratory type oscilloscope or modern Mutual Dynamic tube tester. G. E. Howarth, 216 First Ave. East, Oskaloosa, Iowa.

SALE OR SWAP—Have Lionel train and accessories in excellent cond., cost $90. Will swap parts or whole for the following Heathkits in excellent condition: electronic switch, signal tracer, battery eliminator, audio generator, or condenser checker. R. J. Sandretto, 590 Furlong Rd., Sebastopol, Calif.

FOR SALE OR TRADE—Ham station, tubes, extras, etc. Need scope, tube checker, sig. gen. Also need watchmakers lathe, stake, jeweling set, cabinets, etc. R. A. Williams, R 1, Box 210A, Redlands, Calif.

SELL OR TRADE—Radio tubes, all hard to get types, want quantities traded in 7, 10, and 12 inch TV sets, also good used pic. tubes if cheap. Write for lists. Ray Rowell Radio, 1640 Steiner Ave., Birmingham, Ala.

WANTED—1927 to 32 radio sets, must be in working condition and original speakers, for a.c. Chester Wagren, 51 North Central Ave., Buffalo 12, N. Y.

FOR SALE—Coin operated timers, complete with coin slot and money box with lock. Operate one hour for 25 cents. Suitable for coin operated radios. $2.50 each. McKay Radio, 4015 MacArthur Blvd., Oakland 19, California.

FOR SALE—Radio sales and service business. Well established, pays well, 20 years in same location, city of 22,000 with large trade area. W. S. Hillsman, 205 N. DeLeon St., Victoria, Texas.

FOR SALE—T-23/ARC-5 xmitter, with tubes, less crystals, $20; MD-7/ARC-5 modulator with dynamotor, $10; C-40/ARC-5 control unit, $2. All excellent. E. J. Mack, 82 B'way, Bayonne, N. J.

TRADE—Receiving tubes, meters, transformers, and other radio gear. Want an inexpensive enlarger, 35 mm camera, and other photo supplies. I can also use some radio test equipment. Roman Spinner, 1236 Ave. S, Brooklyn, N. Y.

SALE OR TRADE—Intercom system, Philcophone. Two pushbutton master stations each with six station capacity and eight staff stations to call one master. Good condition, will trade for hi fi amplifier. B. H. Gerard, East Parkway at Central, Memphis 4, Tenn.

FOR SALE—Meissner 8C FM tuner in factory carton, used about 2 months, perfect cond., cost $44.08. My price $35 f.o.b. Harold Garrett, 711 S. New York, Sedalia, Mo.

FOR SALE—Two RCA 833-A with 1 Johnson socket, $45; two C-D 25 mfd., 2,500V d.c. photoflash capacitors, $10 ea.; two 230V a.c. Superior powerstats 3 A., 810 VA. $12 ea. All above good cond. Arthur Koehler, 130 Wadsworth Ave., New York 33, N. Y.

SELL OR SWAP—Sams 1 to 8 like new, binders. Want tape recorder, camera, movie equip., adding machine, hand printing press, new 600-16 tires, 1/2" elec. drill, bench grinder or drill press. Andre Chapdelaine, 122A No. Quinsigamond, Shrewsbury, Mass.

TRADE—26 new Duotone No. 12 Ls. sapphire recording needles listing at $5.50 ea. Want 1951 Heathkit oscilloscope kit or used Hallicrafter receiver. Also have good Kodak syncro flash unit No. 2. P. Lachance, 26 Howard St., Lewiston, Maine.

WANTED—Precision model E-200C signal generator. Must be in A-1 shape. Will pay cash. Chas. S. Brotzman, 173 Main St., Mexico, Maine.

WANTED—Cheap radios, radio books, radio parts, photo equip., etc. Send details and prices. S. Asif Akhtar, Jafri Shop, Mahiar Mansion, Jackson Road, Keamari, Karachi, Pakistan.

FOR SALE—Complete files of transactions Inst. Radio Eng., 1920 to date; also Q.S.T., 1923 to date, all bound in brown cloth. Make cash offer. J. C. Jensen, Nebraska Wesleyan University, Lincoln 4, Nebraska.

FOR SALE—NRI VOM vacuum tube, 20,000 ohms per volt, ranges - d.c. 0-450 - a.c. 0-550 ohms, 0-100 meg., operating instructions and schematic diagram, less batteries, $10 postpaid. Ben Marconi, 120 Gatling Pl., Brooklyn 9, N. Y.

FOR SALE—Hallicrafters S40A receiver in excellent condition, $60. Joseph Zamoyta, 21 Lincoln Pl., Brooklyn 17, N. Y.

FOR SALE—G.E. JFM90 FM tuner in a distinguished handsome cabinet simulating a set of books. Excellent condition, $15. N. Hulemark, 130 - 75th St., Brooklyn 9, N. Y.

FOR SALE—Rider Manuals, 1-5 abridged, 6, 7, 10, 12, and 13 in excellent cond. with index for 1-10, $70 postpaid. Magazine back issues for ½ publisher's price. James Ahlgren, 1807 H St., N. W., Washington 6, D. C.

SELL OR TRADE—Have about 25 magnifying lenses, various sizes, types, and colors. Write for listing. Will accept reasonable offer for entire lot. T. J. Feibleman, 1803 Louisiana Ave., New Orleans, La.

WANTED—McMurdo-Silver 701 transmitter, with coils for 10 and 20 meters. Also need xtal and pwr. supply. Will pay cash. H. J. Burton, AFS Field Engineer, 625th AC & W Sqdn., APO 942, c/o P.M., Seattle, Wash.

FOR SALE—Rider Manuals, 1 to 17 inclusive. 1 to 5 condensed in 1 vol. No. 13 missing. Total of 12 books, $120. Dunbar's Radio, 571 Edinburgh St., San Francisco 12, Cal.

SELL OR TRADE—Surplus receiver in excellent condition, similar to the BC-348, but much better. Write for details and photograph. Want TV set. R. H. Bender, 329 Perry St., Columbia, Pa.

FOR SALE OR SWAP—Elkhart silver plated trumpet in excellent condition, $40 cash, shipped prepaid; or stamp collection worth $40. Will swap for wire or tape recorder in good running cond. W. Donald Curtis, Box 13, Watson, La.

FOR SALE—Eico model 425 push pull scope, factory aligned and in excellent working condition, all instructions and papers included, $45. Joseph A. Frazier, 8510 Packard Ave., Van Dyke, Mich.

WANTED—Late Nilson's Master Course in Radio Communication for cash. L. C. Chapman, Rt. 1, Fairhope, Baldwin Co., Alabama.

WANTED—TV service instruments. State price and condition. Blais' Radio Service, 282 Pleasant, Berlin, N. H.

WANTED—Hallicrafter or any communication BC 348. Need one 200 to 500kc. Florida Air Srv., Radio Div., Box 6284, Jacksonville, Fla.

FOR SALE—TV chassis, 3" x 15" x 20", complete with 21 sockets, terminal strips, layouts for parts, $3.50 plus shipping charges. Aladin Radio Service, 202 Schiller St., Buffalo 6, N. Y.

FOR SALE OR SWAP—RCA 621TS 7" magnetic deflection TV receiver, good working condition, complete. First $50, or what have you? Jack M. Gutzett, 75-02 168 St., Flushing, L. I., N. Y.

FOR SALE—Janette rotary inverter, 110V d.c. - 115V a.c., 300W, $50; 25W phono inverter, $4; Webster 156-1 changer $9. Barton Koslow, 515 West End Ave., New York 24, N. Y.

FOR SALE—Volumes 7, 8, and 9 of Rider Manuals. All in perfect cond., $6 ea., c.o.d., or all three manuals for $15. Thurk's Radio & Appliance Co., Woodsboro, Texas.

FOR SALE—Doz. Solar surplus condensers, 2 x 3500 MF at 25V, $2 ea. c.o.d. Also some 4.5 MC IF coil air trims, $1 ea. c.o.d. B. Gallina, 380 N. 7 St., Newark, New Jersey.

FOR SALE—Turner microphone, excellent freq. response, model 20X, with 5 yards cable and plug, nearly unused, $5. A. H. Russo, 160 Sherman Ave., New York 34, N. Y.

WANTED—Transmitter-receiver for private aircraft. Must be 6V, and perfect. Either 1-f or VHF xmitter, and 200-400kc. rec. State price. John W. Findarle, Rt. 1, Box 1061-G, Modesto, Calif.