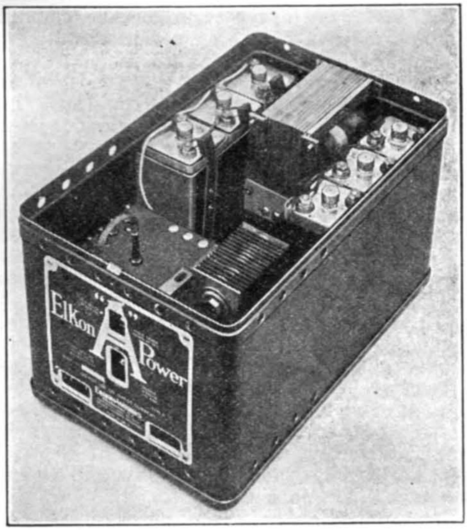
Developments in Dry Electrolytic Rectifiers

By Robert S. Kruse, Technical Editor

IN our May, 1926, issue there was described a trickle charger which makes use of a dry electrolytic rectifier. At that time it was pointed out that it would be very fine if the device could be expanded to handle larger currents and higher voltages so as to make the dry and silent rectifier available for other uses. Some of these developments have now become facts, and the purpose of the present paper is to describe the Elkon 2-ampere charger and the Elkon A substitute which is



INTERIOR VIEW OF THE A SUBSTITUTE
At the left front is the panel covering the transformer and one of the chokes, also carrying the rectifier assembly whose fins can be seen at the right front. At the center rear are two of the chokes above each other and at the sides are the 6 electrolytic condenser cans. The quick-forming switch is reached thru the opening in the upper part of the letter "A" while the opening between the legs of the "A" exposes the 110-volt snapswitch. The two lower openings are for the input and output cords. The rectifier assembly mounts on a separate base and can be replaced when worn. The condenser electrolyte is a harmless one—Borax.

a filament supply capable of delivering the direct filament current required by any present-day receiver using 5-volt tubes. The rectifier coupler, as was stated in my paper on the trickle charger, was devised by Mr. Samuel Ruben. Its conversion into an A substitute and the electrical and mechanical design of that substitute was done by Dr. Harry Shoemaker who needs no introduction to an audience of radio amateurs because he has been in radio from the days when all were amateurs, the vacuum tube had not yet been thought of and broadcasting was in the remote future.

For some time past the device has been in final form and one has been at this office but the final story was obtained from

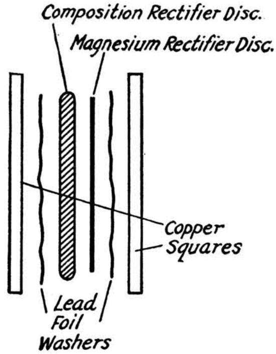


FIG. 1—A SINGLE RECTIFIER ASSEMBLY
These are combined in several ways to work at voltages above the limits of one couple, also to give full-wave rectification.

Messrs. G. N. Sieger and Harry Shoemaker by our good friend Boyd Phelps who after a hasty telephone call rejoined *QST's* staff for the moment, spent the day at the Elkon Works in Weehawken, N. J. and then drove to Hartford with the complete information.

THE RECTIFIER PROPER

The rectifier, as was the case in the trickle charger, is based on dry rectification between two discs or washers laid face to face. A single unit is constructed as shown in Fig. 1. Between two sheet copper squares is laid a pair of discs of which one is magnesium while the other is of a black composition whose exact nature takes a good deal of explaining tho one can say briefly that it contains zinc selenide and copper selenide. The lead washers next to the copper plates are used as "padding" since it is hard to get good contacts otherwise. Some of the rectifier discs are shown in one of the photographs.

As was said in the article on the trickle charger, the exact nature of the rectifying process is not too well understood. For convenience the process is described as "electronic reaction" between the two discs. The mechanics of the thing are probably not the same as in the lead-aluminum rectifier which we are familiar with, and possibly not the same as in the copper-oxide rectifier which has recently appeared on the market in trickle-charger form.

One should not be too unhappy at the lack of a more exact explanation; we have not yet found out just where chemistry leaves off and physics begins, but that does not prevent them from being useful.

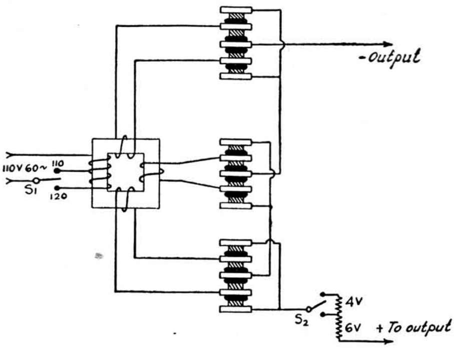


FIG. 2—MANNER OF COMBINING THREE RECTIFIER UNITS OF 4 COUPLES EACH TO OBTAIN A RECTIFIER CAPABLE OF CHARGING AGAINST A VOLTAGE OF 7½

This is the diagram of the trickle charger. The rheostat is made of ballast resistance wire as explained in the text.

At the time of the trickle-charger article it was not possible to operate the Ruben-Elkon discs in series, and as each pair would only stand about 15 volts it was necessary to resort to the curious connection shown in Fig. 2 which is a set of three bridge-connected rectifiers with their d.c. outputs in series. It may seem curious to speak of endangering a 15-volt device when working into a 6-volt battery but one must remember that on the reverse half of the cycle the rectifier stands the transformer voltage plus the battery voltage. The gassing voltage of the battery is 7½ and the transformer voltage must be at least 8 to get anything accomplished. The transformer peak voltage is therefore 11 and this added to the 7½ gassing voltage becomes 18½. As a matter of fact the transformer voltage was a bit higher and therefore three units (as in Fig. 2) rather than 2 units were used.

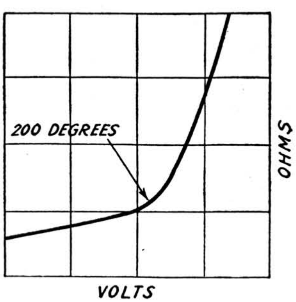


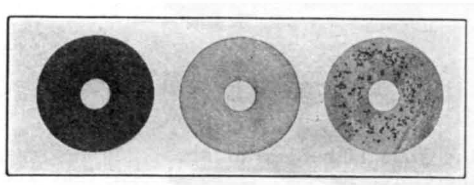
FIG. 3—RESISTANCE-VOLTAGE CURVE OF THE BALLAST WIRE USED IN THE CHARGERS

When the wire has heated to 200 degrees a very slight increase in current raises the resistance rapidly and prevents overloads from becoming damaging.

AMPERE CHARGERS

The trickle charger having given a good account of itself one naturally thinks of chargers operating at a higher rate. At first sight one may think that it is a trifle to go from a 1/3-ampere charger to one working at three amperes—it is only 9 times as much current and the voltage stays the same.

As a matter of fact the transfer was very slow and very painful. A look at the photograph of the discs will show how they wear, for naturally these devices wear out in time. The earlier ones did not wear in this fashion but displayed a disgusting desire to burn across violently at one point, generally short-circuiting the pair and stopping further proceedings. To prevent this the current had to be kept small (which meant a trickle charger) and a protective "ballast" resistance had to be used as is shown in Fig. 2. The problem of producing a 2-or 3-ampere charger was the same as the problem of making the current distribute itself evenly over the disc—and keep on distributing evenly. Those who have tried to make a 3-ampere aluminum rectifier begin to understand that this was somewhat difficult. The thing was finally done however and the 3-ampere charger is a sort of "big brother" to the trickle charger with no very great variation in the arrangement.

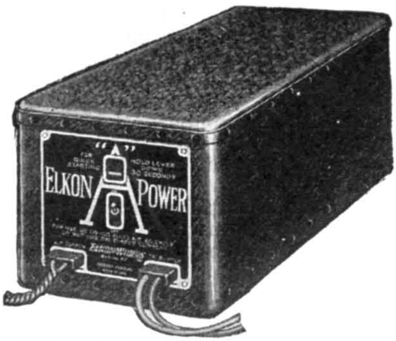


RECTIFIER DISCS

At the left is the black "cupric" composition disc. At the center is a new magnesium disc. At the right is a worn magnesium disc from a test-run showing how the surface has been attacked at various points. In the early discs the failures tended to concentrate at one point and to burn short.

ELECTRICAL DETAILS

The ballast resistance material is present for the purpose of preventing any sudden rises of current which would either cause or aid a local "burn" and tend to damage a rectifier pair. This means that the resistance must rise promptly if anything in the nature of an overload takes place. The ballast is accordingly made of a nickel alloy whose resistance rises rapidly as the temperature is raised. Putting it differently, if the voltage across a piece of the wire is increased the curent will increase slowly and then very rapidly. This means that once we have reached the bend of the curve in Fig. 3 the current will have a hard time to increase further. The kink comes when



EXTERIOR VIEW OF THE ELKON A SUBSTITUTE

the wire is heated to about 200 degrees, therefore, its size is so chosen that the normal charging current of about 1/3 amp. will heat it to that point.

THE A BATTERY "SUB"

Having built a workable 3-ampere charger one naturally wonders if the device will be useful for filament supply, that is as an "A-battery substitute". This divides into two problems; that of devising a rectifier stack to fit this exact job and that of devising a filter to remove the ripple from the rectified output. First, one has to have the rectifier. The filament-supply device ordinarily is not called upon to supply more than about 1¼ amperes, as against the 3 amperes for the charger. This permits the use of smaller rectifier discs and therefore reduces the trouble caused by local current-concentration. The voltage required at the output posts is only 6 as against 7.5 for the charger and this may at first sight seem to be an easier condition. In a way that is true for one can avoid the complex arrangement of Figure 2. On the other hand the rectifier action is such that the tendency is toward a better life when working into a battery than when working into a resistance. This will be explained later. For the present it is enough to say that the disc for the filament supply required a considerable amount of additional work and that those now produced pass thru a complex process during which many are rejected. This of course applies mainly to the "cupric" composition discs.

RECTIFIER DETAILS

Having a pair of suitable discs it is interesting to show how they act. Figure 4 shows the simplest test that one can make easily. A low-voltage battery is connected to an ammeter and a pair of pointed prods. When the prods are put on opposite edges of the cupric disc the current (with the voltage used in the test) was 1.5 amperes The same result was gotten with the magnesium disc. With the pair put together as at the center of the figure the current in one direction was 1.3 amperes and in the reverse direction 0.1 ampere. At a higher voltage the difference would have been much greater up to the breakdown voltage.

When the voltage used is that of the regular "A sub" the resistance in the two directions (average) is different in a ratio of about 1000/1 or more exactly, the resistance from magnesium to "cupric" is 2/10 ohms and the reverse resistance is 200 ohms.

The rectifier will work cold but operates more smoothly when warm—70 degrees Centigrade. The size of the copper fins is accordingly adjusted to keep the unit not cooler than about 70° C which is the same as 160 degrees Fahrenheit. If it warms up

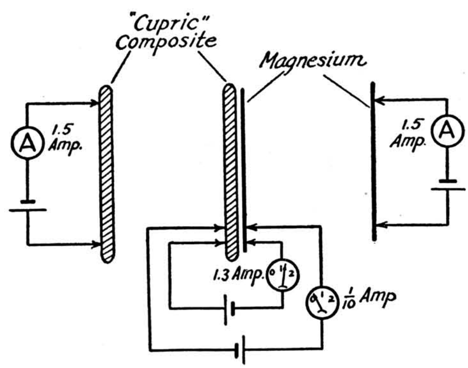


FIG. 4—SHOWING ACTION OF A RECTIFIER COUPLE UNDER D.C. CONDITIONS AT VERY LOW VOLTAGE. THE PERCENTAGES ARE DIFFERENT AT HIGHER VOLTAGE

the resistance of the cupric disc or the contact with it drops and the unit does not overheat. The 3-ampere charger works at 90 degrees C.

Operating at the proper temperature the rectifier has a *static* characteristic like that of Fig. 5A and 5B. As drawn at A the reverse current can hardly be seen at all, therefore the curve has been re-drawn in 5B with two different scales of both current and pressure. Like most d.c. curves on a.c. apparatus these curves must not be taken too seriously. Information that is more to the point can be gotten by using the oscillograph which shows the output current of the rectifier to be like the curve of Fig. 6. It will be seen that the rectification is not as perfect as one would have guessed from a look at the "static" curves of Fig. 5, the actual rectifier efficiency being 35%. A very important point is that the curve shows the output to be of the right wave form for easy filtration.

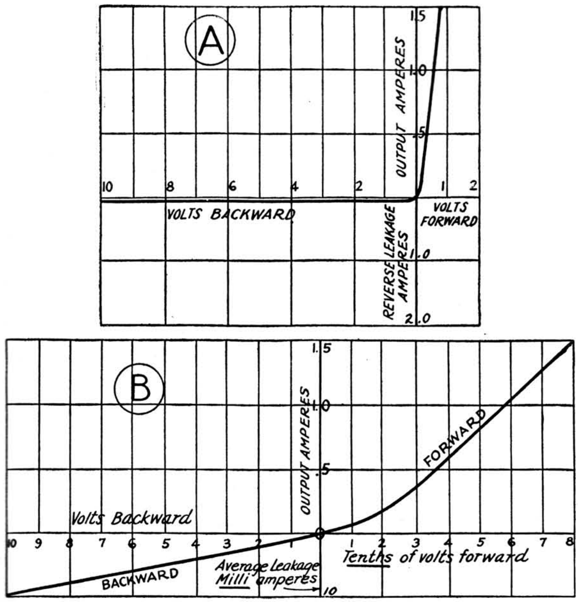


FIG. 5—COMPLETE D. C. CURVES ON RECTIFIER COUPLE

Curve A is to the same scale all the way thru and gives a correct idea of the proportions. Curve B has been drawn on a distorted scale to open out the readings.

Neither curve gives a correct picture of the a. c. action as is explained by Fig. 6 and the text.

The flat-topped shape of the reverse-current is caused by the fact that the contact resistance disappears during the forward half of the cycle and does not instantly grow up again on the reverse voltage half of the cycle. In battery charging the battery voltage aids the reforming. The reverse current furnishes most of the heat which appears in the unit, the rest being caused by the I^2R of the forward current.

The operating efficiencies of the various units are as follows. For the trickle charger (3 units at 2½ volts and 1/3 amp. each).

The operating performance of the rectifier under various conditions is as follows. For the trickle charger whose output is at 7.5 volts. With ½ amp. load the input is 14 watts, the efficiency being about 29%, partly because of the ballast resistance. With a 1-ampere load the input is 22 watts at an efficiency of 34%.

For the 3-ampere charger with normal load of 3 amps at 7.5 volts the input is 70 watts, giving an efficiency of 32%.

These figures compare rather favorably with the usual chargers.

The A-battery substitute, whose output is naturally at 6 volts operates as follows tho it must be remembered that the final output in this case is less than the rectifier output as there is a drop in the filter. The input at no load is 14 watts which goes to reverse current loss and possibly some loss in the filter condensers, loaded with 6 tubes, i. e. 1.5 amperes the input is 46 watts, giving an overall efficiency of 19%. With an 8 tube load drawing 2.25 amperes this becomes 56 watts at an efficiency of 24%.

THE FILTER SYSTEM

The filter system of an "A sub" is a very difficult thing to design as has been said before in these pages. If the rectifier wave form is not good, one may almost stop before starting. It is almost imperative that the filter have large capacities though we have in these pages described an A substitute which did surprisingly well with a resistance filter. In the Elkon device there has been used a 3-stage filter devised by Dr. H. S. Shoemarker who also worked out the electrical and mechanical design of the whole device.

The connections of the rectifier stack itself are shown in Fig. 7 while the complete circuit is shown in Fig. 8. The 3-stage filter was chosen because the inductance cannot be made extremely high without introducing excessive resistance and on the other hand the capacity in the filter is not so effective when concentrated across a single choke. Design considerations that had to be regarded were that the voltage at the output would need to remain between 5½ and 6 with widely varying line voltages and loads and in spite of the unavoidable IR drop in the filter and the rectifier. Taken together these things work out roughly to the effect

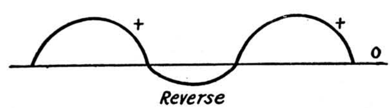


FIG. 6—OSCILLOGRAM OF THE OUTPUT CURRENT

that between the transformer and the output there are the following ratios:

$$\frac{\text{D C Volts}}{\text{A C Volts}} = \frac{.52}{1} \qquad \frac{\text{D C Amps}}{\text{A C Amps}} = \frac{1}{1.5}$$

Overall 30%

As shown in Fig. 8 and also the general photo the transformer is equipped with 8

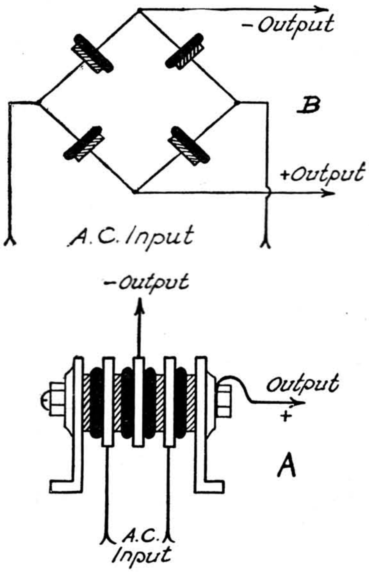
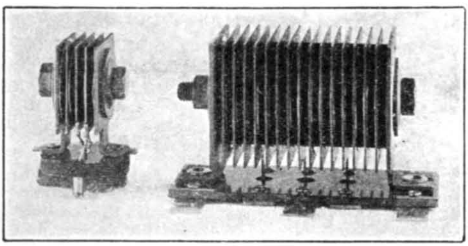


FIG. 7—ARRANGEMENT OF RECTIFIER COUPLES TO FORM FULL-WAVE BRIDGE-CONNECTED RECTIFIER

A is the actual arrangement with the units strung on a machine screw with spring washers while B is the equivalent bridge.

secondary terminals and a traveling plug to permit obtaining various a.c. input voltages so that the d.c. voltage will remain at the proper value. Since the usual re-



RECTIFIER ASSEMBLIES

ceiver has a rheostat this number is very generous and renders it possible to set the voltage at the proper value at the device after which misuse of the rheostat does not endanger the tubes.

The filter chokes have an inductance of 1/10 henry under load and a resistance of .3 ohm, giving a maximum drop of about 1.8 volts. The condensers are electrolytic and have a very large capacity per unit, the total for the 6 cans being 1500 microfarad.

OPERATION

When put into operation initially the rectifier is cold and does not form rapidly. A particular one tried here took about 3 minutes to form sufficiently to give smooth output, after which it slowly warmed up and the voltage rose as it did so. To speed up this operation the set is equipped with a starting switch (SW2 in Fig. 8) which can be closed to throw a temporary overload on the set. This will cause the rectifier to form in 30 seconds.

When used with a 5-tube broadcast receiver having controllable regeneration on the r.f. stages the device introduced no

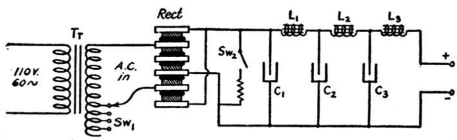


FIG. 8—COMPLETE CIRCUIT DIAGRAM OF THE A SUBSTITUTE

Tr. is the transformer. SW1 is the secondary plug system to adjust for load and line voltage. SW2 is the quick-start switch. C1, C2, and C3 are the electrolytic condensers, each consisting of two cans in parallel L1 L2 and L3 are the filter chokes.

audible hum—although the same receiver has been a star performer in showing up the defects of various A and B substitutes.

Dr. Shoemaker advises that receivers with regeneration be operated with the tubes bright as such sets are inclined to seek out residual ripples and running the tubes too low will cause the remaining ripple to become relatively more important. This precaution was not found necessary here, either with the set just mentioned or with a Browning-Drake receiver, which is another type that demands good plate and filament supply.

A "B" supply is now being worked on. Perhaps some day we may hope for a dry *transmitter* plate rectifier.

Strays

We have been advised by the Sup't of Documents, Gov't Printing Office, Washington, D. C., that the June 30, 1926, issue of "Amateur Radio Stations of the United States" is no longer available. All copies of it have been distributed.