DEVELOPMENT AND STUDY
OF A
FOUR WIRE ECHO SUPPRESSOR
USING A DOUBLE ANODE GAS FILLED TUBE

By
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"Telephone Transmission Over Long Cable Circuits"
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"Echo Suppressors for Long Telephone Circuits"
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"Echo Suppressors for Long Loaded Lines"
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INTRODUCTION

With the development of the vacuum tube amplifier came a solution to one of the most difficult problems that ever has confronted telephone engineers. Up until that time the distance over which man could transfer his voice by means of the telephone had been quite limited. Transcontinental circuits were mere future possibilities.

The vacuum tube amplifier, which in telephone practice is called a repeater, greatly extended the range of the telephone. Its application to telephone circuits, however, was by no means a simple one. The main limitation of this device is that it will amplify speech in one direction but will not permit speech to pass thru it in the other direction. One way of overcoming this limitation is to use two lineups of amplifiers as shown in Figure 1.

Such a circuit would work very well as a permanent connection, but it does not lend itself gracefully to either existing telephone plant or to a flexible subscriber to subscriber switching system. Since telephone plant is in general built up on a basis of having a two wire connection between the telephone subscriber and the central office switchboard it was necessary to develop some other way of using the vacuum tube amplifier in the telephone circuit.

Another solution to this problem was found in
what is now known as the "22" type repeater. This device is essentially a two way amplifier. But before going into the details of its operation we will first consider the fundamentals of the hybrid coil, the circuit details of which are shown in Figure 2.

If the impedance of the balancing network is equal to the impedance of the line the coil becomes primarily a direction selecting device. Energy from the line side will divide in half, one half going over the path A, and the other half going over the path B. The reverse of this phenomena takes place whenever energy comes into the hybrid coil over either path A or path B. Again the energy is split in half, one half being absorbed by the balancing network, the other half going out onto the line. However, due to the impedance balance of the system no energy will flow thru the coil from path A into path B, or from path B into path A.

Practically, as we shall see later, this perfection of balance can never be attained. Due to manufacturing limitations there is always a small difference between the windings of the various coils, and also due to the inequalities of the various impedances of the equipment that is connected on the line side of the coils, the impedances of the line is never exactly balanced by the impedances of the network. Of this more will be said later.
The use of the hybrid coil in the 22-A-1 repeater is shown in Figure 3. Speech energy coming on the East line will, in accordance with what we have just learned of the hybrid coil, split in half, one half going towards the East repeater vacuum tube where it will be lost by the high impedance on the plate side of the tube, and the other half will go to the grid of the West tube, where it will pass to the plate, amplified many times, and from there to the hybrid coil on the West side, where it will again be split in half, one half going out onto the West Line, and the other half being lost in the balancing network. If the hybrid coil is well balanced, little or no energy will be fed thru the West hybrid coil from the plate of the West vacuum tube to the grid of the East vacuum tube to be amplified and fed back to the talker on the East end of the line.

As a usual thing, however, some energy is fed back, and if the line between the East talker and the West hybrid coil is sufficiently long electrically to give an appreciable lapse of time between the moment that it leaves the talker, and the moment that it returns to his receiver, then the talker will experience what is known as a "telephone echo".

The use of the two wire repeater, or 22-A-1 type repeater as it is called in telephone practice, is in
general limited to short haul circuits.

For longer transmission lines another type of circuit known as the four wire circuit has been developed. The details of this circuit are shown in Figure 4. The voice energy from the talker on the East side splits as before at the East hybrid coil, one half being lost in the output of the West to East amplifier, the other half passing to the East to West amplifier, from which the amplified energy goes out onto the East to West transmission line.

At intervals in the line, other amplifiers are inserted in order that the total loss in the long line may be taken care of by a number of amplifiers located at a number of different stations along the route. At the West end of the line, the energy passes thru a final amplifier to the West hybrid coil which passes it along to the terminal line and to the West subscriber.

Speech energy from the West side passes thru the West hybrid coil and over the West to East amplifiers and line to the East hybrid coil, and from there to the subscriber at the East end. In this way voice energy in going from East to West passes over a different line from that on which voice energy is carried from West to East.

Again we have a possibility of an unbalance in the hybrid coil inserting an echo into our conversation. If a little of the East to West voice energy passes
thru the West hybrid coil back into the West to East line, it will travel all the way back over that line to the subscriber at the East end who is doing the talking, and he will hear it in his receiver as an echo. Figure 5 shows the path of direct transmission, together with the echo responses that can be set up when the subscriber is talking at the West end of the four wire circuit of Figure 4. When the first talker echo, which we have just described, passes thru the West hybrid coil, another echo starts back towards the East end over the West to East line. This is the 1st listener echo, and will be heard by the listener at the East end a short time after the original signal has reached him.

In a similar manner a second talker and listener echo is built up, and a third, etc., the echoes getting weaker and weaker until they become inaudible.

THE ECHO SUPPRESSOR

In order to get some idea of the echo, let us consider as an example, a cable circuit 1000 miles long on which H-174-S loading is used on 16 gauge cable, the inductance per coil being .174 henries, the spacing of coils 6000 ft. and the transmission velocity of 10,197 miles per second. The first talker echo will reach its destination, the talker, in approximately 200 milliseconds, that is, 2/10 of a second. The first listener echo in 3/10 of a
second, and the second talker echo in 4/10 of a second, and so on.

Since these echo effects just described can cause considerable disturbance on a circuit, ways and means have been considered for eliminating them. In November, 1922, U.S. Patent No. 1,434,790 was granted to John Mills of the Bell Telephone Laboratories for a device that would effectively suppress the echoes. The essential construction of the device is shown in figure 6. It consists of a two tube amplifier detector associated with a sensitive relay. When voice currents pass over the side of the four-wire circuit across which the amplifier-d detector is bridged, the fluctuations in voltage are amplified and passed on to the detector tube which normally has a grid bias sufficiently low to prevent any appreciable plate current. When the amplified fluctuations reach the grid of this tube, the positive portions produce spurts of current in the plate circuit large enough to operate and hold relay A, which operates to place a short across the opposite side of the four wire circuit.

The application of this circuit to a four wire circuit is shown in Figure 7. Two figures 6 are used to make one four wire echo suppressor. One is bridged across the East to West line to prevent the return of echoes on the West to East line while speech currents are passing in
an East to West direction, and the other is bridged across the West to East line to suppress the echoes on the East to West line while the voice currents are travelling in a West to East direction.

If voice currents are being transmitted over the West to East line, as shown in the diagram, the West to East amplifier detector operates its associated relay to put a short across the East to West side of the circuit before the echo current has time to get around thru the East hybrid coil and back to the point of suppression. In order to accomplish this purpose, the four wire suppressor is usually located near the midpoint of the circuit so that it will be allowed plenty of time to operate to suppress echoes for either direction. If an echo suppressor was applied to the line considered in the foregoing problem, it can be seen that it would require 100 milliseconds for the returning echo to reach the suppressor on the return side after the voice currents had passed the input. Since the suppressor operates in less than 10 milliseconds, this would leave ample time for suppression. In fact, too much time would elapse, for in case of a momentary current, the relay would be operated and released again before the echo got back to be suppressed. For this reason the release of the suppression relay is held up for a period long enough to allow the 1st talker echo to be suppressed, and
die out completely. Since the problem of keeping the suppression relays operated is not being discussed in this paper, we will not consider the details of this portion of the circuit here.

A device that operates along radically different lines is shown in Figure 8. This circuit built by the Siemens and Halske Company, is used extensively in European telephone systems.

If the direction of conversation is from West to East, the voice currents will be picked up by the input of the West to East suppressor and amplified by the amplifier tube. The rectifier tube responds to the amplified voltages to place a highly negative grid bias upon the grid of the E-W repeater in the East to West circuit. This highly negative grid bias paralyzes the repeater and prevents the passage of any echo currents back to the talker. As on the American device previously considered, the echo suppressor must remain operated for a short time after the speech current has died down, but we will not consider this portion of the problem here.

EARLY DEVELOPMENT.

The idea of instantaneous action is, of course, a futile one. Even a beam of light, the fastest known entity, has a finite velocity and cannot cross even a very small distance instantaneously. The speed of the electron, approaching as it does the speed of light, is probably the fastest moving ponderable object, with the velocity of the alpha particle, and the velocity of atoms, also the velocity of molecules in gases that are
Figure 4.

4-Wire Telephone circuit

Figure 5.

To opposite Line

Note: The relays in the hangover system have been omitted from this circuit.

1/2 of Standard 4-Wire Echo Suppressor.

Figure 6.
at low pressures following as moderately close seconds.

The last mentioned agent was considered by the author as probably the best method of realizing his goal, and accordingly a search began for ways and means of utilizing the process. The idea shown in Figure 9 was finally hit upon as a possible solution.

The tube itself was to consist of two plates, P1 and P2, plate P1 being located considerably farther from the filament than plate P2. As long as there was no current flowing on the opposite transmission path, plate P2 would not be charged, and the tube with plate P1 would act like an ordinary vacuum tube and pass voice currents freely. But whenever voice currents were passing along the opposite side of the line, then the amplifier rectifier that was bridged across that circuit would place a high positive charge on plate P2 and as a result attract all the electrons to itself, leaving none for plate P1. As a result the tube would act as a suppressor to any current in that side of the line. Such an operation would take place practically simultaneously with the picking up of the voice current voltage fluctuation by the amplifier rectifier.

As is often the case with invention and development, this idea had to give way to a better one.

Mr. E. A. Veazie of the vacuum tube research department suggested the use of the newly developed gas filled, or
"trigger" type of tube for this purpose.

The so-called "trigger" tube is similar in construction to the ordinary vacuum tube except that it is filled with argon gas. This gives the tube a peculiar grid-plate current characteristic. As long as the potential of the grid remains under a certain critical value, which is usually about +5 volts, very little plate current flows. However, as soon as the critical voltage is reached, the tube breaks down and a very large plate current flows. The impedance of the path from filament to plate often becomes as low as 40 ohms. If this low impedance is placed immediately across a transmission line voice currents on the line will be noticeably attenuated. By coupling the grid of the tube to an amplifier rectifier circuit, the breakdown of the tube can be brought about by placing the input to the amplifier rectifier immediately across a circuit bearing voice currents. In other words, our gas filled tube and amplifier rectifier becomes the desired instantaneous echo suppressor.

It was found after a little experimenting that the single plate tube had a tendency to place a rather serious click in the circuit, a click being nothing more than a surge of current thru the transmission line of sufficient suddenness and intensity as to produce a noticeable sound click in a telephone receiver connected to it.
Analyzation of the circuit shows that this click is due to the inequality in the impedances of the paths that the plate current must follow in order to get to the plate of the tube. This difficulty was obviated by using a gas filled tube with a double plate, together with a new circuit arrangement. Early forms of this development are shown in Figures 10 and 11 and 12.

THE DOUBLE PLATE GAS FILLED TUBE ECHO SUPPRESSOR

After a considerable lapse of time, a number of double plate gas filled tubes were made by the gas filled tube development and design department. These tubes were given the designation 58-GYQ. With the tubes arrived a memorandum, "The Use of the 58-GYQ as a Two Valued Impedance" by Mr. G. H. Rockwood. In this memorandum was suggested a circuit that has already been used in various forms with gas filled tubes. The diagram from the memorandum is shown in Figure 13.

In this circuit, either one tube or the other, but not both, will be in the broken down condition, that is, will be passing current. If the 256-A tube is passing current, then its grid must be positive. The condenser to the plate of the 256-A takes on a positive charge, and in this way keeps the screen of the 58-GYQ negative and prevents it from passing current. If a signal is applied in such a direction that the grid of the 58-GYQ should become
positive, then correspondingly, the grid of the 256-A tube will become negative and when the current begins to flow in the 58-GYQ, the condenser will take on a positive charge of the 58-GYQ side, with the resulting negative charge of the other side to make the plate of the 256-A negative and cause it to stop passing current.

The circuit used in the actual experimental work is detailed in Figure 14. It is essentially the same as the circuit shown in Figure 13 except that meters have been added in a number of places and a few other minor changes made. The nine volt battery and the key provide a means of controlling the discharge. Whenever the key is unoperated, the 256-A is passing current and the 58-GYQ is normal. When the key is pressed, the 58-GYQ breaks down and the 256-A restores. This gives us control over the device in order to enable us to study its use as an echo suppressor.

Two tubes were used in the study, one with a very bad, relatively speaking, unbalance between the two plates, or collectors, and the other with a balance that could be considered as quite good. Transformers of various impedance ratios were used, and finally it was determined that the lowest acceptable ratio was about 500:100,000, that is, 1:200. With this ratio, a loss in the line during suppression could be obtained that would give satisfactory echo suppression. With this point de-
-15-

termined, the real study of the echo suppressor portion of the circuit began.

It was first necessary to determine the amount of loss that the suppressor would place in the circuit, both during the time that the 58-GYQ tube was broken down and during the time it was not broken down.

All transmission measurements were made with a well known device, that was developed for that purpose, the 6-A transmission measuring set. Since this device is only capable of measuring losses that are smaller than 30 decibels, a calibrated amplifier was used in the receiving side to make it possible to measure a loss of around 70 db. Therefore, \textsuperscript{2} a 44-A-1 repeater was connected into the circuit as shown in Figure 15.

Losses were measured at frequencies of 200, 500, 1000, 2000 and 3000 cycles with the echo suppressor in both the suppressing and non-suppressing conditions. These measurements were made for both the good tube and the bad one, and are included in this thesis as data sheet \#1, the tube \#39667 being the one with the unbalance.

It was of interest to know the value of resistance that the tubes were placing across the line while they were in a broken down condition. In order to determine this the 58-GYQ tube was removed from the circuit and a decade resistance box was substituted for it.
Measurements were made for losses of 30, 40, 50, 60, 70, 80, 100, 200 and 1000 ohms. No measurements were taken for losses greater than that corresponding to a 30 ohm shunt, and for losses less than that corresponding to a 1000 ohm shunt because it was felt that these losses would be entirely outside the range of variations in the losses inserted by the tubes. The results of these measurements are shown on data sheet #2. Curves were plotted to show the relation between the attenuation in decibels and the resistance for the various frequencies used. These curves are shown in Figures 17, 18, 19, 20 and 21.

The next point investigated was the action of the tube during actual echo suppression. For this purpose the 6-A transmission measuring set, the suppressor device, and an oscillograph were set up as shown in Figure 16. Oscillographic pictures were taken of the tube action as the key was pressed to start suppression and as it was released to stop suppression. Some of these oscillograms are shown on the page designated Figure 22, diagrams a, b, c and d.

The last point considered was the current surge in the circuit during the breaking down and restoration of the tube. With the oscillator and 6-A transmission measuring set in Figure 16 turned off, oscillograms were taken to show the surges when the control key was operated and released. Some of these results are shown in diagrams (e)
and (f) of Figure 22.

From the curves of Figures 17, 18, 19, 20 and 21 we find that the impedance in ohms of each of the tubes at the selected frequencies are as follows:

<table>
<thead>
<tr>
<th>Frequency Cycles per Sec.</th>
<th>Impedance Tube #38667</th>
<th>Impedance Tube #38668</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>84.9</td>
<td>68.1</td>
</tr>
<tr>
<td>500</td>
<td>80.1</td>
<td>60.0</td>
</tr>
<tr>
<td>1000</td>
<td>85.2</td>
<td>64.2</td>
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<tr>
<td>2000</td>
<td>89.5</td>
<td>68.5</td>
</tr>
<tr>
<td>3000</td>
<td>112.0</td>
<td>69.9</td>
</tr>
</tbody>
</table>

It can be seen from these results that the unbalanced tube has a much higher resistance value than the balanced one. However, this is probably characteristic of the individual tubes and the apparent relation not hold for two other tubes with the same, or similar differences in balance.

It is of interest to investigate the curves (a) in Figures 17 to 21, inclusive. If we place a resistance R in place of the tube in Figure 14, we can represent the loss in decibels of the circuit between the IN and OUT positions by the equation:

\[
\text{Loss} = 20 \log \frac{R/A}{R/A + Z}
\]

where A is the ratio of the high side of the transformer to the low side, and Z is the characteristic impedance of the line.
If we substitute the values for these variables the values from the circuit in Figure 14, we have

\[
\text{Loss} = 20 \log \frac{R/200}{R/200 + 500}
\]

Using the values of the resistances that were used as shunts in place of the 5S-GYQ tube, we have the losses listed in the following table:

<table>
<thead>
<tr>
<th>Resistance (Ohms)</th>
<th>Calculated Loss (Decibels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>72.0</td>
</tr>
<tr>
<td>40</td>
<td>69.5</td>
</tr>
<tr>
<td>50</td>
<td>67.6</td>
</tr>
<tr>
<td>60</td>
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<td>600</td>
<td>46.1</td>
</tr>
<tr>
<td>1000</td>
<td>41.6</td>
</tr>
</tbody>
</table>

These values are shown plotted in the curve (b) on Figures 17 to 21 inclusive. It can be seen that the measured results agree pretty well with the calculated values, the deviations being due probably to the frequency characteristics of the transformers.

Figure 22 shows the oscillograms detailing the performances of the circuit as an echo suppressor. It will be noted that the frequency of 200 cycles is suppressed immediately, and with very little disturbance. The same comment holds for frequency of 2000 cycles. For 3000
cycles it will be noted that the suppression is immediate and of a satisfactory nature, but that the restoration is not as good, there being evidence of a noticeable lowering of the level of the tone. This would sound like a click in a telephone receiver. For a frequency of 6000 cycles it can be seen that the click is still of a more pronounced nature, and still occurs at the end of the suppression period but not at the beginning.

When tone is entirely removed from the circuit a picture of the click may be obtained that is free from all disturbance. Such pictures are shown in diagrams (e) and (f) of Figure 22. The picture in diagram (e) was taken with the suppressor arranged as shown in Figure 14. Experiments were then made to see if the click could be balanced out by using a little resistance in series with one of the windings of the retardation coil. The results of this procedure are shown in diagram (f), the value of the added resistance being 35 ohms.

The fact that the click seemed to affect frequencies around 5000 cycles and over, coupled with the evidence of the click oscillograms in diagrams (e) and (f) which show the click to be made up of a frequency of around 8000 cycles it was surmised that if a filter were placed in the line, most of the click would be removed. This was found to be the case, only a very small disturbance remain-
ing. Since most lines are in themselves effective filters for frequencies above 3000 cycles, it is doubtful if a filter would ever have to be employed in connection with this echo suppressor. Anyway, if the echo suppressor is used in the output of a telephone repeater, the level of the click would be so low in comparison with the level of the voice currents that by the time that both disturbances reached their destination, the click currents would be practically inaudible.

This is as far as we shall follow the development of the echo suppressor at this time. The device as we leave it is still not in its completed form. The matter of adding the amplifier detector to the circuit so as to make the 58-GYQ tube sensitive to voice currents still remains to be investigated. Since this has been done already for another type of echo suppressor using a similar arrangement of gas filled tubes there remains probably little that is new or novel to be done in designing an amplifier detector to fit this circuit. The problem of adding a hangover device to the circuit is also one that we will not consider here.
Figure 7.

Direct Transmission

Suppression of echo

Figure 8.
Instantaneous
A Wire Echo Suppressor

From
Near end 4-wire
hybrid
coil

To plate 1st
Echo suppressor
rectifier tube
50-62480-07
Issue 1.

Witnessed by
Hil. Ronner
7/2/30
The tube illustrated in the above circuit is designed for use as a quick acting relay, especially suitable for short circuiting the two sides of a balanced line. The tube is of the gas-filled type, and any of the gases suitable for use in tubes depending on ionization of the gas by electron impact for operation would be suitable for use in this case. The tube consists essentially of a filament or cathode, a grid, and two plates, so arranged that application of a sufficient negative potential to the grid will prevent breakdown of the gas in the tube. Preferably the two plates should be so arranged that the capacity of each to any of the other tube elements is the same.

The circuit shown schematically above illustrates the type of use for which such a tube is suitable.

Witnessed by: 

Edmund A. Veazie

8/2/30
Before ionization of the gas in the tube takes place, the network may transmit efficiently between its input and output terminals. However, the application of an a.c. voltage between terminals 1 & 2 may be made to start ionization in the tube, and once ionization starts, the impedance between each plate and the cathode becomes small, thus making the impedance between the two plates small and reducing the transmission efficiency of the network. Thus, operation of the tube in effect short circuits the two sides of the line, an effect which previously has required the use of a mechanical relay.

Witnessed by:  

Edmund A. Vrage  
8/2/30
When a small input from one side of a four-wire circuit reaches suppressor lugs 5 and 6, the amplified voltage breaks down the double plate gas-filled tube and instantaneously places a loss on the other side of the circuit. At the same time the amplified input is impressed on the grid of a tube operating as a plate current detector. The currents at the plates of both the gas-filled and detector tubes pass through windings of a relay which, when operated, places a metallic short across the line and opens the plate circuit of the gas-filled tube. The plate current of the detector tube holds the relay operated until the input voltage drops below some critical value, after which the circuit restores to its original condition.

Witnessed by

E. A. Vezzie

H. L. Jones

G. E. Moore

8/26/30
Schematic Circuit of Echo Suppressor.

When a small input from one side of a four wire circuit reaches suppressor lugs 5 and 6, the amplified voltage breaks down the double plate gas filled tube to instantaneously place a leak on the other side of the circuit. The current in the plate circuit operates relay "R". The relay should be designed to first close contact I to place a metallic shunt on the line, next to close contact II to form an oscillating circuit, and then to close contact III, shorting the condenser. The circuit is then such that it will return to its original condition when the input across lugs 5 and 6 drops sufficiently.

Witnessed by

K. L. Jones
E. A. Peazie
Co inventors.
8/25/30
SUGGESTED CIRCUIT FOR

58-GYQ

Figure 13.
(a) Suppression of 2000 Hz tone (41). Key on #3.

(b) Suppression of 2000 Hz tone (41). Key on #3.

(c) Suppression of 3000 Hz tone (41). Key on #3.

(d) Suppression of 6000 Hz tone (41). Key on #3.

(e) Current surges at beginning and end of suppression (41). Key on #3.

(f) Current surges at beginning and end of suppression (41). Key on #3.
# DATA SHEET #1

## Measurements Three Echo Suppressor

<table>
<thead>
<tr>
<th>Freq. (Cycles/Sec.)</th>
<th>Repeater Calibration</th>
<th>Non Suppressed Condition</th>
<th>Suppressed Condition</th>
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<tr>
<td></td>
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<td>Measured</td>
<td>Loss</td>
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<tr>
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<td>+48.2</td>
<td>+42.0</td>
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<tr>
<td>3000</td>
<td>+47.8</td>
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**NOTE** The above results are in decibels, the + sign indicating a gain, the negative sign, a loss.
ATTENUATION IN DECIBELS FOR VARIOUS VALUES OF
RESISTANCE IN PLACE OF TUBE IN ECHO SUPPRESSOR

<table>
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<td>66.1</td>
<td>-22.5</td>
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</tr>
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NOTE Losses for resistance shunts of 10ω and 20ω were too high, to be measured.