DISCUSSION ON "MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES." CHICAGO, JUNE 28, 1911.

Frank B. Jewett: The phenomena which underlie what seem at the present time, to be the most promising lines of investigation for the development of wireless telephony, namely, the utilization of one very high-frequency alternating current as what might be termed the "carrier" for other and lower frequency alternating currents, appeal to the imagination not only of the engineer but also of the physicist. It was consequently with more than usual interest that I commenced an investigation of Major Squier's work in the early part of this year at the time the newspapers first announced the issuance of his patents and described in a general way the character of his discoveries.

My investigation had for its object the determination of whether any of Major Squier's reported discoveries contained the germ of a speech transmission system that could be made commercially applicable in a general, universal telephone system. There were two main questions to be answered, first, were the newspaper accounts of Major Squier's work correct as to what he had accomplished, that is, was it possible even on a single circuit to obtain the results claimed? Second, on the basis of an affirmative answer to the first query was there anything in Major Squier's research that would make his discoveries commercially applicable to either a local or long distance telephone plant? If not, did the research give promise of ultimate commercial adaptation and what further developments would be needed to so adapt it?

I think that Major Squier's paper as presented at this Convention will remove any doubts as to the first of the above queries. Major Squier's paper indicates very clearly that what has been accomplished in wireless telephony, namely, the transmission of intelligible speech by means of a high frequency alternating current carrier, can also be accomplished on a simple telephone circuit consisting of wires, either metallic or grounded, by the same or similar means and apparatus. This being so, we come at once to the second query, namely, that relating to the practical utility of the work in a commercial telephone installation. As yet I have not been able to determine that the research, beautiful though it may be from a physical standpoint, possess any great commercial value or possibilities.

In studying this phase of the matter, it is necessary to take account of all the factors which enter into the design and maintenance of circuits and equipment needed to afford commercial service. In a general telephone plant, the first essential is, a sufficient amount of energy, closely approximating the form in which it was put on the line at the beginning of the circuit, should be transmitted and delivered at the instrument of the receiving subscriber; it is also essential that this be accomplished in such a way and by such means that the plant has a maximum flexibility of operation. Further, from a commercial and operating standpoint it is essential that the circuits used for the transmission of speech be of such a character that the necessary signaling current can be transmitted and that signaling means be provided which will give the operators immediate and complete control of the circuit. While it is not always necessary to transmit the signaling current over the same wires that are used for talking, these currents are usually so transmitted and in any plant for general telephony and telegraphy, where the wires are used to proper efficiency combined talking and signaling currents will in general be found on all wires.

In the matter of the necessary energy to be supplied, a very rapid and cursory examination of the conditions which must be fulfilled in a commercial plant, especially in a long distance telephone plant, will indicate that the general characteristics to be taken account of in considering high-frequency transmission analogous to that suggested by Major Squier are not nearly as simple as on the short circuit which he used between the War Department and the Bureau of Standards in Washington and which, under the circumstances, we might term a laboratory circuit. Further, a few simple computations will show that the attenuation of current at the high frequency which must be used in Major Squier's system is enormously greater than the attenuation at the frequencies which go to make up ordinary speech. The phenomena of current attenuation on long telephone circuits are not different in character for frequencies of from 15,000 to 100,000 periods per sec. than for frequencies of from 200 or 300 to 3,000 periods per sec. and the same attenuation formulas can be used. In rough computation work it is customary for telephone engineers to take a single frequency as designating the average of what takes place in the transmission of speech. The generally accepted single frequency for computation work is 800 periods per sec. Major Squier mentions, as the range of frequencies which are applicable to his adaptation of wireless methods to wire telephony a range from about 15,000 to about 100,000 periods per sec., the lower limit being set by considerations of audibility and by the upper or higher harmonics in ordinary speech and being quite definite. The upper limit is set primarily by considerations of current attenuation and is not quite as definitely marked.

As an illustration of the great difference in attenuation between these high frequency currents and the currents which go to make up ordinary speech transmission, let us consider what will happen on some of the open wire and cable circuits that are ordinarily used in long distance telephony—as examples of these circuits, I have taken first a No. 8 B. W. G. copper circuit, which is the largest copper wire used in commercial telephony in America; second, a No. 12 N. B. S. G. copper circuit, which is the size of wire ordinarily used for rather short toll work and third a No. 13 B. & S. gauge cable circuit, which is about the largest size copper wire circuit generally used in underground telephone cables. Comparing the attenuation of the current at the very high frequencies needed in Major Squier's arrangement to the attenuation at 800 frequency, we find the following:

At 15,000 frequency, which is the lowest frequency Major Squier suggests, the attenuation constant on the No. 8 gauge circuit is 2.2 that at 800 frequency. This ratio increases to 5.4 at 100,000 frequency. On the No. 12 gauge circuit the ratio of high frequency to 800 frequency attenuation constants ranges from 1.6 at 15,000 to 3.5 at 100,000 frequency, while on the No. 13 gauge cable circuit the range is from 1.9 to 4.2 for the corresponding frequencies.

Although the above figures indicate a markedly more rapid attenuation for frequencies above 15,000 than for frequencies in the neighborhood of 1000, they do not show in the most striking manner the serious way in which this rapid attenuation limits the commercial application of any high frequency carrier scheme of telephony. As noted before, it is necessary in a commercial telephone plant to deliver to the subscriber at the distant end of the line a sufficient amount of energy with approximately the form of the current at the sending end to give him an audible amount of sound from his receiver. If we take as a basis of our comparison the amount of energy, which at 800 frequency represents the commercial limit of telephone transmission and assume that at the receiving end of a circuit operated on Major Squier's principle, the amount of energy received in the form of high frequency current is equal in amount to this, and then determine the amount of energy that will have to be put in at the sending end of the line, we obtain some very startling figures.

In obtaining these figures it is assumed that the high frequency receiving apparatus is equal in efficiency to the regular apparatus.

The commercial range for non-loaded No. 8 B. W. G. copper wires is about 1,000 miles and the corresponding lengths for No. 12 N. B. S. G. copper circuits and No. 13 B. & S. gauge cable circuits are respectively 450 and 61 miles. Using these lengths and making the comparison noted above we find that on the 1,000 mile No. 8 B. W. G. circuit it is necessary to put 4,000 times as much energy in at the sending end at 15,000 frequency as is required with 800 frequency, if the energy at the receiving end is to be equal in the two cases. At 50,000 frequency the ratio has risen to 300,000,000, while at 100,000 frequency the ratio of energy at this frequency to that at 800 frequency to obtain the same amount of energy at the receiving end is $7 \cdot (10)^{12}$.

On the 450 mile No. 12 N. B. S. circuit, the ratios for 15,000, 50,000 and 100,000 frequency are respectively 50, $3 \cdot (10)^4$ and $2 \cdot (10)^7$ while for the 61 mile circuit of No. 13 B. & S. cable the corresponding ratios are 500, $1 \cdot (10)^6$ and $3 \cdot (10)^9$.

These figures show, I think, that the problem of applying a high-frequency method of transmission to an existing wire plant would be an exceedingly difficult one, even if there were no other objection to the system and on the assumption that the required terminal apparatus could be readily obtained, due merely to the enormously greater amount of energy required at the sending end of the line. Furthermore, if the system were to be of any great value in a commercial plant, it could not be limited to a single frequency, but would require a large range of frequencies. The figures just given show that with such a range of frequencies the range of energy which must be supplied to lines of similar length will be very great if uniform transmission is to be given. While this might not be a serious objection in a plant comprising but few toll lines, it becomes one of very grave importance when a comprehensive net work has to be taken into account.

I have not as yet been able to see how this difficulty can be overcome in a way that will admit of applying this kind of a system to the complicated requirements of a commercial wire plant. Nor have I yet been able to find affirmative answers to certain other questions which must be satisfactorily disposed of before the device of high-frequency transmission can assume commercial value and proportions.

The more important of these questions are, first, the question of interference between high frequency circuits, 2nd, the question of signaling, and 3rd, the question of modifications required in the existing telephone plant to make possible the application of high-frequency transmission.

With regard to the question of interference, Major Squier points out very clearly that there is no interference between the ordinary talking currents and the high-frequency currents which may be superimposed on the same circuits. This point, can I believe, be granted without further consideration. There would be, however, in a commercial plant operated on the high-frequency system the question of interference between a circuit operated on one of these high frequencies and a neighboring circuit operated with another high frequency. To a certain extent this kind of interference could be avoided by a system of tuning for the terminal apparatus, as Major Squier points out, but we have only to glance again at the figures for the 1,000 mile circuit to see what difficulties there would be in the way of accomplishing commercial results in this manner. Let us consider for example the case of a toll line 1,000 miles long on which there are two pairs of No. 8 B. W. G. copper wires and assume that both circuits are being operated on a high-frequency method and are supplied with sufficient energy at the sending end to give commercial transmission at the distant end. If simultaneous sendings were always from the same end of the line there would probably be no great difficulty in eliminating interference even if there was considerable unbalance between the four wires making up the two circuits. In a commercial plant this simultaneous operation from the same end could not, of course, be obtained, and we have to consider interference between sending on one circuit and receiving at the same end on the neighboring circuit. A consideration of the relatively large amount of energy at the sending end, to give commercial transmission at say 100,000 periods per sec. over a circuit 1,000 miles long shows that a degree of balance between the four wires of the system which is commercially unattainable would be required to block out interference between the sending end of one circuit and the receiving end of the other circuit, even where the two circuits are operated on two rather different frequencies.

Even if it were physically possible to obtain the degree of balance needed for the elimination of interference, that is, to transpose the wires against each other at sufficiently frequent intervals, a scrutiny of the distance factors will show that with open wire lines constructed in the manner ordinarily employed for telephone plants, there are not a sufficient number of poles provided to make possible the necessary transpositions. On well transposed lines for ordinary talking circuits the transposition poles, that is, the points at which the two wires of a circuit are turned over, occur on the average at between one-half and one mile apart, say from twenty to forty poles apart. When we come to consider high-frequency currents of from 15,000 to 100,000 alternations with their very much shorter wave length we find that in order to provide the same number of transpositions per wave length, we would not have a sufficient number of poles in the line as ordinarily constructed and would have to put in additional poles. From this standpoint also, therefore, it will be seen that there are very serious objections to any general application of the idea of using high-frequency current for the purpose of superimposing one talking circuit on another. The same objection arises in the case of cable circuits where current can pass from one circuit to another if there is any capacity unbalance between the pairs of wires which make up the adjacent circuits. Even in the present state of the art the degree of balance required to prevent excessive cross talk is very great and a high-frequency system would necessitate a degree of balance that appears to be commercially unattainable in the present state of cable manufacture.

In order to operate telephone circuits commercially it is necessary to provide means for signaling. The suggestion has been made that in a high frequency system this would not have to be done on the circuits themselves, but that all orders could be passed over special order wires. As noted previously, however, the full utilization of a wire plant in a system devoted to combined telephony and telegraphy practically requires the sending of both talking and signaling currents over the same wires. It would seem, therefore, that this point can not be dismissed so easily and that signaling apparatus must be provided on the talking circuits before a high-frequency system can be considered as having any great commercial applicability. Major Squier points out that in the particular circuit which he used, *i.e.*, a pair of wires in an underground cable, considerable reflection of the high frequency currents occurred at the protecting heat coils in the central offices. If this is so, it is evidence that even the simplest form of relay or retardation coil will act almost as a solid barrier against high-frequency currents unless it is bridged by a condenser.

Thus, even if we could get a sufficient amount of energy over the line it would be difficult to operate a high-frequency relay commercially and at the same time prevent its operation through extraneous disturbance. If, as in the case of the ordinary supervisory relay in a subscribers loop, the apparatus is in series in the line, it would seem to be almost impossible to insure proper signaling operation and at the same time to permit of efficient talking.

The necessity for bridging relays and impedance coils with condensers in order to permit the passage of high-frequency currents would be in itself a very serious bar to any general application of such a system, as it would not only greatly enhance the first cost of the equipment, but would also throw an unduly great burden on the maintenance force. Further, in the case of long distance telephone lines as they exist in this country today and as is pointed out in the paper by Mr. Gherardi on "Commercial Loading of Telephone Circuits," the tendency is to increase the efficiency of the talking circuits by means of inductance coils applied in accordance with Professor Pupin's invention. In this system inductance coils are placed in the circuit at definite intervals, the coils in some cases having an inductance as high as a quarter of a henry each. At the present time the entire toll plant in the long distance system of the American Telephone & Telegraph Co., is rapidly approaching the condition in which all of the circuits contain these inductance or loading coils. There are thousands of these loading coils distributed today along the open wire and cable circuits which form the telephone net work and the problem of applying and maintaining suitable condenser shunts of any form whatever around each individual loading coil would be well nigh insoluble. Also, the presence of these shunts would be seriously detrimental to the efficiency of the circuits for their ordinary use.

I have made one or two short computations to see what this shunting might mean, even assuming that we could maintain condensers around each loading coil, that is that we could build them to withstand commercially the effects of lighting low insulation, etc. For the purpose of comparison let us take the case of a No. 12 N. B. S. aerial copper line which is loaded with inductance coils of 0.25 henry each at eight mile intervals. Further, let us take a frequency of 50,000 periods per sec. which is about midway in the range suggested by Major Squier. In the computation I have assumed that we would install at each loading coil a condenser of sufficient capacity so that the reduced attenuation of the line at 50,000 frequency would not be more than $2\frac{1}{2}$ per cent higher than the attenuation at 50,000 frequency over the same line without any loading coils whatever. This would require a condenser of about 0.04 microfarads for each wire at each loading coil. While such condensers around the loading coils would keep the attenuation at 50,000 frequency down to about $2\frac{1}{2}$ per cent higher than it would be if there were no loading coils on the wire, they would tend to destroy the effect of the loading coils for ordinary talking currents. If we take 1,500 frequency, which is above the mean telephonic frequency but is still within the range necessary for intelligible transmission, we find that the presence of these condensers around each loading coil increases the attenuation by about 7 or 8 per cent. It will thus be seen that for the sake of obtaining a reasonably good circuit for high frequency currents we would have to very seriously impair the talking frequency of our loaded lines when operated in the ordinary way.

In conclusion and as previously remarked I would say that I commenced my investigation of Major Squier's work with a great deal of interest, not only on account of the engineering features involved, but also because the fundamental idea of the system appealed to me very greatly. In the course of this investigation I have had not only the pleasure of reading Major Squier's paper, but in addition the further pleasure of discussing his work with Major Squier personally and of examining his apparatus on the line in Washington and I can assure you that the experiments which he has performed over this line are indeed beautiful. There is absolutely no interference between the battery current and the high-frequency current and over the circuit which he was operating, *i.e.*, a relatively short cable circuit, it was easily possible to get a reasonably good volume of transmission with good articulation. As I have already said, however, I have not as yet been able to satisfy myself that there is any affirmative answer to the engineering questions which must be satisfactorily answered before there is any possibility of applying Major Squier's invention generally to a commercial plant used for universal service. I do not say, of course, that it may not be feasible to apply it commercially in certain localized cases where there are special reasons for desiring an additional circuit without the necessity for running additional wires. This could hardly be considered as a general commercial application, for the purpose of extending the range or efficiency of telephonic communication.

E. F. W. Alexanderson: I have prepared for this meeting a paper on "Magnetic Properties of Iron at Frequencies of 200,000 Cycles," but failed to get it ready in time for printing. I just mention this in connection with Major Squier's paper in order to show that 100,000 cycles is not any longer the limit for mechanically generated frequency, but otherwise it is quite clear, particularly in view of the figures shown by Mr. Jewett, that any frequency of 200,000 will be of no value at all for transmission over wires. I have had the same feeling in some experiments I made two years ago—that even 100,000 cycles is altogether too high to be used on a wire service. The experiments were made with the frequency of 10,000 cycles, and the same mechanical parts were used as the 100,000 cycle alternator; however, with a differently designed armature. The pulsating current of the microphone was used as the exciting current of the alternator, which was able to generate a high frequency current of much greater volume than the current used for excitation. The generated current was sent through a mercury rectifier and it was found that an image of the original telephone current could be produced. A special winding was used in order to increase the efficiency, so that the telephone current and the high frequency current flowed in the same conductors.

In connection with those experiments it was naturally thought that there is a possibility of transmitting a high frequency—in that case of 10,000 cycles—over a wire circuit, and in that way have the advantage of tuning the wire circuit to a definite frequency and avoid the distortion of wave shapes, which is bound to occur in ordinary long distance telephony due to the simultaneous transmission of different frequencies. It may be that even 10,000 cycles is too high, in view of the figures that we have had, and it might be out of the question to even use this system for transmission over wires. However, there may be hope for new developments that might solve the problem of long distance transmission. In fact, an alternator is just being constructed by which it is hoped that the frequency of 3,000 cycles can be used without interference with the voice, and in such a case it might seem reasonable that the telephone engineers would find a way of tuning their circuits to approximately 3,000 cycles, and in that way introduce some form of multiplex telephony by which messages may be transmitted long distances without distortion of wave shape or change in the quality of the speech.

John B. Taylor: There are a number of points of similarity between the electric telegraph systems and the electric telephone systems. Therefore, we can profitably look back over the attempts at multiplex telegraphy and see why some have worked out and some have failed.

Various means of separating one set of operators from another set using the same conductor, have been suggested or tried. Some of these means are: (*a*) difference in polarity; (*b*) difference in current strength; (*c*) successive assignment of the circuit to different operators, and (*d*) "resonance" methods. The paper under discussion is an example of the last method. These have all been suggested, and to some extent used on telegraph work. Some of them, I think, we can dismiss right away for the purpose of multiplex telephony.

Polarity seems to be pretty well out of the question, as telephone current is essentially an alternating current and it is hard to see how we can arrange to have one speaker use only currents of one polarity, while other speakers use currents of the opposite polarity.

A method depending on strength of the current seems to be quite out of the question, because the telephone current must go to zero and pass through various values.

The Gray harmonic telegraph system seemed to have great possibilities but, as far as I know, it is nowhere in commercial use. In the paper under discussion we have offered a modification—harmonic telephony in which we are using frequencies so high that the currents do not interfere with standard telephone apparatus, and it is intimated that a number of frequencies may be used for independent telephonic conversations. The complications would seem to be much more in the case of the telephone than with the harmonic telegraph, and the latter has not yet proved successful.

The other possibility, the successive assignment of the line to one station and then to another, (in the "synchronous telegraph" use is made of a so-called "sunflower" rotating distributor whereby the line is assigned for a short space of time, first to one operator and then to another) may be considered for telephony. It is surprising how much can be eliminated from the telephone current and still have recognizable speech. There are various ways of attacking the problem of multiplex telephony, and some have possibilities.

The system of multiplex telephony under discussion is a resonance method making use of intensity variations in the strength of an alternating current of frequency greater than that to which the standard telephone receiver and human ear are sensitive.

Major Squier refers to the possibility of solving the problem by the use of a similar method in which the transmitted alternating currents are of frequency below those to which the ear is sensitive, or in the neighborhood of 16 cycles per sec., but has apparently dismissed this from serious consideration on account of the difficulty of securing a pure sine wave. It may be well to point out here that entirely apart from any question of difficulty in securing a perfect sine wave of the frequency of 16 cycles or lower, that such a system is fundamentally wrong for purposes of speech transmission. That this is the case will be evident on slight consideration. Fairly rapid speech may have as many as ten distinct syllables in each second, so that one or more of these syllables occurring at or near the zero part of the 16 cycle wave, would be either entirely lost, or of such low intensity compared with those syllables occurring at or near the peaks of the 16 cycle wave, as to seriously change the quality of the speech. This is not equivalent to saying that speech over such a low frequency system could not be recognized, but that the distortions are so great as to debar the matter from serious practical consideration. In some of my own tests, making use of alternating currents of relatively low frequency as a source of current supply in the transmitter circuit, instead of the usual cells of battery, and working with simple musical tones instead of the more complex speech, some very curious effects were noted, which can not be discussed at this time beyond mentioning the fact that the simple musical tone of the source comes out of telephone receiver as a compound tone (generally a discord) apparently consisting of two tones, one of pitch corresponding to the sum and the other to the difference of the frequency of the musical tone and the frequency of the alternating current source of energy.

Dr. Jewett has satisfactorily answered many of the questions that naturally come to mind on first acquaintance with the general scheme of Major Squier's system, and the figures Dr. Jewett has given showing the enormous sending current required for a moderate receiving current over a line of sufficient length to justify the employment of high frequency generators and other special apparatus, tell at least one of the difficulties in the way of putting such a system into commercial operation.

S. G. McMeen: Dr. Jewett's statement, as to the lack of the ability to signal over the strip of ether, impels me to remark that we have good, useful physical circuits today over which we can not signal in the ordinary sense. I refer to composited lines, from which the usual signaling ability is taken away by adding the telegraph. But we do use such circuits to great advantage, and without trying to signal over them.

Dr. Jewett comments on the hurtfulness of series windings, such as relays, in these high-frequency circuits. Series windings, other than loading coils, have steadily become less common in all telephone circuits during the last 20 years. All reactances required in Major Squier's methods, whether of capacity or inductance, are of small dimensions because of the high frequencies. It easily may come about that the capacities may be sufficient when formed of a few turns of wire laid side by side.

Mr. Alexanderson says there is hope for further development. It is that outlook which makes this work notable. Since 1900, there has been no announcement of large addition to our fundamentals in telephony. We may well consider this work another such addition.

Mr. Taylor says the harmonic telegraph did not make good. It *did* give us one great result: Observation of a single phenomenon in harmonic telegraph experimentation diverted Professor Bell directly to the invention of the telephone.

Dr. Jewett further says that Major Squier's invention is "a beautiful laboratory apparatus." I beg to remind him that the telephone itself was that, *and that only*, when Professor Bell finished it.

Frank F. Fowle: Major Squier's achievement in duplexing a telephone circuit by superimposing waves of a frequency beyond the range of audibility will rank high among scientific accomplishments. It marks a new and extremely interesting development in the art of telephony.

Telephone engineers will analyze it in the light of their experiences with voice transmission, at relatively low frequencies, ranging from 100 to 2,000 cycles per second. As others will doubtless point out, it appears to have serious defects and a very limited commercial value from such a standpoint. There are two fundamental reasons for this. In the first place, the rate of attenuation at such high frequencies will be relatively enormous in comparison with the values of attenuation now obtained with voice frequencies. Consequently the maximum attainable distances will fall far short of present accomplishments, even at comparatively high impressed voltages. Secondly, and perhaps of most import, the difficulties of preventing cross-talk between two or more high-frequency circuits in the same cable or on the same pole line appear to constitute an almost insurmountable problem.

For these reasons Major Squier's invention seems to have a very limited commercial value at present, at least in relation to its use on existing wire plants. As to its ultimate value it is unsafe to predict, because it opens the door of a new development whose possibilities are yet unexplored.

The two large problems needing immediate attention are those of minimizing the attenuation and controlling the cross-talk. It seems fairly apparent that the lowest safe frequency from the standpoint of interference will be the best one, because thus the attenuation is made a minimum. The control of cross-talk is perhaps the most difficult problem. In this connection it may well be pointed out that for high-frequency transmission the present situation is parallel to the one which existed 30 years ago in the development of long distance transmission at synchronous frequencies. The grounded line of those days gave serious trouble from cross-talk as soon as appreciable parallel lengths were exposed to each other. The metallic return diminished the difficulties but was not a satisfactory remedy. It was not until the transposed metallic circuit was developed, through the work of Carty and Barrett, that long-distance service became commercially feasible in 1885.

Apparently the wire plant of today will need radical alterations to permit secret transmission over high-frequency circuits lying side by side for many miles. If this can be accomplished without sacrificing present efficiency in relation to the use of the composite and the phantom, it will bring Major Squier's achievement to a state of great social and industrial value.

In connection with the paper I note that the measured constants of the cable circuit employed are very unusual. The measured loop resistance averages 110 ohms per mile, which is normal with the gauges used. But the capacity of 0.69 microfarad, if it represents the whole seven miles, is much too low;

it might be very nearly right if it represented the mutual capacity per mile. The insulation resistance is exceedingly low and indicates very poor conditions somewhere in the circuit.

Béla Gáti: I have made a number of experiments from which I conclude that Major Squier's explanations are not always right.

It seems Major Squier has not enough measuring instruments for alternating (high frequency) currents. Major Squier measures the capacity (one minute electrification) and the insulation resistance with direct currents. He does not say so but the "one minute electrification" verifies my opinion. I have written a number of articles discouraging the use of direct-current measurements for high-frequency circuits. There is no connection between direct-current isolation and high-frequency dielectric resistance. I found the latter one is 1,000 to 10,000 times smaller than the direct-current value. I believe the isolation (dielectric resistance) of the said telephone cable can be only some hundred ohms. I should like to have data obtained by measurement with 20,000 to 100,000 cycles.

Major Squier states that: "The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles . . . " This opinion is the most dangerous one imaginable, for the future. We know that in wireless telegraphy the damping factor depends, in the first place, on the energy consuming resistances. How Major Squier's opinion was formed, can only be explained as follows (*a*) by the phenomenon that when the current is over a certain value, (5 milliamperes on the Hungarian receivers) the telephone receiver does not give a stronger sound. I showed these curves relating to this phenomenon at the second conference of the Telephone Techniciens in Paris. If we have 4, 8 or 12 milliamperes received currents in the receiver, the sounds remain about of the same strength and so we cannot judge, by hearing, the strength of the incoming currents, nor the total resistance of the line.

(*b*) As I have already stated, the insulation for high frequency current must be very small, the capacity between the wires is large enough, the cross-talk for these cycles exists and so we cannot speak about the ohmic resistance of one wire, but only of the whole cable bunch. Major Squier found the transmitting impedance under 100 ohms (87) for high-frequency-currents, and one metallic circuit had 776 ohms resistance.

(*c*) I experimented with telephoning on single aerial wires. I had the same effect at the receiving station (2,500 km., 4 mm. diameter bronze wires), whether the two wires were connected in parallel or not. Then I changed the line, using a three-mm. wire, and have spoken over only 1,000 km. instead of 2,500 km. In this case the whole line, if the cross-talk is not avoided, forms only one wire.

I hope that Major Squier will make other experiments and verify my explanation. Assume for example, that the Commercial Cable Co. should have a new cable laid between New York and England with a self inductivity 10^{-2} henry per kilometer, but 10 ohm resistance instead of 0.9 ohm, provided Major Squier's opinion about the ohmic resistance is a correct one. This new cable with 10 ohms per kilometer would be a complete failure, but with 0.9-1 ohm resistance and with the same 10^{-2} henry inductivity this could alone make up for all the other Atlantic cables and make the cable rates 10 times cheaper.

The present type of microphones are not fit for high-frequency currents. The microphone effect is caused by the imperfect contacts; for high-frequency currents there are no imperfect contacts; they make conductive the worst contacts of the crystal detectors, therefore the need is felt for another type of

TABLE I

THE SPEED OF ELECTRICITY ON BRONZE WIRE TELEPHONE CIRCUITS

$\omega = 2\pi n$	v
$\omega = 2\pi n = 9000$	$v = 240{,}000$ km.
8000	239,500
7000	239,000
6000	238,000
5000	237,500
4000	235,500
3000	231,500
2000	222,000
1000	196,000
628	173,000
263	133,500
131	112,500
62	101,000
31	97,000
18	95,500

microphone. I made experiments with 4,000 cycles, and was able to throw out the disturbing effect of the ground-current. Today, I believe the frequency of about 10,000 cycles is the best. The telephone receiver does not respond to disturbances when the cycles are over 7,000.

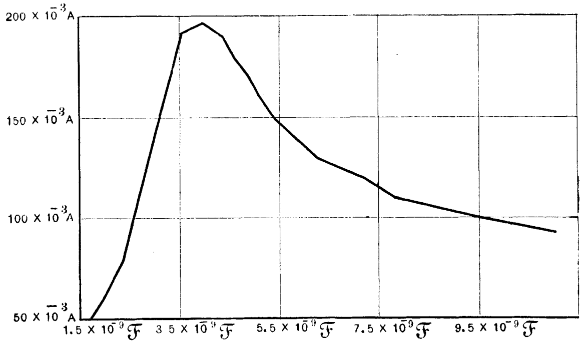
Telegraphy with high frequency currents is an old thing; I experimented with it many years ago and worked it out especially for cable telegraphy. I am glad that Major Squier's experiments confirmed the unlimited possibilities of this kind of telegraphy; perhaps existing cable-companies will now pay more attention to it.

Major Squier uses the $\lambda = 2\pi V\sqrt{LC}$ expression and supposes that $V = 300{,}000$ km. per second. According to my experiments on aerial lines (Table I) it can be said that the speed is *never* 300,000 km. I made various experiments and have never found this value. I do not believe that this 300,000 km. is a definite value. According to Kennelly's formula $V = \frac{w}{\beta_2}$ where

$$\beta_1 + j\,\beta_2 = \sqrt{(r + j\,\omega\,l)\,(g + j\,w\,c)}$$

I will not say that in the case of the cable line $V = 500{,}000$ km., as the preliminary computation shows this, but I am of the opinion that V differs from the value of 300,000 and so the resonance curves and other computations of Major Squier are incorrect.

The same is applicable to the L^1 0.260 millihenry value. The cable line has a comparatively large capacity joined in series with the tuning capacity; this also somewhat modifies the result.



Resonance curve

I believe for effective voltage measurements the string electrometers, for instance Woulff's electrometer with short platinum string, are sensitive enough even for small values. The impressed voltage is surely larger than one volt, and thus measurable.

In my experiments the resonance curves were also unsymmetrical. I constructed curves at one single frequency; the ordinates were the currents in milliamperes, the abscissas were the capacity values in microfarads. I found the cause of the unsymmetrical position in the dielectric resistance of the condensator. According to my experiments 0.001 microfarad has at $w = 2\,\pi\,n = 10{,}000$ a dielectric resistance, (isolation) about 1 megohm, but 1 microfarad capacity has about 1,000 times less, that is only 1,000 ohms. This dielectric resistance is not constant, it is for higher frequencies less so; I believe this diminution of the isolation (dielectric resistance) for higher frequencies causes the unsymmetrical state. I obtained the values of the resonance curve, ($n = 95{,}200$) according to my process, the ordinates were the milliamperes, the abscissas, the capacities. This curve was very unsymmetrical.

I constructed the curves not only for the outgoing but also for the incoming currents. In wireless telegraphy from these resonance curves the attenuation is computable. Of course, the hypothesis is that the curve of the resonance is symmetrical; perhaps some one could find the mathematical expression of the attenuation from these unsymmetrical curves. It would be very useful for long distance telegraphy to have them. The measuring of the ratio of the outgoing and incoming current is only applicable over some thousand kilometers distance; at this distance, the disturbing (vagabond) currents are always larger than the talking currents, and so the measurement is very difficult.

The selectivity curve is in reality the same as the resonance curve; hence the unsymmetrical position.

Of course, it would be more interesting to know the selectivity curves of the received (incoming) currents. My barretter set measures without shunt to one milliampere, with shunted galvanometer, to 5-10 milliamperes maximum values (pointer-galvanometer), beginning the measurement with 0.5-0.1 milliampere, which is the value of the commercial talking (received) telephone-current. If Major Squier wants to make experiments over some 100 or 1,000 kilometers, he will need this instrument, therefore I call his attention to it.

The manufacture of large condensers with large dielectric resistance is the most difficult problem in high frequency telegraphy. Perhaps it would be of interest to know that I use the condensers of Mr. Szvetics, (the director of the Telephone News, in Budapest) which I have found the best and the most practical for this purpose.

On cables, the voltage has no tendency to rise after having thrown in resonance, but on aerial lines I experienced the increase of the received currents. At open ends there is always increase in voltage. Probably Major Squier will make further experiments with 100,000 cycles; I should like to know the results.

The small dielectric resistance (isolation) of the cable causes the phenomenon that the resonance curve is the same when the distant end is open or short circuited. I experienced on aerial-lines that the outgoing current was always larger when the distant end was *opened*. At the short circuited distant end the outgoing current is only a small value of the former. This seems at the first moment very strange; Kennelly's formulas (hyperbolical treatment of telephone-currents), however, explain it quite correctly.

When the impedance of the whole line is 87 ohms, it is not permissible to measure with a galvanometer which has 171 ohms. The so called attenuation curve in Fig. 22 Major Squire's paper is the attenuation curve of this galvanometer (at least 60 per cent) and not of the line. When the outgoing current decreases from 240 milliamperes to 5-1 milliamperes at 11.26 kilometer distance, it proves the system to be a disadvantageous one. With barretter set (1-10 ohm resistance) Major Squier could obtain more current at the receiving end. We see here that the effective ohmic resistance is a very important one for these high-frequency currents. Of course the outgoing current must be in resonance.

I have the same opinion regarding the submarine cables as Major Squier. A cable with 10^{-2} self inductivity per kilometer and working with high-frequency current would be able to settle the whole business of the existing Atlantic cables. The rates could be decreased to two cents per word. This time is not so far off; however, at the present time, the cable companies are too conservative. On account of this, I emphasize again that the ohmic resistance of the wire is a very important one, and one unsuccessful experiment could cost millions of dollars and prevent the application of the high-frequency currents for some decades.

Finally, allow me to congratulate Major Squier. My above remarks are not intended as a criticism. I had no intentions of that kind. I simply wanted to communicate the results of my experiments made during the past eight years and thereby hasten the development of high frequency telegraphy and telephony. I will further remark that with high-frequency currents the speed is unlimited. I succeeded in sending 20 to 60 letters per second. The signals are not intermixed, the incoming signal is not expanded as in direct-current telegraphy. The German Telephone Experiment Station in Berlin (Mr. K. W. Wagner) claims and also deduces mathematically that the signals are expanded at high-frequency currents. But this statement is quite incorrect. I have made experiments over a 4000-km. line; the direct-current signals were expanded perhaps 300 per cent, the alternating current signals not at all.

Telephoning with high-frequency currents has also been attacked, but I proved mathematically (Electrotechnische Zeitschrift, 1909, copy 39) the possibility of talking between London and Kurachi (India) a distance of 8000 km.

This statement as well as a lot of statements like the expansion are ones which we are obliged to disprove with experiments. I should be very glad if Major Squier as well as others would continue experiments along these lines so as to help us in this matter.