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CONFERENCE ON NON-LINEAR PROCESSES IN THE IONOSPHERE DECEMBER 16-17, 1963

EDITORS

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On Some Resonance Phenomena Near the Gyrofrequency Obtained During the Propagation of a Radiowave in Plasma (Ionosphere)

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Abstract

The discovery of non-linear effects in the ionosphere has produced, as a consequence, some modifications in the theories of propagation of radiowaves in plasma.

This paper describes our experiments on gyro-interaction, ionospheric self-modulation, and artificial airglow.

Some results of these experiments have not yet been made known to the public. On the other hand, although some of these experiments have been illustrated in preceding papers, they are now presented as we interpret them after detailed study, taking into account new theories recently developed on these non-linear effects in ionized mediums.

After explaining the existence of resonance in gyro-interaction (Bailey's effect), we describe the experiments carried out in daytime. We have noted the influence of solar activity on gyro-interaction.

We have discussed pulse techniques, including the special technique introduced in order to obtain the one-humped or "dromedary" curve descriptive of the interaction as a function of frequency, and the method by means of which it is possible to pass from the dromedary curve to the two-humped or "bactrian" type. This paper also deals with the experiments carried out on self-gyromodulation and self-modulation phenomena, and presents the technique necessary to bring the mentioned phenomena into evidence.

The use of "modulated pulses" permitted observation of self-modulation in the daytime. The results clearly show that this phenomenon is not due to selective fading.

Lastly, we mention the experiments on the artificial airglow carried out in the laboratory.

In a separate paper we will give some theoretical consideration to the interpretation of these phenomena together with a discussion of obscure points of the physical mechanism responsible for these effects.

Introduction

The non-linear processes observed at about 90 km above the surface of the earth are particularly important when radiowaves, passing through that zone of the ionosphere, possess carrier frequencies near the local gyrofrequency of the plasma.

It is well known that the action of the terrestrial magnetic field generates some particular properties of the ionosphere from which one can infer the total intensity of the terrestrial magnetic field at 90 km. The study further gives information concerning the behavior of the dynamo-currents in the lower region of the E-layer.

The phenomena, which result from resonance between the carrier frequencies of the radiowaves and the gyro-magnetic frequency of the plasma, include the following:

1. Gyro-interaction (which we call Bailey's effect).

2. Self-gyro-interaction or self-gyromodulation, self-modulation, and self-demodulation.

3. Artificial airglow.

These effects have been intensively studied in Italy since 1946.

While the self-gyro-interaction phenomenon was observed for the very first time by the author, the gyro-interaction and the artificial airglow phenomena were interpreted and predicted in 1937 and 1938 by V. A. Bailey. Historically, gyro-interaction is certainly the best known and most important of these related phenomena.

In this report I shall describe the new techniques introduced in order to get experimental evidence of the existence of gyro-interaction and the other three associated phenomena. I shall also give a brief resume of the observations, both published and unpublished, and discuss our attempts to interpret the physical processes that generate these phenomena.

1. Gyro-interaction or Bailey's Effect

In 1937 V. A. Bailey pointed out that a modulated radiowave having a carrier frequency near the gyrofrequency (the unwanted wave) would interact with another radiowave with a carrier frequency completely different from the first (the wanted wave). The second beam, reflected from the same zone of the ionosphere (at about 90 km of height), would receive a cross-modulation from 4 to 10 times greater than that produced by a wave of the same power but having a carrier frequency far from the gyrofrequency [Bailey, 1937 and 1938].

The experiments performed by Bailey in 1937 between Great Britain, France, and Belgium, by means of radiophonic stations emitting on fixed frequencies near the local gyromagnetic frequencies, proved to Bailey that a resonance effect did exist and, consequently, encouraged him to continue the development of the gyro-interaction theory.

Additional evidence concerning the existence of the mentioned resonance effect, could also be obtained by measuring the amount of transferred cross-modulation as a function of the carrier frequency. The theory indicated that a maximum should occur on or near the gyrofrequency.

Since Bailey had difficulty in getting an Australia broadcasting station having higher power than 10 kw to participate in his studies, he stopped making experiments.

In order to verify the nature of gyroresonance in the Luxembourg (or Tellegen) effect, and to make an investigation about other branches of the gyro-interaction theory (e. g., a resonance curve with a two-hump "bactrian curve", and a resonance curve with a one-hump "dromedary curve"), a series of experiments were organized and performed in Italy (1946-1950) by my colleagues and myself.

1. 1 Resonance Observed by Means of Employing 500 Watt Only

The first series of experiments was performed between March and April 1946. It lasted 14 nights and experiments were always carried out from 0130 to 0500 hours, Central European Time [Cutolo, Carlevaro, and Ghergi, 1946; Cutolo, 1946].

The Navy stations at Taranto (465 kc/s, 1 kw antenna), Naples (338 kc/s, 700 w antenna), and the Aeronautics station of Crotone

(531 kc/s, 1 kw antenna) were operating as wanted transmitters. Vatican Radio operated as the disturbing or unwanted transmitter.

The wanted transmitters were emitting the carrier only, while the disturbing station (gyrostation) was emitting waves whose carrier frequency could be varied between 1200 and 270 kc/s in steps as fine as 3 kc/s. The frequency of audio modulation was kept constant (400 c/s--depth of modulation, 70-80%). We must point out that the power of the disturbing transmitter (input in the antenna--Marconian type) was only 700-800 watts. Consequently, the power radiated had a maximum of about 500 watts.

The main receiving station, equipped with suitable instruments, was located at the Polytechnic School of Turin, while the other auxiliary receiving stations were placed in Genova, Livorno, Rome, and Naples. The wavelengths of the wanted transmitter were always chosen on the basis of the distance existing between each station and Turin.

In spite of unfavorable meteorologic conditions and the occurrence of magnetic storms, the effect of the cross-modulation impressed on wanted waves by the wave of Vatican Radio was almost always observed at Turin, on the carrier from Taranto and rarely on that from Naples. From all the auxiliary stations, the effect was observed just once, at Livorno on the carrier from Taranto.

From the diagram of figure 1, it can be seen that the effect occurred with a specific frequency used by Vatican Radio at a certain hour at night. The waves that generated the interaction were those of 258 and 266 meters. The 266 was a characteristic wavelength on which the effect appeared between 0155 and 0220 hours, Central European Time; for the 258, however, the effect appeared between 0310 and 0330 hours, Central European Time.

As can be seen from the diagram, the phenomenon appeared on frequencies that increased with the night hours. It never appeared on waves greater than 270 meters or on waves less than 250 meters. From the data reported, it is very evident that by varying the frequency of Vatican Radio the effect was observable at a certain frequency and time of the night. When this frequency and time were increased, the phenomenon appeared always on higher and different frequencies, the later the night time shows, at least for the first two hours of transmission. Between 0230 and 0330 hours (CET), the intensity of the phenomenon was so weak that it could not be detected with certainty.

This brief resume of the experiments carried out in 1946 shows clearly how a resonance effect did really exist in the interaction of the radiowaves and also that this resonance was much greater than that predicted by V. A. Bailey. In fact, the resonance has been generated by an electromagnetic power of only 400-500 watts and not by 1 or 2 kw as Bailey predicted.

1.2 Method of Pulses

In order to compensate for the low power of the Naples station, which made observation of the phenomenon very difficult, the pulse-method was applied to this station. In other words, instead of emitting the disturbing wave on continuous wave, we arranged to emit it in pulses. In this way we overcame the great difficulty of obtaining powerful radio transmitters which, just after the second World War, were impossible to find in Italy [Cutolo, 1947].

The Italian Navy constructed a suitable pulse-transmitter with carrier frequencies near the local gyrofrequency. The pulses were roughly triangular in form and lasted 40-400 μsec. The pulse cadence was varied from 300 to 500 pulses per second. The peak power was, however, a little higher than the mean.

Further investigations were made between February and July 1947 in three different series of experiments [Cutolo, 1948]. The pulse-transmission was made during the second series of experiments (April-May 1947). Before and after this period, the gyro-interaction was observed only occasionally, because of the low power of the gyrotransmitter, which was operating on continuous wave. The use of pulse techniques, however, greatly increased the interaction and the phenomenon was observed almost continuously during the pulse experiments.

We also employed Naples as a disturbing station, Radio Augusta of the Italian Navy as a wanted station (630 m, 1 kw), with Venice and Rome as control receiving stations. The gyrotransmitter of Naples was emitting at pulses (1 kw antenna) with a carrier frequency varying from 1135 to 1063 kc/s, that is, with a frequency lower than the gyrofrequency (Ω = 1200 kc/s).

The numerous observations made during the experiments carried out in 1947 confirmed the existence of the gyro-interaction and the regular nightly variation of the resonance frequency, just as it was observed in 1946. The greatest success of the experiments carried out in 1947 was, however, the employment for the first time of the pulse-method and the observation that, despite the fact that the peak power was only slightly higher than the mean, the phenomenon could be observed more often and with greater intensity than when the transmitter operated on continuous wave.

It is to be pointed out that the pulse-technique was later adopted and perfected by V. A. Bailey and his colleagues [1952], and also by J. Fejer [1955], and other investigators of the radiointeraction.

1.3 Gyro-interaction Obtained During Daytime by Means of Waves Vertically Incident in the Ionosphere

From May to June 1948, a new series of experiments was carried out with the purpose of studying the gyro-interaction behavior as a function of the modulation frequency.

The station of Taranto (610 m, 1 kw), Augusta (530 m, 0. 8 kw), and Palermo (531 m, 8 kw) operated as "wanted stations", and Vatican Radio as the disturbing station. While the wanted stations were emitting only the carrier, Vatican Radio (5 kw) transmitted a fixed frequency (266 m) on a continuous wave, modulated at 20 or 50% with modulation frequency of 230, 450, and 620 c/s.

The observations were made between 0030 and 0402 hours (CET). The measurements of the percentage modulation were obtained by the comparative method [Cutolo and Ferrero, 1948a, 1948b, and 1949].

The phenomenon was observed on each of the "wanted" wavelengths, but it was recorded on only the Taranto transmitter.

Figure 2 shows the variation of the parasitic depth modulation as a function of the modulation frequency of the disturbing wave. This curve agrees well with the theoretical one predicted by V. A. Bailey [1937 and 1938].

Figure 3 shows the variation of the parasitic depth modulation as a function of the time, with the modulation frequency taken as a parameter.

During 1948, the important results included the first photographic record of oscillograms of the gyro-interaction phenomenon, despite the low power of the disturbing wave (5 kw). The interaction proved to be extremely weak when the power of the wanted wave was higher than the perturbing one.

Gyro-interaction proved to be an effective method for studying of the overlapping D and E regions. Prior to 1948 investigations by means of Luxembourg and gyro-interaction effects could be accomplished only during nighttime by experiments over a long path. To overcome the difficulties in making experiments over large distances, and in order to make experiments in both day and night, observations were initiated in 1947 to generate the interaction by emitting all the waves along the vertical. In this way the three stations (wanted, receiving, and disturbing) could be located near one another.

The first attempt, carried out in Naples in 1947, gave uncertain results. A second one, carried out in Rome in 1949, with suitable equipment, gave satisfactory results [Cutolo, 1949 and 1950a]. The wanted station (λ = 970 m) was placed in Santa Rosa (12 km from Rome). Vatican Radio operated as the disturbing station. The receiving station, equipped with a receiver tuned to a 970 m wave, was placed in Rome in the residence of the Navy Ministry of Defence. The aerial of Santa Rosa consisted of a bifilar antenna 85 m long and set toward the southeast. The Vatican Radio aerial consisted of a wire 25 m long.

Sixteen experiments, covering 32 hours of observations, were carried out from May 12 to May 24, 1949. While Santa Rosa was emitting only the carrier (about 500 w), Vatican Radio (~ 700 w) was transmitting modulated waves (200-250 c/s) whose lengths varied from 248 to 270 m, in two-meter steps. The experiments were carried out between 1130 and 1400 hours and between 1930 and 2100 hours. In 1949 the gyrofrequency in Rome (at 100 km above ground-level) corresponded to a wavelength of 248 m.

During the 32 hours of experiments, 58 observations were made. It was noticed, during these experiments, that the resonance frequency was varying with the daylight hour, that is, the generation of the gyro-interaction occurred at about midday by means of disturbing waves (260-266 m), and at sunset by means of waves within 250 and 254 meters. These experiments showed for the first time how the gyro-interaction could be generated at vertical incidence at midday and sunset.

The method of the vertical incidence for the study of the gyro-interaction and Luxembourg effects, which I had devised [Cutolo, 1949 and 1950a] proved to be a very important tool for investigation of the structure of the D-region. This method was greatly improved by J. Fejer and other eminent investigators of the subjects.

1.4 Experimental Determination of the Resonance Curve with Two Humps (Bactrian Curve)

Bailey's theory of gyro-interaction shows that the degree of penetration of the E-layer by the wanted wave led to two different resonance curves when the disturbing carrier frequency varied about the gyrofrequency, the so-called bactrian and dromedary curves.

If the penetration of the non-modulated wave is within 2 and 4 km of the zero level (90 km) of the E-layer, there results a resonance curve with one hump. As soon as the penetration exceeds the value of 4 or 5 km of the zero level, a resonance curve with two humps will be obtained.

The greater the penetration, the farther apart the peak points and the flatter the curve will be. Therefore, as the penetration of the wanted wave varies, one passes from gyro-interaction (Bailey's effect) to interaction without resonance (Tellegen or Luxembourg effect).

With the purpose of proving experimentally the existence of the resonance curves, certain original experiments were performed during June and July of 1949. These experiments permitted us to demonstrate the existence of the "bactrian curve", that is, the curve with two resonance humps.

Since the mentioned experiments are well known, I shall report a single example of bactrian curves experimentally obtained (figure 4) during the night of July 13, 1949, while Taranto Radio (430 kc/s, 1 kw) of the Italian Navy was operating as the wanted station and Florence Radio (3.3 kw) of the RAI operated as the disturbing station [Cutolo, Ferrero, and Motzo, 1950; Cutolo, 1950b].

Properly calibrated radiofrequency oscillators, voltmeters, and so on, permitted us to measure the percentage of cross-modulation by means of the comparative-method.

Since the gyromagnetic frequency over Montefalco in the Province of Foligno, half-way between Taranto and Turin, at a height of 90 km, was around 1200 kc/s, the frequency of the disturbing wave was varied from 1333 to 1070 kc/s, usually in 5-meter steps and, sometimes in one-meter steps.

The weak power of the two transmitted waves made it difficult to determine the resonance curve during the 12 nights of work (40 hours of observation), except during the night of July 13, when the phenomenon was very intense and lasted for almost the full period of the experiment.

The experiments performed in 1949 showed that bactrian resonance curves do exist as V. A. Bailey predicted. It was shown, moreover, that with a frequency of 475 kc/s, the penetration of the wanted wave led to a resonance curve with two humps.

1.5 Experimental Determination of the Dromedary Curve

In order to verify further the theory of gyro-interaction and to observe experimentally a curve with a single hump, a new series of experiments was carried out during May and August 1950 [Cutolo, 1952a]. Since the experiments performed about the dromedary curve are not well known, I shall dwell on this subject at some length.

For the series of experiments performed in 1950, two wanted stations, that is, Taranto (1 kw) and Venice, both of the Italian Navy, were used. Radio Florence II was used as a disturbing station. The receiving stations, each equipped with measuring apparatus as already described, were installed in the Laboratory of Naples Radio Propagation Studies Center, and in Turin laboratory of the Electrotechnical Institute "G. Ferraris". While the station of Naples was tuned to the frequencies emitted by Venice, the Turin station was tuned to the frequencies transmitted from Taranto. The points of reflection of the sky waves coming from Taranto and Venice were over Montefalco and Tolentino (Macerata). Therefore, the gyrofrequencies were practically the same for the two paths.

In order to obtain a curve with one hump, it was necessary that the wanted wave should penetrate the E-layer as little as possible. The new experiments were begun with the intention of obtaining again, under experimental conditions identical with those of the year before, a curve with two humps. Using the same wanted-wave frequency of 475 kc/s, curves with two humps were obtained on the same wavelengths as in 1949 (respectively, 232 and 272 meters) four times out of thirteen nights of experiments.

It is worthwhile adding that, even though two humps were obtained, it was not possible to determine experimentally all the points on the resonance curve as in 1949. Yet the experimental conditions were identical. The difference in the effect must certainly be due to the solar activity of 1950, which differed from that of 1948-1949. The remarkable diminution of solar activity produced a result different from the correlation between Wolf's number and gyro-interaction.

During the night of June 7, 1950, noting that the phenomenon was not obtained on the usual humps, it was decided to vary the frequency of the disturbing wave from 245 to 260 meters (that is about the gyrofrequency). The frequency of the wanted wave was 475 kc/s. The experiment showed for the first time the existence of a curve with one hump on the wavelength of 255 meters.

Figure 5 (where the wavelength of the disturbing wave is indicated on the axis and the volts of modulation read from the receiver) shows the form of a curve with one hump.

This phenomenon occurred all 4 times, but it was possible to construct a resonance curve only twice. In general, a curve with one hump was had with a wavelength from Taranto, different from the usual one of 630 meters, except, as is seen, on the night of June 7, 1950. On two nights the phenomenon was obtained with a wanted wave of 545 meters.

During the night of August 1, 1950, it was possible to perform a very interesting experiment. It began with the usual length of 630 m from Taranto and a disturbing wave that varied from 225 to 280 meters.

With this program, some principal points were obtained of the two-hump curve. After this first result, confirming the possibility of obtaining a curve with two humps that night, it was decided to increase the wavelength from Taranto by 5 meters steps from 630 meters, while the disturbing wave was varied by a few meters about the gyrofrequency. As soon as Taranto emitted the wavelength of 697 meters, instead of a curve with two humps, a resonance curve with one hump around the gyromagnetic frequency was obtained (figure 6). When the wavelength was slightly increased beyond 697 meters, it was not possible to find the gyro-interaction phenomenon.

This experiment showed how one may pass from one type of resonance curve to another by varying the penetration of the wanted wave in the layer. It is thus possible to have a new confirmation of the gyro-interaction theory.

During the trials that produced a curve with one hump, the Wolf's sunspot number was about 58 units as against 140 units when the two-hump curve resulted.

On the nights of June 1 and June 7 the researches in the Naples laboratory of the Radio Propagation Studies Center gave a curve with its maximum on the gyromagnetic frequency. The frequency of the wave radiated from Venice and which was tuned on Naples apparatus was 430 kc/s.

For the distance of 528 km between Venice and Naples, the wanted-wave frequency of 430 kc/s was too high in respect to that of 200 kc/s, which according to V. A. Bailey's theory should have been necessary, for which the penetration of electromagnetic energy was such as to generate the resonance curve with one hump [Colonnese, 1952].

During the night of August 1, 1950, a particular experiment was made. The gyro-interaction effect was so intense that the parasitic modulation (about 10% or more) was appreciably audible through the loud-speaker. Therefore, the loud-speaker was placed near the microphone of the telephone wire that connected the Turin Electrotechnical National Institute with Radio Florence II station of the RAI. In this way the technicians of Radio Florence II were able to hear from Turin, by means of a telephone, the modulation emitted by them at Florence on the wave of Taranto Radio (630 m) to which our radio receivers of Turin were tuned.

The described experiment, the transition from a resonance curve with two humps to one with one hump, by means of varying the carrier frequency of the wanted wave (in this way the penetration of the wave in the layer was varied by 5 km or more), has been most interesting, because it once again confirmed the truth of the gyro-interaction theory.

At this point I should like to mention the great interest roused in the participants of the meeting of the General Assembly of the URSI which took place in Sydney in August 1952, when Sir E. Appleton, on the basis of the results of the Australian and Italian experiments, proclaimed the existence of the gyro-interaction by saying: "The phenomenon of gyro-interaction does exist."

1.6 Influence of Sunspots on the Gyro-interaction Phenomenon

A notably interesting result, obtained for the first time during my experiments in 1948 and 1949, was that of a decisive influence of sunspots on the gyro-interaction phenomenon. In fact, in 1948 twelve experiments were made between May 12 and June 9.

During only 7 nights was it possible to observe the phenomenon and measure the parasitic modulation, precisely during the days in which Wolf's number had an average value of around 150 units. In 1949, fourteen nights of experiments were performed during which the phenomenon was measured only nine times, and those on days when Wolf's number fell to values between 90 and 130.

On the other days, when Wolf's number was superior to the above indicated values, the phenomenon was not observed, while it clearly showed itself very intense when Wolf's number descended below 90. In particular, the observation of the phenomenon seemed to depend more on the daily variation than on Wolf's number, even if it was slight.

Figure 7 gives the correlation noted in 1949 between Wolf's number and the percent of parasitic modulation. An analogous behavior of the correlation was observed in 1948.

The existence of the phenomenon with a low Wolf's number is explainable in that, at that time, the action of solar sunspots did not alter the conditions of the ionosphere suitable for generating gyro-interaction, contrary to what occurred with a high Wolf's number.

The disappearance of the phenomenon cannot be attributed to variations in the earth's magnetic field, which would have to be 1/10 Oersted to displace the gyrofrequency $\pm$ 200 kc/s from its normal value in Italy of 1200 kc/s so as to vary from the gamma of the disturbing frequency explored during the experiments (from 1070 to 1360 kc/s), while the variations observed during the period of observation were all more than hundredths of gamma.

More probably the hypothesis seems instead that the disappearance may result from the increase in electronic density caused by the increase of solar activity. The increase of electronic density could extend the maximum points of the resonance curve from the gyrofrequency, flattening them as if the wave had penetrated some 5 km into the ionosphere.

The extension of the maximum points could be such as to increase the depression of the curve between the two maxima, and to carry the same points beyond the gamma of the frequencies explored so they would remain precisely in the depression. Consequently, the phenomenon would be so weak as to not be any longer observed with a disturbing power of only a few kw.

1.7 Comments and Conclusion

The excellent results obtained from the numerous experiments carried out in Italy from 1946 to 1950 allow us to state that a resonance effect in the gyro-interaction does exist, and that such a resonance is more intense than that theoretically predicted by V. A. Bailey. In fact, the phenomenon was generated by means of extremely low radiated power, sometimes with only 500 w.

During the experiments carried out from 1946 to 1948, disturbing carrier frequencies less than the gyrofrequency were used; from 1949 to 1950, the disturbing frequencies varied on both sides of the local gyrofrequency.

The significance of the observations made with very low power as in 1946-1948 becomes clear when we note that the phenomenon was observed by means of frequencies of 266 meters, that is, frequencies near the upper maximum (figure 4a) of the bactrian resonance curve.

On the contrary, the phenomenon, as noted above, was observed only once with frequencies very near the gyrofrequency. With low power, the phenomenon could appear only near the apexes of the bactrian curve. The observations were in keeping with the later discovery of a resonance curve with two humps and a great depression on the gyrofrequency. For the wanted waves employed between 1946 and 1949, the penetration of the E-layer by these waves was such as to produce solely the bactrian curve.

The experiments demonstrated the existence of both bactrian and dromedary curves and, above all, that varying the frequency of the wanted wave (that is the penetration of the wanted wave in the E-layer) made it possible to pass from one type of curve to another.

As is known, I. J. Shaw, in one of his papers published in 1951, had stated that the resonance in interaction predicted by V. A. Bailey, and experimentally proved by my colleagues and myself during four years of work, did not exist [Shaw, 1951].

The reason why Shaw did not observe the resonance was apparently due to the fact that he employed a wanted wave that had too high a frequency (391 meters). Consequently, the reflection occurred at a height greater than 90-95 km (Bailey's layer), where the resonance actually occurs. It is also to be pointed out that Shaw's experiments made the disturbing wave frequency vary only about 5 meters around the gyrofrequency value calculated by him. Now, taking into account that the real value of the gyrofrequency very rarely corresponds to the theoretical calculated value (because of the fluctuations of the earth's magnetic field, which often are quite remarkable), the 5-meter variation was not sufficient because, as it can be seen from figure 4a, the variation must be at least 40 meters. If the variation is 5 meters only, the parasitic modulation will be too little, because the frequencies are still within the depression of the curve of figure 4a.

Contrary to what Shaw had thought, his experiments indirectly confirm Bailey's theory. In fact, those experiments demonstrated that when the penetration of the wanted wave exceeds Bailey's layer the resonance does not appear.

I was at Cambridge (England) in March 1951 as the guest of Mr. J. A. Ratcliffe, of the Cavendish Laboratory, who also had questioned the existence of resonance interaction. He conducted a series of experiments on gyro-interaction with the help of R. B. Clayton. They obtained a resonance curve with two humps.

During those experiments, the Star Point transmitter (1052 kc/s, 100 kw) operated as the wanted station; the Cambridge station (Cavendish Laboratory) as the receiving station; and that of Washfor (70 kw) as the disturbing station whose carrier frequency varied from 1214 to 1421 kc/s, with 67 c/s as frequency modulation and 60% of the modulation percentage. The frequency variation was 36 meters instead of the 5 meters used by

Shaw in his experiments. The experiments carried out by J. A. Ratcliffe and R. B. Clayton showed that the parasitic modulation does experience and increase, because of a resonance effect.

The existence of resonance in the interaction of radiowaves in the ionosphere was confirmed by means of the experiments conducted in 1952 by Professor V. A. Bailey and his colleagues in Australia [Bailey, et al, 1952b]. These scientists introduced a new technique by means of which the disturbing frequency could be varied around the gyrofrequency over a very wide frequency range in only 20 minutes. They also introduced a device that eliminated fading on cross-modulation percentage. Contrary to the procedures followed by J. A. Ratcliffe at Cambridge and myself in Italy, the Australians used a disturbing transmitter functioning by pulses.

The existence of a resonance in interaction of radiowaves in the ionosphere, experimentally proved, has permitted a direct verification of the substantial part of the magneto-ionic theory of Appleton and Barnet, Nichols, and Shelling, the existence of a gyro-frequency in the ionosphere attributed to the action of the earth's magnetic field on the free electrons. However, such a verification presented great difficulties because of the many perturbing phenomena such as meteorologic conditions, fading, etc. , which interfered with the obtaining of reliable data on the intensity of reception.

Tarfor, for instance, made reception measurements of transmissions by employing several stations of the same power but of different frequencies at about 200 meters. From the curves obtained, he ascertained that a strong absorption would take place around the wavelength 214 meters. Therefore, he inferred that 214 meters corresponded to the gyrofrequency. Other experimenters such as Anderson, Bailey, Espenchield, Hulbert, Smith-Rose, etc., reached analogous conclusions. Opposite results were obtained, however, by Meissner, Eckersley, Mesny, Gherzi, and others.

An accurate verification of the magneto-ionic theory was made by V. de Pace and G. Todesco [de Pace, 1925; Todesco, 1932]. By means of original laboratory experiments, they were able to demonstrate in 1932 the existence of the gyrofrequency as predicted in the magneto-ionic theory. Using as an ionized medium the electronic gas existing between the filament and the anode of a thermionic tube, they showed that those electromagnetic waves passing through the ionized medium experienced selective absorption near the Larmor gyrofrequency for an impressed magnetic field, H. However, I emphasize that this verification was accomplished by laboratory experiments only; therefore, the true verification of the existence of the gyrofrequency in the ionosphere and the determination of its value is due to my experiments described in the preceding paragraphs.

The construction of the resonance curve (figure 4a) with two humps is sufficient to determine the gyrofrequency Ω. The mean value of two frequencies at the position of the maxima is Ω [Cutolo, 1953a and 1953b]. $\Omega = e\ H/2\ \pi mc$, where e is the electronic charge, m is the electronic mass and c is the velocity of light, H is the total intensity of the earth's magnetic field in the lower part of the E-layer, which extends approximately 90-95 km above ground level. Values of H in Oersteds (oe) found in Italy by gyro-interaction were 0.430 on July 3, 1949; 0.431 on July 6, 1949; 0.423 on July 17, 1949. Montefalco (Foligno) is the sky point to which the H value is referred. As H at ground level during the experiments was 0.477 oe, we see that H in the E-layer is smaller than on the earth. This measurement reveals the presence of electric currents in the E-layer, which are postulated to account for terrestrial magnetic variations.

A. Napoletano obtained a correlation of the depth of cross-modulation in the effect of gyro-interaction (for which the values are regulated by the ionization of the E-layer) and the barometric pressure on land in terms of the data obtained in the gyro-interaction studies of May-June 1950 [Napoletano, 1956]. To avoid the moderating action of the earth's surface on atmospheric pressure, the author extended his study also to high-level pressures, using charts representing the isobaric surfaces of 500 mb. An inverse correlation at ground was then found; while at high levels, a lowering of the 500 mb surface caused by an increased density of the air mass, corresponded to a higher depth of modulation.

In a second part of this survey the resonance curves illustrated in the preceding paragraphs will be explained.

2. Ionospheric Self-modulation

2.1 Self-gyro-demodulation

During the experiments on gyro-interaction made in Italy during May-June 1948, we often observed that the modulation percentage of the station Radio Vatican (emitting on 266 m with a power of 5 kw and about 70% carrier modulation) as received at Turin (with a receiver tuned to 266 m) was 30-35%; the modulation frequency was 230 or 450 c/s. This result caused some surprise; some time later we thought that it was a phenomenon caused by the absorption of energy by the ionosphere, particularly at a frequency near the local gyrofrequency. We therefore supposed that, by varying the frequency of a transmitted wave around the local gyrofrequency, we might obtain a decrease in the modulation percentage after passage in the ionosphere.

During May-August 1950, new experiments were made in order to examine the prediction experimentally. Radio Florence II was used as transmitter, and, modulated 80% at 230 c/s, the carrier wavelength was varied step by step within the range 215-280 m so as to include the local gyrofrequency, estimated as 1200 kc/s (250 m). The receiving station at the Istituto Elettrotecnico Nazional "G. Ferraris", Turin, consisted of a "Safar" receiver tuned to Radio Florence II, with its intermediate-frequency output coupled to an oscillograph. The envelope of the oscillograph trace gave a measure of the modulation percentage. Figure 8a is typical of a number of graphs obtained, and shows, as the frequency was varied around the gyro-magnetic frequency, how the modulation percentage of the received radiation decreased to a minimum of less than 40% as compared with the 80% of the original transmission, the whole curve giving the appearance of an inverted resonance curve with a minimum near the gyrofrequency.

It has not been possible, for technical reasons, to determine the exact frequency on which the minimum is obtained, and then find whether because of the ionospheric conditions, the values are higher or lower than the theoretically-calculated gyrofrequency. It seems probable that the minimum was at the lowest night frequency. Measurements were carried out simultaneously in Naples to confirm the existence of the phenomenon, and similar results were obtained. The form of the curve obtained at Naples allowed us to interpret the phenomenon as it has been traced in figure 8a, as a continuous instead of a dotted line.

New experiments made in the autumn of 1950 showed that, with a carrier near the gyrofrequency, the percentage modulation of the received wave decreased according to the increase of modulation frequency. Figure 9 shows results of the reception at Naples of radiation of wavelength 240, 247, and 255 meters, respectively, all of which were originally modulated 80%. In figure 9 we may observe how for the wave of 247 m, whose frequency is nearer to the theoretically-calculated gyrofrequency (about 1200 kc/s), the depth modulation of the wave is lower than that for waves of 240 and 255 meters. In both the figures, every point is the mean value of many experiments. Particularly interesting was the technique adopted to make the phenomenon evident.

At that time (1950) I termed this phenomenon "self-gyrointeraction" or better, "self-gyro-demodulation" [Cutolo, 1951 and 1952b; Carlevaro, 1951]. Important experiments made in 1953 in India by S. N. Mitra confirmed self-demodulation around the gyrofrequency and therefore the effect obtained by me [Mitra, 1954]. The discovery of self-gyro-demodulation raised a great interest in the ranks of the researchers. Some of these researchers attributed this phenomenon to selective fading (J. A. Ratcliffe, J. King, and F. Hibberd). However, if self-demodulation was caused by fading, the phenomenon would take place simultaneously on all frequencies, as fading does, and not on gyrofrequency only.

G. J. Aitchinson and G. L. Goodwin [1955] have been able to carry out, in Australia, measurements of demodulation around the gyrofrequency under conditions where the occurrence of any type of fading was out of the question. They measured gyrofrequency percentages of demodulation stronger than those observed by me. These results suggest that fading, when present, may decrease rather than increase demodulation.

A clear proof that this phenomenon is not due to selective fading has been obtained by means of transmission by pulses carried out with the introduction of a new technique which we call the technique of the modulated pulses, which we will mention later.

A wide program of experiments was proposed by me to Mr. E. Picault, Chairman of the Subcommission III_b of the URSI, and these were performed in March 1953 [Picault, 1954]. Many interesting results were obtained in Naples [Cutolo, Bonghi, and Immirzi, 1956]. During these experiments the receiving station of Naples consisted of a receiver with tuned circuits (3 HF circuits). The output was coupled to an oscillograph with a cinematographic apparatus. The envelope of the oscillograph trace gave a measure of the modulation percentage. The transmitting stations were Radio Paris (863 kc/s, 150 kw) and Radio Strasbourg (1160 kc/s, 200 kw), which emitted their carrier frequency modulated 60 and 30% full and half power from 50 to 4000 c/s.

Diagrams obtained in Naples clearly showed, at least on nights when the ionosphere was undisturbed, a strong demodulation effect that favored the lower audio frequencies (figure 10).

New experiments were carried out in 1954 and in March 1955. They were intended to show the dependence of the phenomenon on the emitted power. The transmitter was Radio Paris (863 kc/s, 150 kw) modulated 60 and 30% with modulation frequencies from 30 to 4000 c/s. Strong demodulation was always observed and was most pronounced at high modulation frequencies up to at least 3000 c/s (figure 11). On the average the demodulation was stronger in 1953 than in 1955. As far as the dependence of the phenomenon on the power is concerned, no conclusion was obtained, and new experiments were necessary. We may conclude by saying that between 1950 (first observation of the self-demodulation) and 1955, besides the resonance curves of figures 8a-b, we observed the following behavior:

α. A percentage of demodulation increasing up to 1500 c/s with the frequency of modulation (figure 10).

β. Percentage of demodulation almost constant from 30 to 4000 c/s (figure 11).

The second behavior was also observed by Aitchinson and Goodwin in Australia [1955].

2.2 Ionospheric Self-modulation

Another series of experiments on the phenomenon described above was made between July 1957 and November 1959. We referred to these experiments in two scientific reports made for the United States Air Force [Cutolo, Cioffi, Grimaldi, and Lo Storto, 1954; Cutolo, 1954]. Therefore, I shall give just a brief resume on the main results obtained.

The phases of the experiments were eight, with a total of 30 nights of experiments and 75 hours of observation. Measurements made totalled 121,273, of which, unfortunately, only 70,581 were of use. In fact, various disturbances (interference from radiotelegraphic stations, defect of camera) affected 22,504, and the remaining 8,188 could not be used because of distortions caused by the ionosphere.

A careful examination shows that the results are very good and clarify the general behavior of the phenomenon. For the first time it was ascertained that one may produce overmodulation as well as demodulation. For this reason I decided to call the phenomenon "ionospheric self-modulation" instead of "ionospheric self-demodulation", as it was called in the past years.

During these experiments we used the American Radio Station, AFN Frankfurt (872 kc/s, 150 kw), kindly put at our disposal by the Air Research and Development Command, United States Air Force (Bruxelles).

The experiments were carried out in 8 groups, one for each season of the two-year interval, during nighttime from 0115 a.m. to 0325 a.m. (Mean Time Central Europe). Reception was always made in Naples, at the Laboratory of the Technical Physics Institute of the University of Naples.

In May 1958 and 1959, reception was also made in Göthenburg (Sweden) at the Research Laboratory of Electronics, at Kiruna Geophysical Observatory, and at the Ecole National Supérieure d'Electrotechnique of Toulouse (France).

The Naples receiving station consisted of a superheterodyne receiver. The output of the second IF (intermediate frequency) was connected to an oscillograph so as to record the envelope of the modulated wave. From the envelope it was possible to measure the instantaneous receiving percentage M''.

The AFN Frankfurt emitted its carrier frequency (873 kc/s) at 150 kw, 100 kw, and 50 k2, modulated at 60%, 80%, and 90% of modulation from 30 c/s to 4000 c/s. Variations of emitted power (from 150 to 50 kw, 150 to 100 kw, 100 to 50 kw) took place in one minute. Sixty or more oscillograph pictures were taken for each frequency of modulation. Each one of the frequencies of modulation was emitted during one minute. Each point of the curves of figures 12, 13, and 14, represents the average measurements of M'' of the sixty pictures taken. The vertical segment represents the fluctuation of the receiving percentage of modulation during the minute of transmission. To avoid any effect of selective fading, only sinoidal oscillograms were considered, when the percentage of these (85%) was much greater than the distorted ones.

The behavior of the phenomena indicated above with α and β (figures 10 and 11) was never observed during 1958.

The behavior noted in 1958 instead was as follows:

a. Percentages of modulation greater than those transmitted by the station were observed at the lowest frequencies of modulation (figure 12).

b. Appreciable demodulation was observed at the lowest frequencies of modulation with a slow asymptotic return to the emitted modulation at the higher frequencies (figure 13).

c. Demodulation at low frequencies and overmodulation at the highest frequencies of modulation were obtained with a tendency to return asymptotically to the emitted modulation (figure 14).

The behavior of the phenomenon during 1959 was similar to that of 1958 and only slightly different from that of the year 1957. During 1958, only the three types of behavior, a, b, and c, were observed, but in 1957 (July and August) the behavior α of 1953 was also observed, that is, the demodulation increased with the frequency of modulation.

The results of Göthenburg, Kiruna, and Toulouse, coincide with the behaviors α and β.

During the experiments made in 1957, 1958, and 1959, with AFN Frankfurt, it was pointed out that, in the case of the phenomena a, b, and c, the phenomenon, particularly for a and b, depended distinctly (at the lowest frequencies of modulation) on the power emitted by AFN Frankfurt.

In the case of the behavior α and β, the dependence on the power is not clear. On the contrary, it is seen, at times, that the percentage of demodulation is greater at 50 kw than at 150 kw. This strange dependence of the phenomenon on the power makes it uncertain whether self-demodulation can be explained by the theory of interaction.

2.3 Self-modulation at Vertical Incidence Obtained During Daytime by the Method of "Modulated Pulse"

In order to study the behavior of self-modulation around the gyrofrequency, a series of experiments were carried out (October 1960-February 1961) by emitting radiowaves along the vertical, the carrier frequency varying from 1050 kc/s to 1370 kc/s, so as to pass through the local gyrofrequency.

The transmission was made using the new technique of "modulated pulses". The advantages of this method are that the experiments could be performed during daytime and that one was able to measure with sufficient accuracy the height of the region at which the phenomenon occurred. As is well known, I made similar experiments in 1950 at oblique incidence; consequently, self-modulation (or better, self-demodulation or gyro-interaction as it was then called) could be studied only at nighttime (1953).

In Australia a series of remarkable experiments were made at vertical incidence (nighttime) by G. J. Aitchinson and G. L. Goodwin (1955), who used continuous waves with a fixed carrier frequency (almost equal to the local gyrofrequency). Here we refer to the experiments conducted at vertical incidence by modulated pulses using frequencies varying around the local gyrofrequency during daytime.

The study of self-modulation around the gyrofrequency at vertical incidence requires a pulse transmitter whose carrier frequency varies around the gyrofrequency by at least 400 kc/s, and a receiver that is capable of receiving the pulses at radio frequency in the band desired. This receiver can be placed in the transmitting station or at a distance of few kilometers from it. While the receiving antenna must be capable of receiving the ionospheric echoes and of reducing the intensity of the direct ray appreciably, a suitable aerial transmitting system permits us to emit the radio waves. In our experiments, the transmitter is capable of continuously varying the carrier frequency from 1050 kc/s to 1370 kc/s by means of a manual system.

Since the reception of the signals occurs at vertical incidence, or very nearly so, if we wish to explore the lower border of E-layer, the transmission should be done with pulses whose duration must not exceed 600 μs. In fact, if we imagine that the reflection occurs at a height between 75 and 95 km, the duration of the pulses must not exceed 550 μs if we are to avoid the masking the echo by the direct ray.

The new feature in our experiment is the fact that we used pulses instead of continuous waves. The pulses at radio frequency are of rectangular form, and the bases of the rectangle are sinusoidal. In other words, we have introduced a new technique of modulating the pulse at radio frequency by impressing on it a frequency of modulation.

Since we cannot impress on the pulse anything less than one and one-half cycle, the duration of the pulse cannot be less than 500 μs; therefore, the frequency of modulation cannot be less than 2000 c/s. In our experiments the frequency of modulation was 2800 c/s; consequently, to impress on the pulse one and one-half sinusoids, the duration of the pulse cannot be less than 550 μs.

To study the behavior of the phenomenon for frequencies lower than 2000 c/s, the pulse must be lengthened, a procedure that hinders the study of the behavior at vertical incidence in the E-layer, though within certain limits this is possible for F-layer. When signals are received at oblique incidence and over long distances, the duration of the pulse can be considerable; therefore, the frequency of modulation can be noticeably lessened.

Since the object of this work is to study the behavior of the phenomenon around the gyrofrequency and not its dependence on the frequency of modulation, we have used a pulse having a duration of 550 μs and a frequency of modulation of 2800 c/s. To measure the depth of modulation, we employed the "envelope method" (1959-1960). To make sure of the depth of modulation, we lengthened the pulse so as to obtain three or four sinusoids; we then measured the percentage modulation and, thence, we reduced the duration of the pulse to 550 μs, checking to make sure that the depth of modulation would remain constant. In order to observe the variation in the percentage modulation suffered by the wave during propagation through the ionosphere, one needs a radio receiver whose band is contained in that of the transmitter.

Since the depth of modulation is obtained by the envelope method, the signal must be received at high frequency or in the output of the second intermediate frequency of the radio receiver by connecting the latter with an oscillograph. The advantage of this technique of the modulated pulse consists also in the fact that by obtaining on the oscillograph screen both the direct-ray and the echo, the depth of modulation of the signals (generally different) are independent of any eventual variation of the depth of modulation due to the receiver or to that generated at the station.

The transmitting and receiving equipment and the results obtained are described in [Cutolo, 1954].

Figure 15 shows a modulated pulse emitted by the transmitter.

Figure 16 shows a modulated pulse. On the left side a direct wave is shown, and on the right side, the reflected wave. Since the latter has a little amplitude, the oscillograph sensitivity has been modified; therefore, the direct wave is distorted. The reflected wave reproduces the shape of the direct wave with little modulation depth variation (from 11 to 14%). (See figure 17.)

During the total solar eclipse of February 15, 1961, we were able, by means of this technique, to make a series of measurements on self-gyromodulation. The transmitting equipment, which consisted of a pulse-transmitter and a self-synchronized modulator, was placed in the area of Monte Conero (Ancona). The receiving equipment, which consisted of a receiver equipped with a cinematographic camera, was placed in the area of Monte Pulito, which is about 9 km distant in direct line from Monte Conero. During the eclipse, using a method described by the author [Cutolo, 1956], we continuously varied the carrier frequency of the transmitter from 1080 to 1320 kc/s, so as to pass through the gyrofrequency, which corresponded to about 1200 kc/s.

Figure 18 represents a resonance curve obtained during the eclipse. Each point of the curve represents the average of 60 measurements made for each carrier frequency of the percentage of modulation received. The vertical segment traced across the mean point of the curve represents the minimum and the maximum value of the percentage of modulation observed for each echo. The positive values indicate overmodulated signals, while the negative values indicate demodulated signals. The peak of the resonance curve seems to fall just in correspondence of the gyrofrequency.

2.4 Conclusion

From all that has been said in this chapter, it becomes clear that self-modulation does occur, both near the gyrofrequency as well as somewhat far from it. The phenomena may also be obtained during the day even with a vertical incidence, thanks to the technique of a modulated pulse. By means of this technique, it has been possible to show how the phenomena is not at all due to the interference among the waves which are reflected by the E or F layers or which have run different paths in the ionosphere.

The long series of experiments performed from 1950 to 1962 has shown that the phenomena varies with the frequency of modulation, according to the fundamental behaviors indicated respectively by α, β, a, b, and c.

Concerning the dependence of the phenomena on the power emitted, it has been determined that the dependence is quite clear for a and b, but not always so clear for c, while for α and β it is doubtful. There are, in fact, many proofs that it does also exist for α and β, but there exist contrary proofs that the dependence does not exist.

As will be shown in the second part of this work, the actions of a, b, and c, may be interpreted by the theory of interaction developed by M. Carlevaro, F. Hibberd, D. H. Menzel, and D. Layzer, and above all, by Ginzburg and Gurevich. However, none of the behaviors of α and β may be interpreted by these theories. The questions, therefore, arise: is the reason for the lack of an interpretation for the actions of α and β due to the fact that the theory of interaction is not perfect enough to explain the reason of α and β, as it is also not able to explain the reason for resonance, or are we dealing here with two different phenomena: self-demodulation and self-modulation or self-interaction? It is hoped that the exacting study being made now by P. Caldirola and O. de Barbieri may soon give us a complete answer to the above mentioned question.

3. Artificial Airglow

In 1938, as consequence of the theory of gyro-interaction, V. A. Bailey [1937 and 1938] suggested, theoretically, that a really powerful radiowave with a carrier frequency close to the gyro-interaction may produce a visible airglow into the ionosphere. This is possible because the terrestrial magnetic field strongly reduces the voltage air breakdown.

As this might happen, he admitted that the ratio $\frac{Z}{P}$ must be about equal to 16 (Z is the effective value of the electric field of the radiowave and P is the pressure of the gas). Later, Bailey wrote, instead, that the ratio $\frac{Z}{P} = 11$ (1939) and finally, in 1959, he established (as a result of experiments of the attachment of the electrons) that $\frac{Z}{P} = 2.5$.

To verify the theory originated by Bailey [1937], Towsend and Gill made some experiments in the laboratory in 1937. The experiments effectively showed that a magnetic field causes the electric potential the start of the oscillations lowers notably. Notwithstanding, they found that the ratio $\frac{Z}{P}$ was greater than 500. From here, we see that production of the electric discharge requires a considerable potential and power.

After Towsend and Gill, Brown in the USA continued this study; no longer with air, but with helium and nitrogen. After Brown, others have studied the action of the magnetic field making use of centrimetric waves and guide waves, therefore, avoiding the fundamental problem of producing an electric discharge in the ionosphere.

The problem was resumed by M. Cutolo in 1953 for the study of the ionosphere. To measure the minimum value voltage air breakdown (necessary to start an artificial airglow in the ionosphere), M. Cutolo thought of making an experiment using a <u>radiation field</u>.

The radiation field is given by the following relation:

$$E = \frac{7\sqrt{w}}{r}$$

where w is the power emitted by the transmitting aerial and r the distance from the antenna. The first opportunity of making the following experiments in Naples occurred between December 1953 and the first semester of 1955.

A VHF transmitter (199 Mc/s) radiated about 27 watts from an aerial system formed by two simple perpendicular dipoles, about 90° out of phase. The electromagnetic wave was thus nearly circularly polarized. The receiving system was formed by two perpendicular dipoles both tuned to the frequency of 100 Mc/s and connected to a pair of metal plates that formed a condenser. These electrodes were set into a glass globe, which was evacuated to low pressure, with dry air as the gas. Two coils external to the globe gave a magnetic field perpendicular to the electric field produced between the electrodes. The current in the coils was varied to produce gyroresonance at a frequency of about 100 Mc/s.

A luminous discharge was observed to occur up to a distance of about 12 meters between the transmitting and receiving aerials. Surprised by the low potential of breakdown and the very low power required to start the discharge, we carried on the experiments using evacuated globes of different diameter, at different pressures, and different transmitter frequencies.

Further experiments were carried out using pulse-waves instead of continuous waves because, as we observed in 1947 [Cutolo, 1947], the pulse seems to be more efficient than the continuous wave for the production of gyro-interaction.

An experiment of remarkable interest was made December 8, 1956 [Cutolo, 1956 and 1957]. A transmitter emitted pulse-waves on frequency of 64 Mc/s with an average power of 68 watts and a peak of 1.6 kw (certainly from the aerial, a lower power was irradiated). The aerial's system had a gain of about 16 db. The transmitter was placed on the terrace of the "Istituto di Fisica Tecnica" of the University of Naples and the receiving station in another building at about 800 meters away from the transmitter. The receiving station consisted of a half-wave aerial (situated on the terrace of the building) equipped with a cable 20 meters long, carrying the radio frequency to a system of two parallel plates situated in a room two floors below the terrace. The system of plates was placed in a coil that produced a magnetic field whose direction was perfectly orthogonal to the direction of the electric field existing between the plates.

A glass globe containing dry air at low pressure that reproduced, almost, the conditions of the lower base of the ionosphere (at 90 km of height) was placed between the plates. The value H of the magnetic field was 22 Oersteds.

As soon as the transmitter emitted the waves and the magnetic field was working, a perceptible glow was produced in the globe.

The luminous flux (about a lumen) varied in intensity with H near gyrofrequency, and the phenomenon of resonance occurred in a very narrow band. The glow occurred only when the magnetic field was present and set nearly resonant to the frequency of the electromagnetic field. The electric field between the plates, capable of producing the glow, may decrease even to a few peak volts measured before the breakdown.

In conclusion, here are the principal results we obtained [Cutolo, 1961]:

The electric potential of the start of the oscillations was notably lowered because the phenomenon of the resonance (gyro-interaction) was provoked, not with continuous waves as Towsend and Gill did, but in a pulse regime according to the scheme realized, for the first time in 1947, by me.

Working in this way, it was possible to obtain the luminous electric discharge even with about 3-4 peak volt for a distance of 20 cm between the metallic plates. The bulb is put between the metallic plates (0. 2 v/cm). The ratio $\frac{Z}{P}$ therefore results very low.

The value was determined with values of V very much greater than those necessary to have the smallest possible luminous intensity. It has not been possible to determine the minimum value of the voltage experimentally because the introduction of the measuring instruments hindered the luminous electric discharge in the bulbs.

The determination of the minimum voltage occurrent between the metallic plates, between which the bulb is situated, to produce the smallest visible electric discharge would show that $\frac{Z}{P}$ is 2 or 3 or perhaps even less.

Methods to determine, with sufficient precision, the exact value of $\frac{Z}{P}$ are in the course of elaboration.

The possibility of starting the discharge by means of extremely low powers (of the order of the tens of milliwatts) is due to the resonance effect and also to the usage of a particular type of resonant line, which has been described in the USA Patent No. 701-493 and in Cutolo [1961].

The resonant line behaves as a transformer at resonance, in the meaning that it provokes overtension at one of its extremes, and this in accordance with a theoretical study developed by I. del Gaudio [Private Communication].

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List of Captions for Figures

Figure 11. Experiment of March 20, 1955. Transmitter: Radio Paris. Receiver: Naples (863 kc/s, 150 kw).

Figure 12. Experiment of November 17, 1959 (872 kc/s, 50 kw).

Figure 13a. Experiment of May 17, 1958 (872 kc/s, 150 kw).

Figure 13b. Experiment of March 28, 1958 (872 kc/s, 150 kw).

Figure 14. Experiment of March 28, 1958 (872 kc/s, 50 kw).

Figure 15a. A modulated pulse emitted by the transmitter.

Figure 15b. A modulated pulse emitted by the transmitter.

Figure 16. A modulated pulse.

Figure 17. A modulated pulse.

Figure 18. A resonance curve obtained during the eclipse.

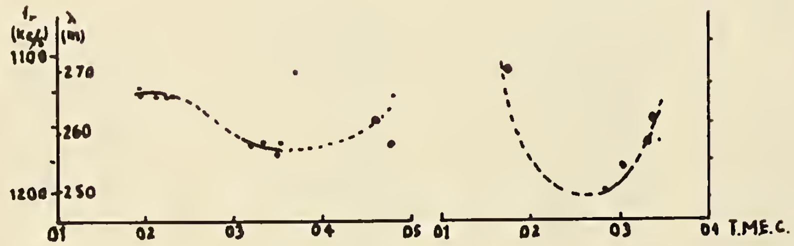


Figure 1. Variation of resonance-frequency as function of the time.

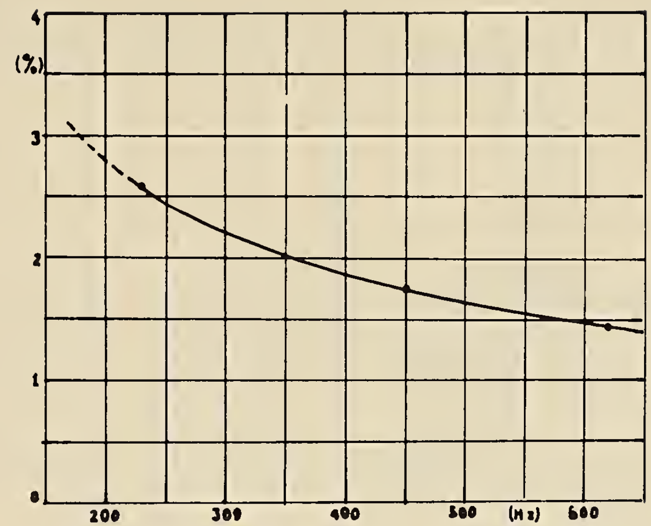


Figure 2. Plot of depth of cross-modulation as function of modulation frequency.

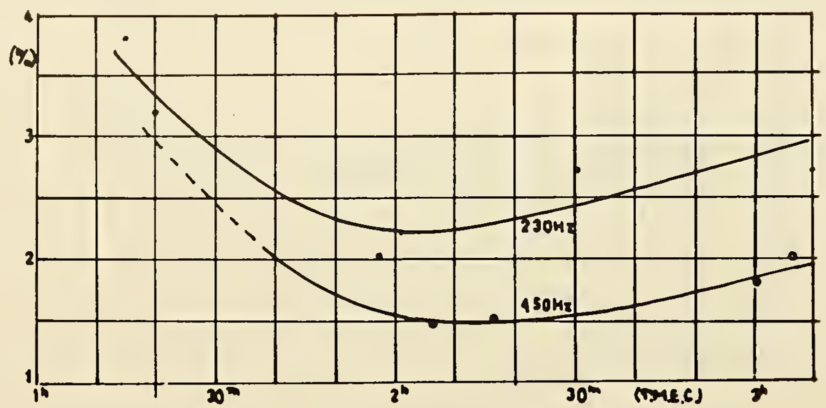


Figure 3. Plot of percentage of cross-modulation as function of the time.

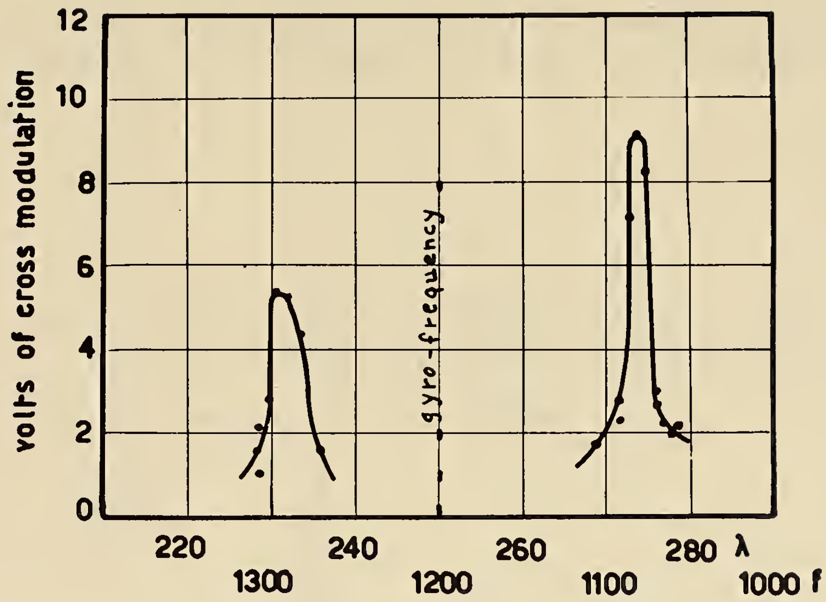


Figure 4a. Example of curve with two humps, experimentally obtained in Italy. The ordinates represent volts of cross-modulation.

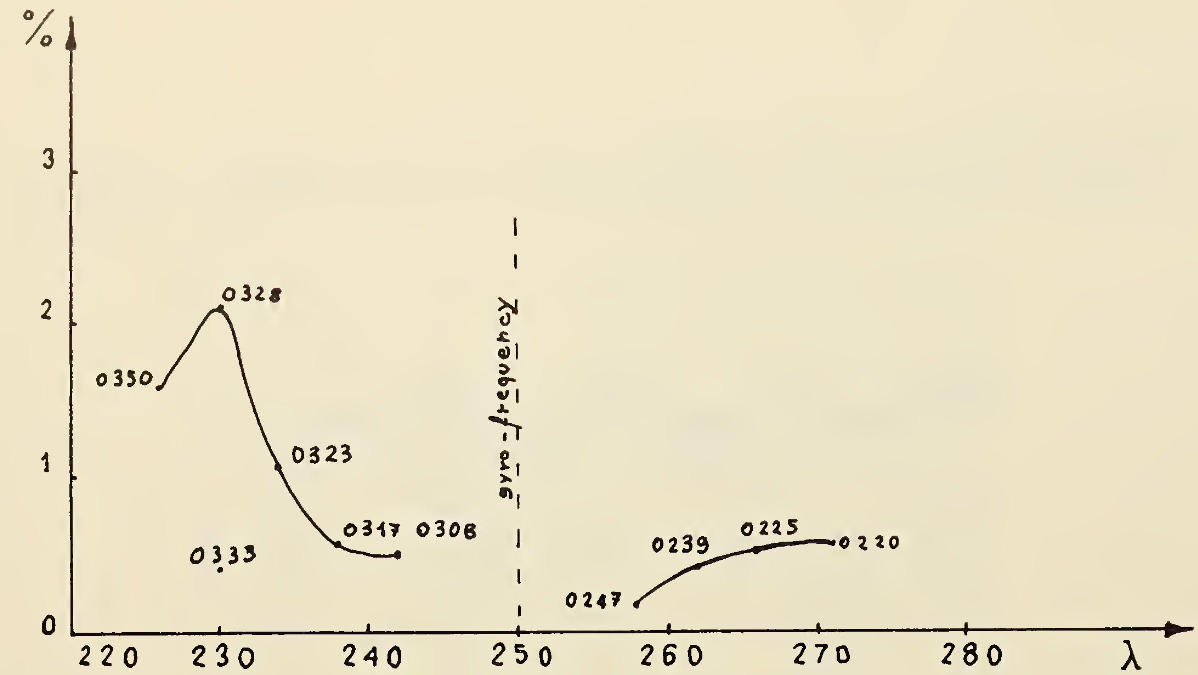


Figure 4b. Example of curve with two humps, experimentally obtained in Italy. The ordinates are the percentage of cross-modulation.

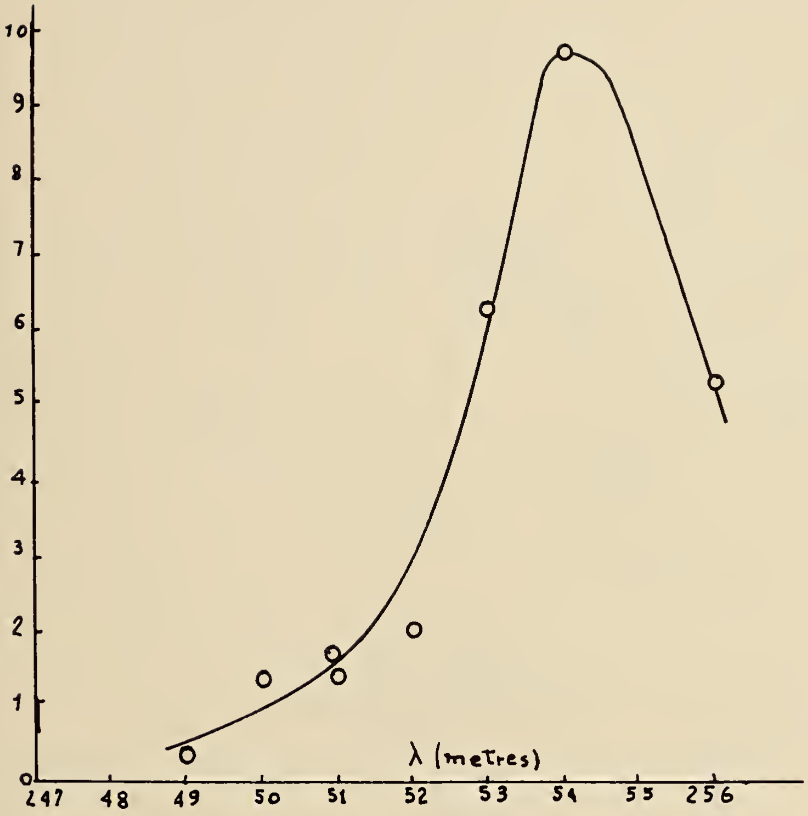


Figure 5. Experimental curve with one hump.

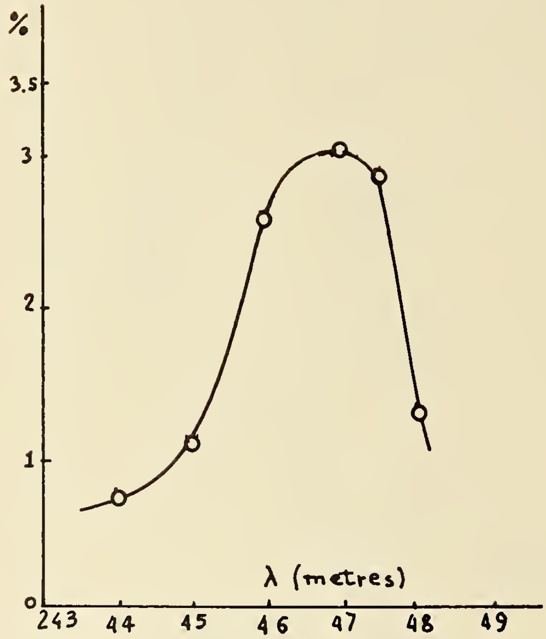


Figure 6. Experimental curve with one hump.

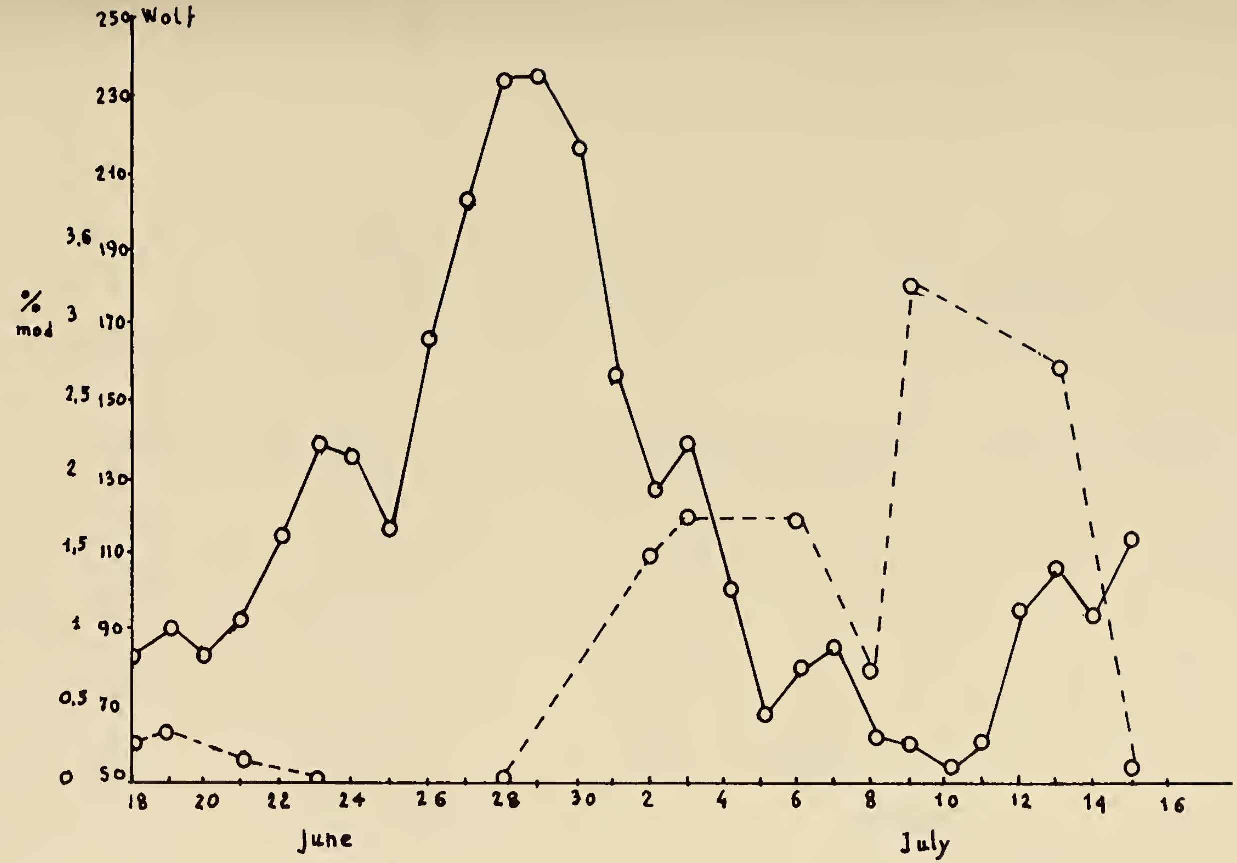


Figure 7. Correlation between Wolf's number and cross-modulation.

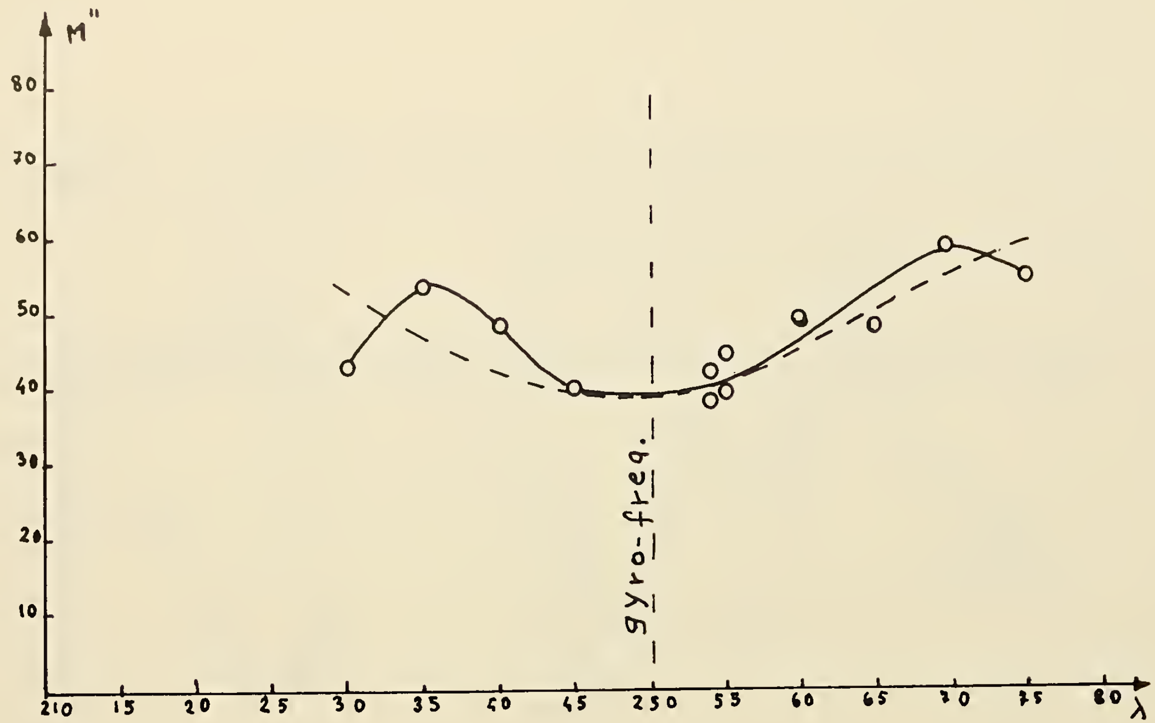


Figure 8a. Example of an experimental curve of self-gyro-demodulation. Frequency of modulation is 230 c/s. The ordinates represent the residual modulation observed in Turin, while the primary modulation from Florence (RAI) was 80%.

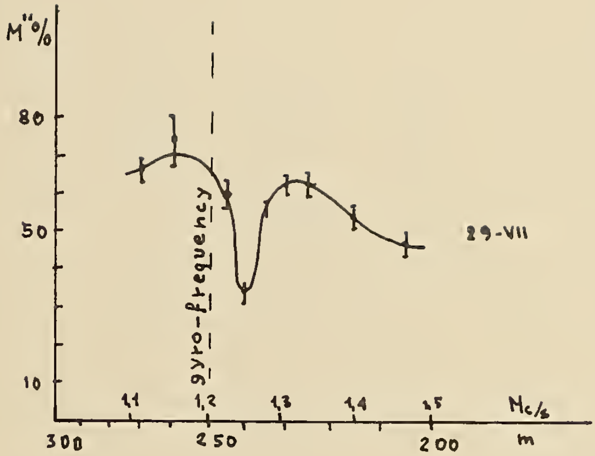


Figure 8b. Example of an experimental curve of self-gyro-demodulation. Frequency of modulation is 230 c/s. The ordinates represent the residual modulation observed in Turin, while the primary modulation from Florence (RAI) was 80%.

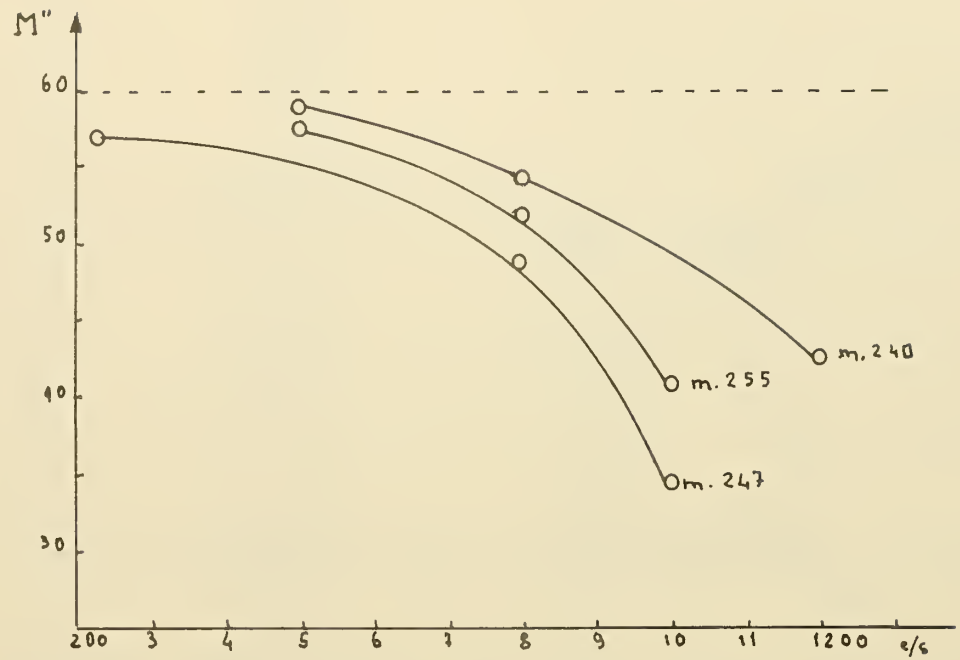
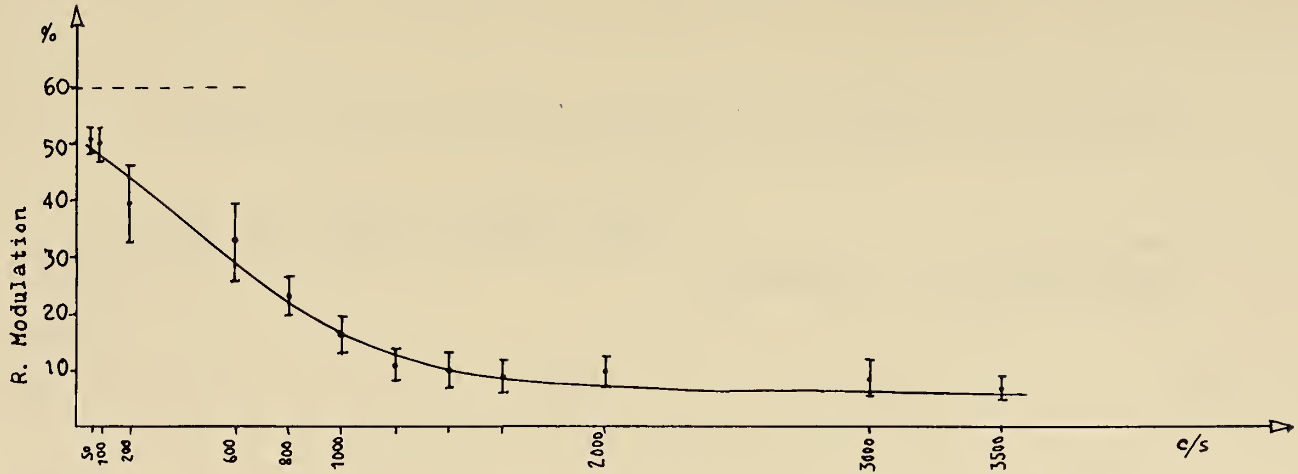


Figure 9. Primary modulation degree 80%.

Figure 10. Experiment of March 28, 1953. Transmitter: Radio Paris. Receiver: Naples (863 kc/s, 150 kw).



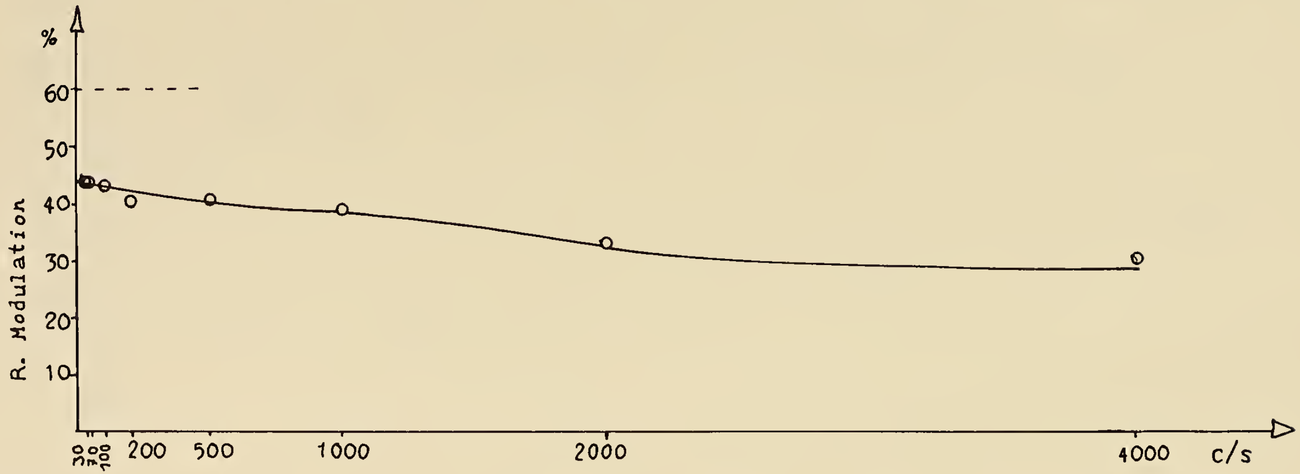


Figure 11. Experiment of March 20, 1955. Transmitter: Radio Paris. Receiver: Naples (863 kc/s, 150 kw).

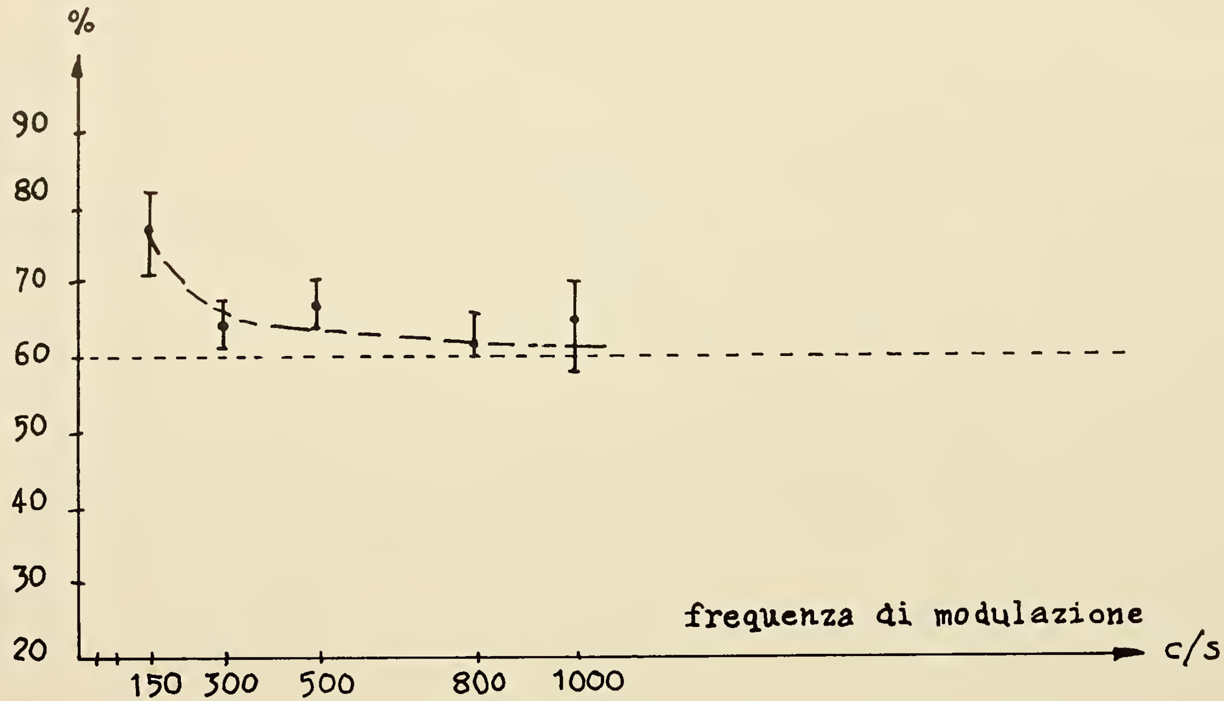


Figure 12. Experiment of November 17, 1959 (872 kc/s, 50 kw).

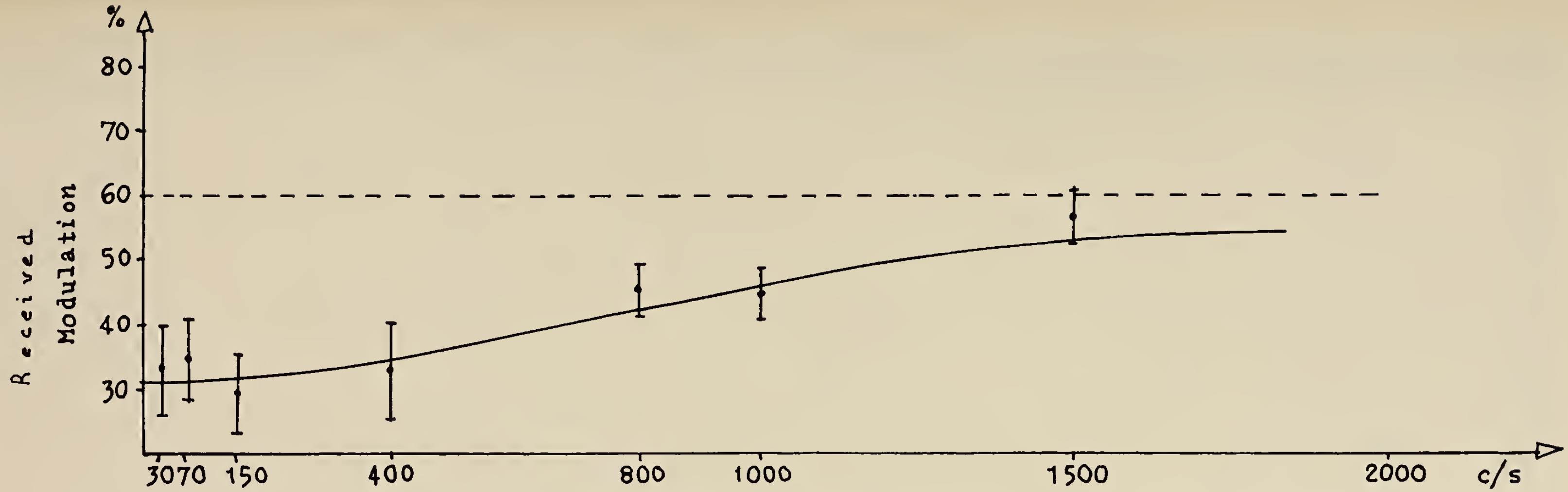


Figure 13b. Experiment of March 28, 1958 (872 kc/s, 150kw).

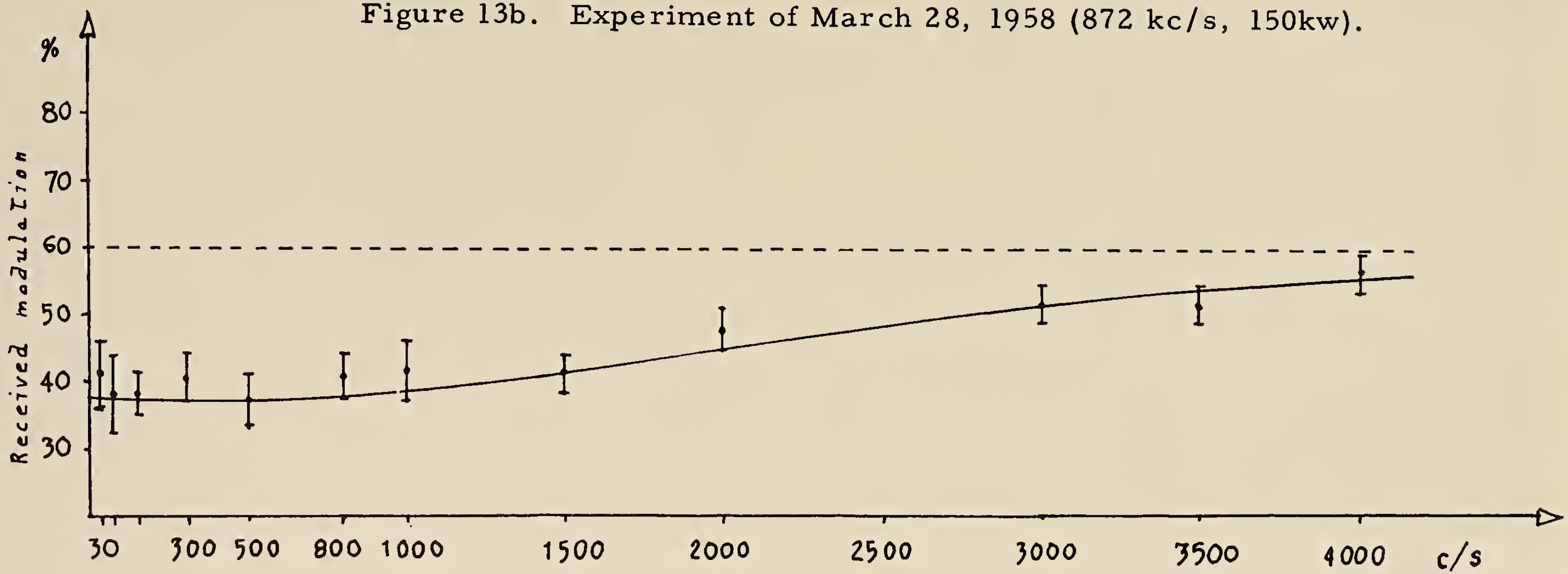


Figure 13a. Experiment of May 17, 1958 (872 kc/s, 150 kw).

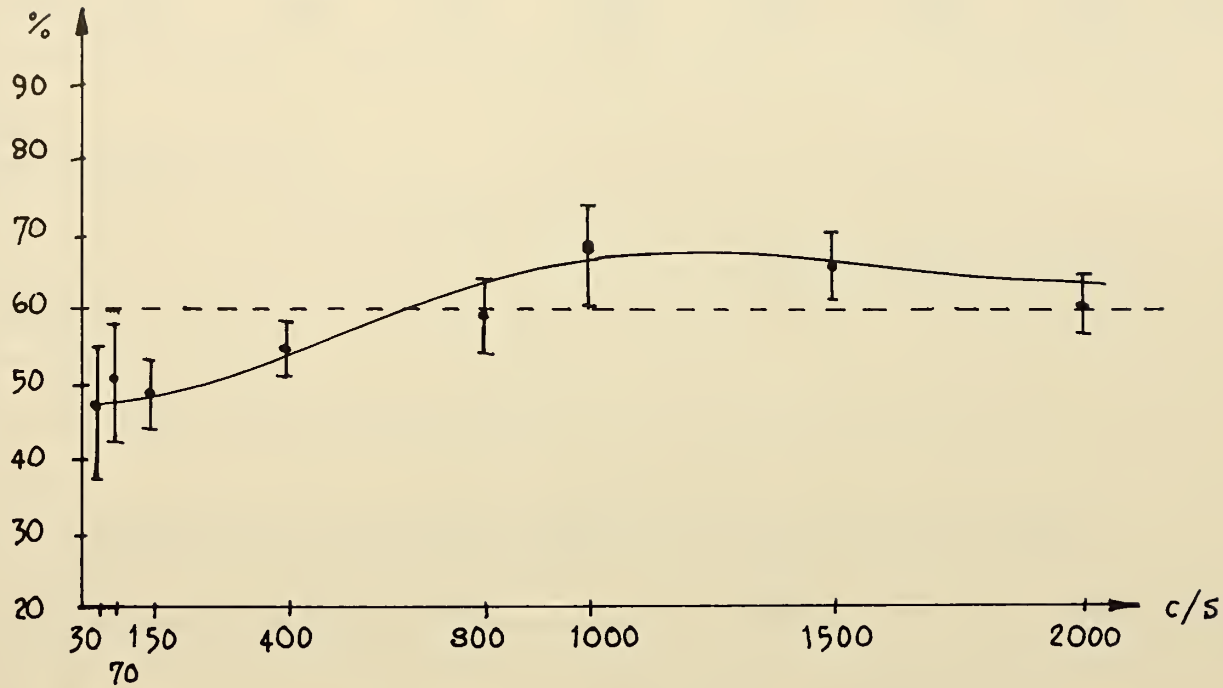


Figure 14. Experiment of March 28, 1958 (872 kc/s, 50 kw).

Top

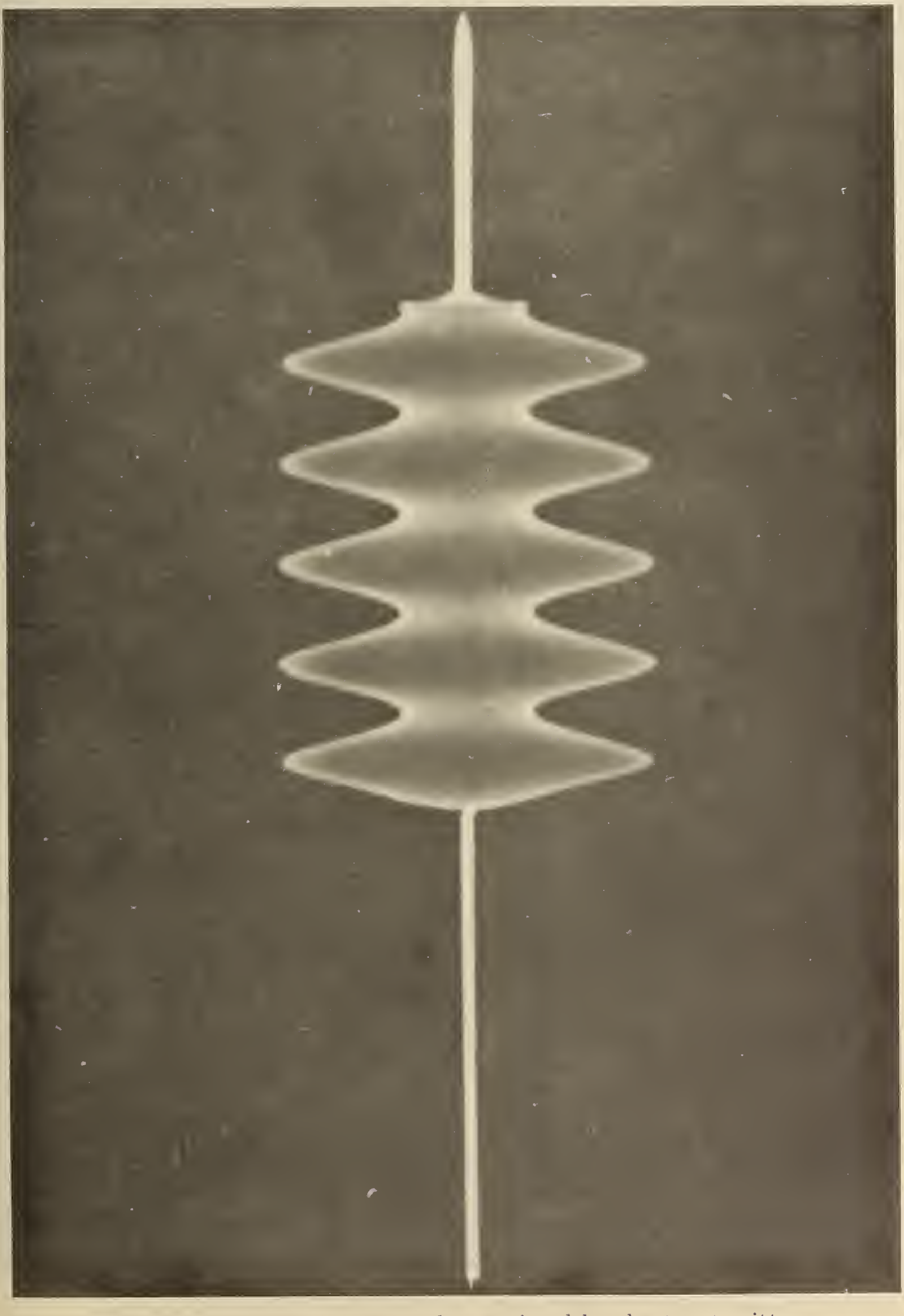


Figure 15a. A modulated pulse emitted by the transmitter.

Top

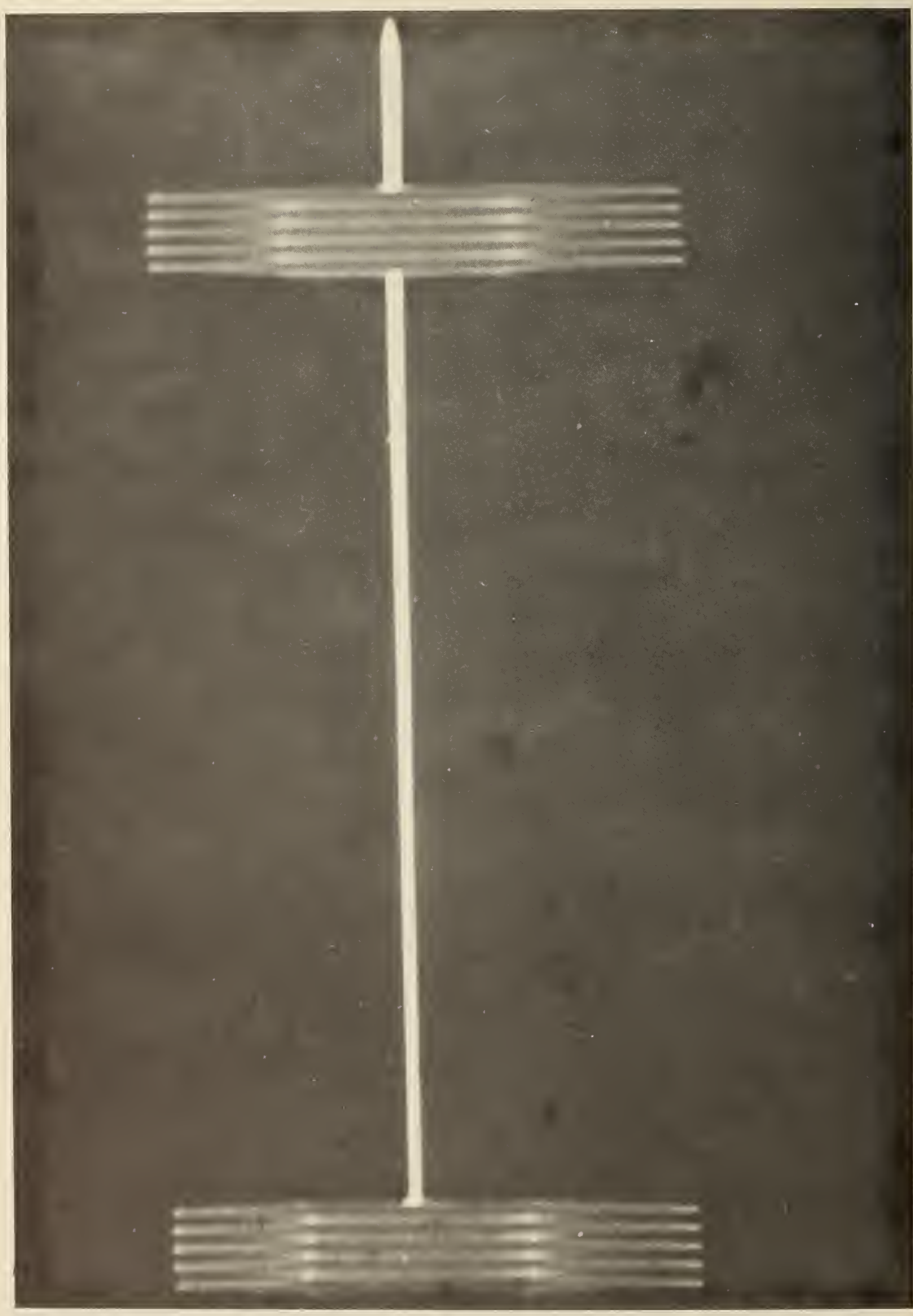


Figure 15b. A modulated pulse emitted by the transmitter.

Top

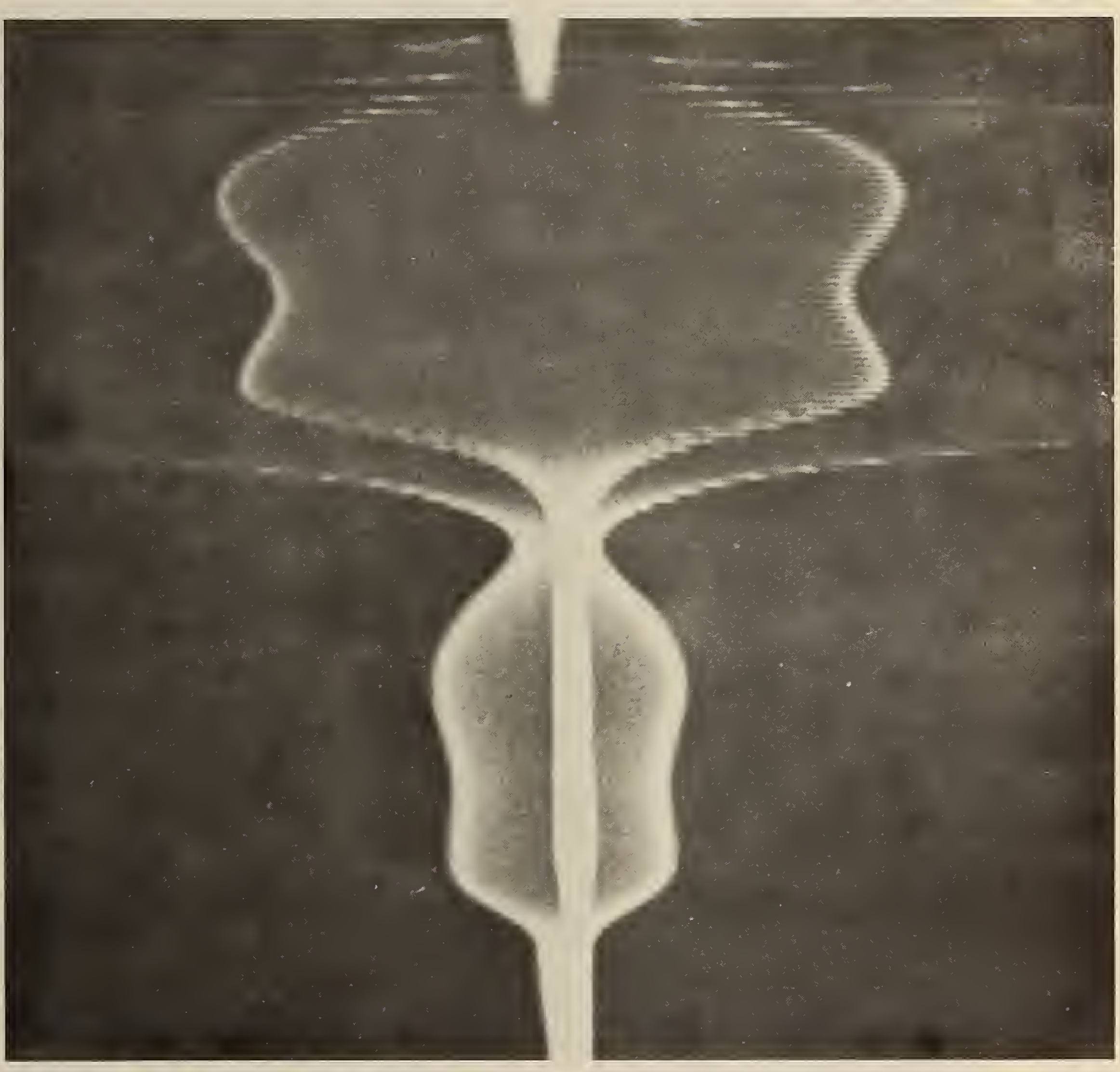


Figure 16. A modulated pulse. On the left side a direct wave is shown, and on the right side, the reflected wave is shown. Since the latter has a little amplitude, the oscillograph sensitivity has been modified; therefore, the direct wave is distorted. The reflected wave reproduces the shape of the direct wave with little modulation depth variation (from 11 to 14%).

Top

Figure 17. A modulated pulse emitted from transmitter.

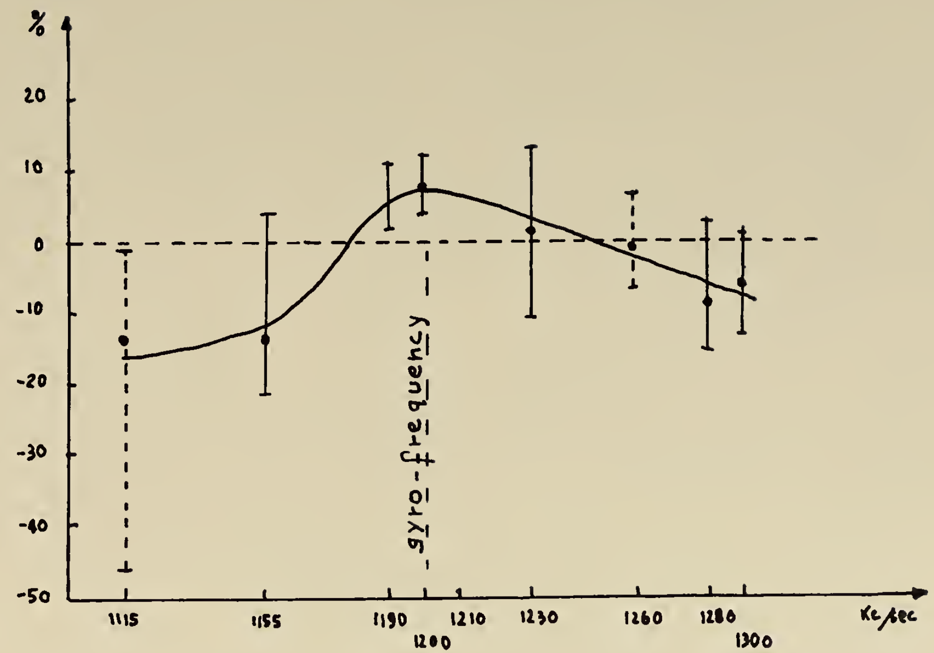


Figure 18. A resonance curve obtained during the eclipse.

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