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THE SCHORNSTEINFEGER PROJECT

Reported By

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CIOS Target Number 1/549
Radar

COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE
G-2 Division, SHAEF (Rear), APO 413

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List of members and itinery of Party NT 39 and CIOS Trip No. 89 on Schornsteinfeger

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	Lt. (jg) Paul W. Wilkinson	239157	USNR
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ITINERARY

Leave London 8 April	Arrive Frankfurt 13 April
Leave Frankfurt 18 April	Arrive Heidelberg 18 April
Leave Heidelberg 1 May	Arrive Paris 2 May

PART I - General Intelligence.

1. Historical Background.

In June of 1943, a conference was apparently called in Berlin by the OKM (Ober Kommando der Marine) at the instigation of Admiral Dönitz for the purpose of presenting the problem of protecting U-boats against Allied radar. It was realized at this time that the U-boat war would be lost unless a successful countermeasure could be found. At this conference, which was attended by about 400 technical representatives from various organizations in Germany, the problem was discussed by Konter Admiral Stummel, who was designated as the senior naval officer for the project, which was named Schornsteinfeger (Chimney Sweep). It appears that the military requirements of the problem were not clearly defined at this time, particularly with respect to wave length coverage, allowed weight and thickness of the coating, durability standards etc. Plans for operational use of Schnorchel were not presented, as the discussion concerned the need of providing radar camouflage for the conning tower and possible for part of the hull. Top priority was assigned, and the representatives were asked to submit proposals immediately, with the aim of solving the problem within three months !

The only Allied radar known to be in use at this time was on the 1.5 meter band. When the decision was reached early in 1944 to adopt the Schnorchel operationally, many naval officers were of the opinion that no radar camouflage would be needed. This attitude resulted in slowing the Schornsteinfeger program somewhat, even though the formal priority was unchanged, until the fall of 1944, when it was decided that Schnorchel protection was required. While Allied use of S band radar had been known since the fall of 1943, and of X band since about the middle of 1944, it is not quite clear just what caused this decision. In any event plans were made and put into effect at this time to provide micro-wave protection for all U-boats, and the evidence suggests that perhaps 100-150 craft were actually fitted with coated Schnorchels before the end of March 1945.

2. Four Main Lines of Development.

Out of a large number of proposals, four were selected for further development. These were placed under the direction of a civilian technical director, Marineoberbaurat Kühnhold (OKM Wolfenbüttel), although a man named Prof. Kupfmüller appears to have been able to override Kühnhold's decision beginning about July 1944. Neither Kühnhold nor Küpfmuller have been available for interrogation to date. The four principal projects organized on Schornsteinfeger, out of which two successful devices were produced, are enumerated below:

(a) Netzhemd
(b) The Becker-Hellwege Absorber
(c) The Jaumann-Absorber
(d) The Wesch-Absorber

The Netzhemd was an attempt carried out under Dr. Bachem of Constance, near Switzerland, to adapt the principle of the quarter wave plate by the use of conducting screens, for a wave length of 1.5 meters. Although a model made by I.G. Farben at Höchst to Dr. Bachem's prescription was given an operational trial near Kiel, it was entirely unsuccessful because of mechanical failure, and was dropped about January 1944. This type of device is incapable in principle of absorbing over a wide band of wave lengths.

The Becker-Hellwege type of absorber was studied by DEGUSSA, (Deutsche Gold-und-Silber-scheideanstalt, near Frankfurt), under Dr. Untermann. It consisted of several layers, alternately semi-conducting and non-conducting, and employed a Buna lampblack mixture and air for the alternate layers. The development, which originated from theory of Profs. Becker and Hellwege of Geottingen, did not reach a practical stage at DEGUSSA, for vaious reasons, including wave length selectivity and mechanical problems, and was finally dropped by order of OKM in July 1944. Work on it was also dropped about this time by I.G. Hoechst because of inability to cover both S and X bands. Dr. Untermann, by order of Dr. Kuepfmueller, continued to be associated with Schornsteinfeger, however, in connection with the development of certain iron powders at Prague under Prof. Huettig. The use of these iron powders is discussed in par. 1 (f) of part II below. In view of the difficulties encountered with the Becker-Hellwege Absorber, DEGUSSA's role during the last months appear to have been confined to the problem of developing and classifying materials according to their electrical properties and suitability for projected Schornsteinfeger applications. The successful development of the Jaumann and Wesch absorbers, items (c) and (d) above, is outlined in the remainder of the report.

3. The Jaumann-Absorber

(a) Background

This absorber which was the first to be put into operational use (about September 1944) was developed theoretically by Prof. Johannes Jaumann of Bruenn. The actual development was centralized under contract with OKM at the I.G. Farben factory in Hoechst, near Frankfurt, where Prof.

Jaumann acted in the advisory capacity. The I.G./Hoechst undertaking was organized under Dr. Kiesskalt, who was responsible within I.G. Farben for the general project, and more directly under Dr. Patat, who was in charge of the development, production and testing of the components. The development and control of the materials required where th responsibility of Dr. Brennschede, a chemist, and all electrical measurements were the responsibility of Dr. Rathscheck. Dr. Kiesskalt provided the liaison between I.G./Hoechst and the OKM, and in this connection be made frequent visits to Kiel, and other naval and I.G. Farben activities.

The development of this absorber did not commence for several months after the Berlin conference of June 194. The steps leading to it are outlined below.

Initial efforts to solve the Schornsteinfeger problems were concerned with the 1.5 meterband. Among vari ous attempts at this long wave length problem, I.G. Hoesch constructed the single operational model of Netzhemd (According to Dr. Bachem's prescription), which was completed in the fall of 1943. At about this time evidence of the u of S band radar by the Allies was obtained (a wave length between 20 and 25 cm. was also reported), and this led Dr. Kiesskalt to abandon the long wave length problem, in favo of the Becker-Hellwege proposal, which appeared to be suitable for S band coverage, although it is in principle selective, and therefore could not be expected to be effect ive outside of this band. Experiments on a preliminary form of the Becker-Hellwege device were unsuccessful, primarily because of the need for a suitable dielectric material, in place of air, for maintaining the separation between the buna-lampblack layers. Such a material should al so be impervious to water, and have sufficient mechanical strength to withstand the pressure of U-boat operation.

A substance having promise for this application was found in the form of cellular "igelit", which was made by the firm, RECORD, in Schwiebus for use in bullet-proof tires, and for rescue boats and rafts. Further development initiated by I.G./Hoechst resulted in the successful adaptatation of cellular igelit for the Schornsteinfeger application. It is understood that cellular igelit is well know in the U.S., under the name of "Thermazote", where it has been developed by the Goodyear and Goodrich Rubber Companie

As the above development was progressing, during 1944, it became known that the Allies were also employing X band radar against U-boats, and the need for an absorber which would be effective at both X and S bands, was felt. It was believed that this could be obtained more practicall by designing an absorber which would be effective over the entire range of 3 to 10 cm., rather than by an absorber which would absorb only at these two spot frequencies.

In view of the wave length selectivity of the Becker-Hellwege device, however, it was therefore necessary to seek a new design. It was at this time, summer 1944, that Kiesskalt learned of Jaumann's scheme of using multi semi-conducting layers, which is effective in principle over more than one octave. Since a suitable dielectric material for maintaining the separation of the conducting layers had now been found, in the form of the improved cellular igelit, the project, which resulted in the Jaumann-Absorber, was begun.

This aim of the Schornsteinfeger program, up to this time had been camouflage of the conning tower, but actually the Jaumann-Absorber was never used in this way.

(b) Physical Description

The production form of this absorber consists of a hollow cylinder, which fits over the Schnorchel, and which has a wall thickness of about 3 inches. The cylinder is made up of seven layers of thin, semi-conducting paper, as illustrated in fig. 1, which are separated by layers or spacers about 9 millimeters thick of cellular igelit.

The surface conductivity of the paper is graduated exponentially from layer to layer, as described in the technical portion, Part II of this report. The function of the cellular igelit, whose electrical properties resemble those of air, is to maintain constant spacing between the paper layers, and to maintain the overall form of the absorber.

(c) The Jaumann type of absorber is efficient over a wide band of wave lengths, as illustrated by the fact that measurements on the reflection from flat plates, with respect to the reflection from a flat metal plate of equal size, are said to show a reflection coefficient of 10% or less (in amplitude) for all wave lengths between 3 cm. and 30 cm. Similar measurements on coated and uncoated Schnorchel cylinders (Ringschwimmer type valve) show only slightly worse results, so that a reduction in the range of radar detection of about 65% or more for any wave length in this band might be expected. No documentary report on the success of operational trials has been located, but according to verbal reports the range of detection was reduced to 15% of uncoated Schnorchel range against airborne Rotterdam radar on 9.3 cm., under calm sea conditions. While the details of this test are not known, the reported results do not appear to be inconsistent with theory, or knowledge obtained from similar tests in the U.S. when the effect of sea returns is included.

(d) The military requirements finally specified by the OKM, in addition to broad wave band coverage, included the requirement that the performance of the absorber should not be injured by submergence of the U-boat to a depth of 150 meters. The absorber would actually stand a depth of nearly 200 meters, which represents approximately the limiting depth for the strength of the cellular igelit. Depth tests to determine this were conducted in a water pressure chamber at Kiel.

(e) In spite of the efficiency of the Jaumann-Absorber, there appears to have been a certain amount of pessimism prevalent, due to the belief that the Allies could change operational wave lengths at will, and thus negate the entire Schornsteinfeger program if a wave length outside of the 3 - 30 cm. band were adopted. It was indeed reported by German "Snooper" units, towards the end of 1944, that the Allies were again using wave lengths in the 1.5 meter band. This circumstance caused an increased effort to broaden still further the effective band width by introducing iron into the absorber spacers. Since it was thought to be unfeasible at I.G./Hoechst to design an absorber which would be effective over the entire band of 3 to 200 cm., an attempt was begun to design a separate absorber of the Jaumann type, which would be effective over the band 1 - 2 meters. Since an absorber of this type, employing spacers of cellular igelit would be very thick (about 30 inches), the use of buna (containing iron) spacers, in place of the igelit, was contemplated, since this would increase the appropriate electrical constants, and permit the thickness to be reduced to perhaps 6 inches.

(f) While the Jaumann-Absorber could be adapted to a circular cylinder, by bending the igelit sheets before gluing, it was considered too difficult to cover more complex surfaces, such as elliptical cylinders, or the top of the Kugelschwimmer, or ball float type of Schnorchel valve, (Dr. Kiesskalt stated that streamlining was unimportant for the Schnorchel, and that only circular cylinders were to be used). In spite of efforts of Dr. Kiesskalt to influence the OKM to adopt the Ringschwimmer exclusively in this connection, because of its geometric simplicity, the marine engineers objected, and a decision to adopt a new type, called "Heep" Schnorchel employing a ball float valve, was announced by the OKM at a meeting held at Goettingen in December 1944. It was then decided to employ the Jaumann-Absorber for the cylindrical Schnorchel tube, and to employ the Wesch-Absorber, which is discussed in par. 4 below, for the top or Kopf, of the Kugelschwimmer. The Wesch-Absorber is more selective than the Jaumann type, being most effective for S and X band frequencies, but it is much easier to apply to curved surfaces of complex shape.

(g) Production Data

A list of the types of Schnorchel in use, together with the type of absorbing layer employed, as enumerated by Dr. Kiesskalt (and Wesch), is given below:

(1) R VII C - Schnorchel with ring float valve, (Ringschwimmer), for use on 500 ton, and possibly also on type 23, U-boats. Diameter 430 mm. Treated with Jaumann-Absorber.

(2) K VII C - Schnorchel with ball float valve, (Kugelschwimmer), for use on 500 ton, and possibly also on type 23, U-boats. Diameter 600 or 650 mm. Treated with Wesch-Absorber (Note: It is also possible that some Kugelschwimmers were treated with a combination of Wesch mats on the Kopf, and Jaumann-Absorber on the cylinder or neck.)

(3) K IX D - Schnorchel with ball float valve. For use on 750 ton, and possibly also on type 21, U-boats. Treated with Wesch mats.

(4) R IX D - Only a limited quantity produced before production was stopped (December, 1944). There may be a few 750 ton or type 21, U-boats so equipped, and treated with Jaumann-Absorber.

(5) "HEEP" - This was to be a new "electro-pneimatic" type of Schnorchel, equipped with Wesch mats on the hood and Jaumann Absorber on the neck.

The total number of Jaumann-Absorbers, which had been fabricated, between November 1944, when production began, and March 1945, when production was disrupted by Allied action, is estimated to be just less than 100. A monthly production rate of between 50 and 60 output well below this figure. The number actually completed and shipped during about half of March 1945, for example, was between 12 and 15. The total number of U-boats fitted with the Jaumann-Absorber was stated by Dr. Kiesskalt to be about 60. The average time interval between production and final testing after installation was said to be 4 - 5 weeks. Rejects at Kiel averaged 30% in October, and only 2% in March.

(h) Several establisnments were involved in the Jaumann-Absorber program, including the following:-

<u>OKM</u> - (1) Berlin (H.Q.)
(2) Wolfenbuettel bei Braunschweig (Kuehnhold headquarters; clearing house, and source of military requirements, for the entire

Schornsteinfeger Project).

(3) Kiel (Ship Yards)
(4) Pelzerhaken (Electrical Tests)

(i) <u>I.G. Farben</u>

(1) Hoechst, Frankfurt (Center of I.G. activity)
(2) Leverkusen (Source of Glues)
(3) Ludwigshafen; Oppau (Cellular igelit develop here, source of iron powder for later develo ments).
(4) Heiligenhaven
(5) Neustadt in Odenwald (Assembly point for Jaumann-Absorbers)
(6) Koenigstein (Shadow factory for I.G. Hoechst not actually used.)
(7) Constance (Source of some of electrical test equipment.)
(8) Bitterfeld (Source of raw lampblack for conducting paper.)
(9) Berlin (Central I.G. administrative point fo transportation and other facilities.)
(10) Dynamit Nobel, A.G., Troisdorf (and Eilenbur in Saxony. Source of cellular igelit.)
(11) Prague (Development of iron powders for late long wave work.)

(j) The number of personnel in the above activities engaged in the Jaumann-Absorber program is estimated conservatively to exceed 150, of which perhaps 15 were skilled physicists or chemists.

(k) A flow sheet, indicating sources of material testing and assembly points is presented on next page.

Cellular igelit, Troisdorf.

Conducting paper Okriftel, etc

Glues, Leverkusen.

↓

I.G. Hoechst, for testing of samples of cellular igelit and glue, and measurement and classification of conducting paper.

↓

I.G. Neustadt, in Odenwald for assembly of semi-cylinders.

↓

Navy Yard, Kiel for mounting, electrical tests (at Heiligenhaven), and final fitting of U-boats.

4. <u>The Wesch-Absorber</u>

(a) The Wesch-Absorber, or "Wesch-Mat", was developed under the leadership of Prof. Wesch of the Welt Post Institut (WPI) in Heidelberg. In July 1943, Wesch attended the conference called by Admiral Doenitz to discuss protection of U-boats against radar. Wesch met Konte: Admiral Stummel, who told him that anti-radar covering would, when available, be applied to whole U-boats. The wavelength, against which protection would be required, wa: not stated. In September 1943, Wesch was told that the band to be covered was 100 to 200 cms., and that only the conning tower was to be covered. Although offered a research assignment by OKM, Wesch refused it, as he preferre(to work under contract from BHF. He said that in this way he retained his freedom and individuality.

In November 1943, facilities of I.G. Oppau were placed at Wesch's disposal for development of suitable materials. Between November 1943 and January 1944, experiments were made on 1 to 2 meter band using a single layer of lossy material 2 to 4 cms. thick. These experiments dic not result in reflection co-efficients less than 30%. In January 1944 Wesch produced an absorber for 1 to 2 meter band using I-Gummi with 80% iron. The reflection co-efficient was as low as 15% in middle of band, rising to 40% at its ends. This absorber was rejected by OKM.

Following this lack of success, Wesch concentratec his effort on improving the apparatus and measurement techniques used in his laboratory. In March he had available radiation in the band 8 cm. to 200 cm. Between March and September 1944 he developed the essential features of the Wesch absorber. In August or September 1944, Prof. Kuepfmueller learned of Wesch's activities and brought Wesch into contact with the new operational requirements for protection of Schnorchel against 9 cms. radar. Up to this date he had not heard of Schnorchel. For test purposes a dummy Schnorchel, made of wood and sheet metal was set up at Kohlhof, but Wesch did not consider such tests capable of yielding useful results. He used the Schnorchel eventually only as a show piece.

In October 1944, Kuepfmueller announced that the Wesch-Absorber was shortly to be tried out with the ball-float type Schnorchel. Tests were made at Kiel and it was reported that the range of detection by a Rotterdam equipment was reduced by 50%. As a result of these tests an order was placed with I.G. Ludwigshafen to produce these absorbers. Nevertheless it was late in December 1944 before the manufacturing difficulties had been overcome and the Wesch-Absorber was accepted for operational use on the ball float type Schnorchel.

In December 1944, Wesch heard of an "electro-pneumatic Schnorchel" proposed by Kiel. This was known as the Heep Schnorchel and was to have Jaumann-Absorber on the cylindrical part and Wesch-Absorber on the hood. It was also proposed to cover the periscope, and mention was made of a new type, said to be in existence, which could be so covered and still function properly.

Also in December 1944, a request was made for coverage on 3 cms. band. Although the Wesch-Absorber was designed to have an absorption band around 9 cms., it did, in fact, exhibit a further absorption band around 3 cms. Consequently the request for coverage on 3 cms. was largely met before it was made.

The most important individuals at I.G./Ludwigshafen-Oppau, and later at Weinheim, who were involved in the production development, and actual production, are enumerated as follows:

Dr. Ambros
Dr. Herbeck
Dr. Jordan
Dr. Berger
Dr. Weber
Engineer Klant

In the course of the interrogation of Prof. Wesch, some information on the organisation of German Scientific Research was obtained. This is summarized in the chart given in Appendix I. It is not thought to be complete but may assist others working on organisation.

(b) Description

The production form of this absorber consists of a rubber mat about 50 cms. square, containing a high percentage of iron powder. The mat was produced in "waffle", or Matrix form, in a thickness of about 4 millimeters, with the height of the waffle ridges about 4 mm. above the mat surface. For operational use, or testing, this mat is glued to a sheet of rubber about 1 mm. thick, known as Oppanol-O, and this assembly is glued to the metal surface.

(c) Performance

The absorption coefficient, as a function of wavelength, of the service production material is illustrated in figure 7. Good coverage is provided at S and X band frequencies, where the reflection coefficient for flat plates is said to be everywhere less than 10% (amplitude), although there is a maximum between these two bands of about 30% in the neighbourhood of 6 cm..

(d) The Wesch-Mat is much more suitable mechanically for use on curved surfaces than the Jaumann-Absorber, and this is the reason it was adopted for the curved top of the Kugel-schwimmer by the OKM. From the beginning, the OKM had also believed in the importance of providing uniform coverage over a wide frequency range centered around S band, however, and for this reason there was a reluctance to discard the Jaumann-Absorber where it was suitable mechanically.

(e) Establishments involved on this project include the OKM activities already listed in par. 3 (h) above, as well as the following:

(1) Welt Post Institute) Heidelberg, Theoretical work and testing of
(2) Philip Lenard Institute) samples.
(3) I.G. Farben, Ludwigshaven.
(4) I.G. Farben, Oppau.
(5) I.G. Farben (Freudenberg), Weinheim (Shadow factory to Oppau, for fabrication.)
(6) I.G. Leverkusen - Perbunan.

The number of personnel involved full time in the above activities was approximately ten physicists or chemists, and perhaps, fifteen of semi and unskilled types.

(f) Production Data

The total service production of Wesch-Mats, between January and March, 1945, was stated by Dr. Wesch to be enough for about 200 Schnorchels, and this appears to be consistent with what was learned of the manufacturing details at I.G. Oppau and Weinheim. The method of manufacture employed is well known in the rubber industry, and standard roller and press equipment only is required.

The number of Schnorchels fitted with Wesch-Mats was stated to be about 100, but some of these were of the ring float type where a combination of the Jaumann and Wesch-Absorbers was adopted.

II. Technical Intelligence

1. Jaumann-Absorber (Principles and Practice)

(a) Description of final form of absorber: See Figure 1.

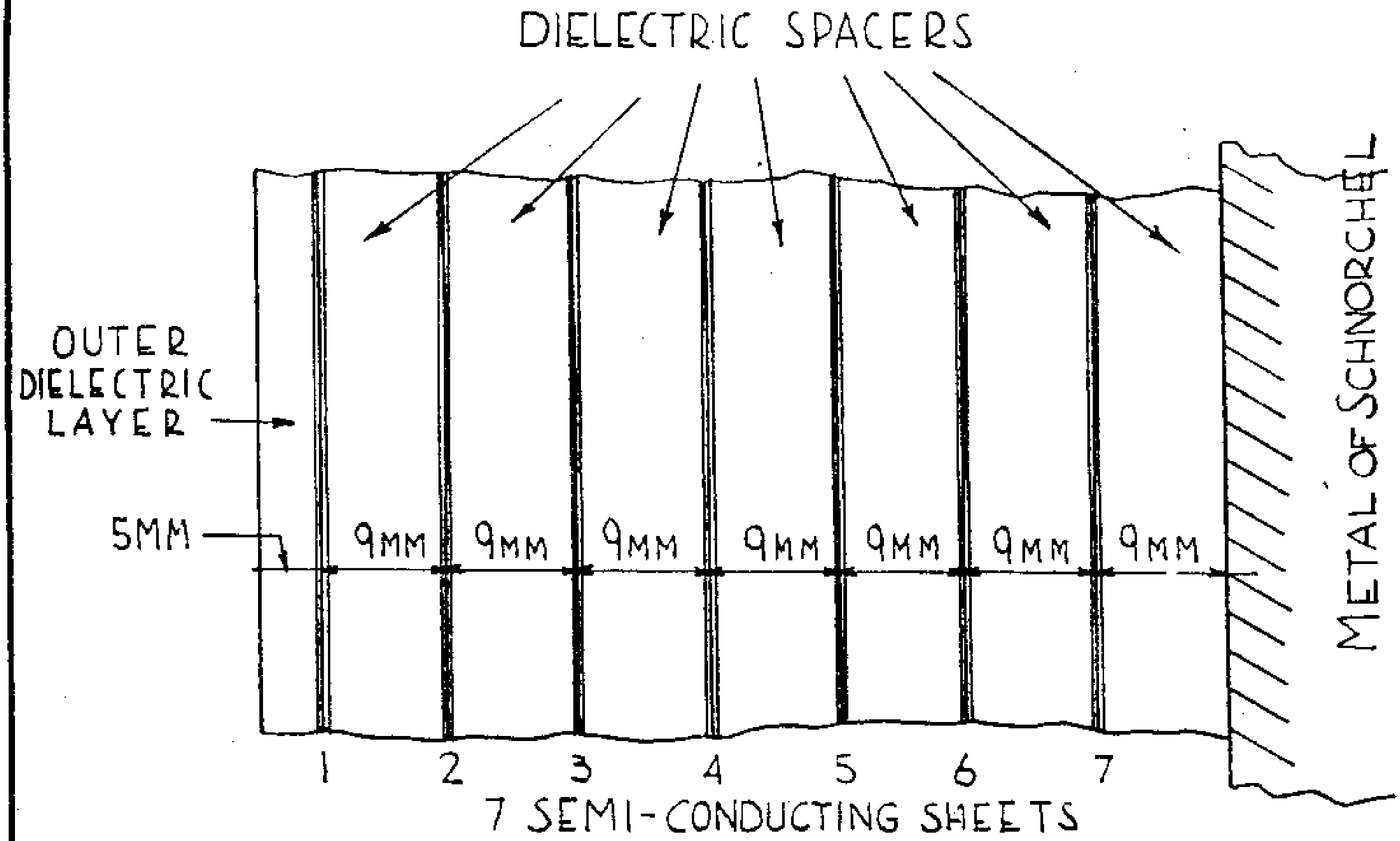


FIG. 1. I-G. JAUMANN ABSORBER.

The absorber is made up of seven thin semi-conducting sheets separated by seven dielectric layers of spacers all of the same thickness. The absorber is faced with a thin dielectric layer on the outer side. The arrangement is shown in figure (1). The dielectric spacers are made of cellular igelit; the thickness of each is about 9 mm. The outer dielectric layer is also made of cellular igelit of thickness about 5 mms.. The semi-conducting sheets are made of lamp-black paper about 1/10 mm. thick. They are perforated in order that the glue used to stick the layers together can adhere to the cellular igelit through the sheets. A special kind of glue is used for sticking the layers together and another for gluing the absorber onto the metal of the Schnorchel. The outer surface of the absorber is coated with a water repelling wax.

Absorber units are built up in cylindrical segments, two or three in number. The sheets of cellular igelit are bent before being glued together. When the cylindrical segments are assembled on the cylindrical neck of a Schnorchel, narrow slits of width from 3 to 10 mms. occur at the junctions of the segments due to inaccuracies in manufacture. These slits are left open.

(b) Electrical Properties and Theory

Cellular igelit has a dielectric constant of 1.3 and permeability unity. Lamp-black papers are graded in value of surface resistance, which decreases exponentially from 30000 ohms to 300 ohms in going from sheet 1 to sheet 7. The surface resistance is defined as the resistance between opposite edges of a square sheet of the paper. Table 1 gives values of surface resistance in ohms and ratio of surface conductance to wave admittance in cellular igelit.

	1	2	3	4	5	6	7
N = No. of semi-conducting sheet	1	2	3	4	5	6	7
R_n = Surface resist. in ohms.	30000	14000	6500	3000	1400	650	300
G_n = Ratio of surface conduct. to wave admit. in dielect.	0.011	0.024	0.051	0.110	0.24	.51	1.10

Table (1) Surface Resistance of semi-conducting sheets. The Jaumann-Absorber in the form of flat sheets is exactly equivalent to the loaded transmission line shown in figure (2).

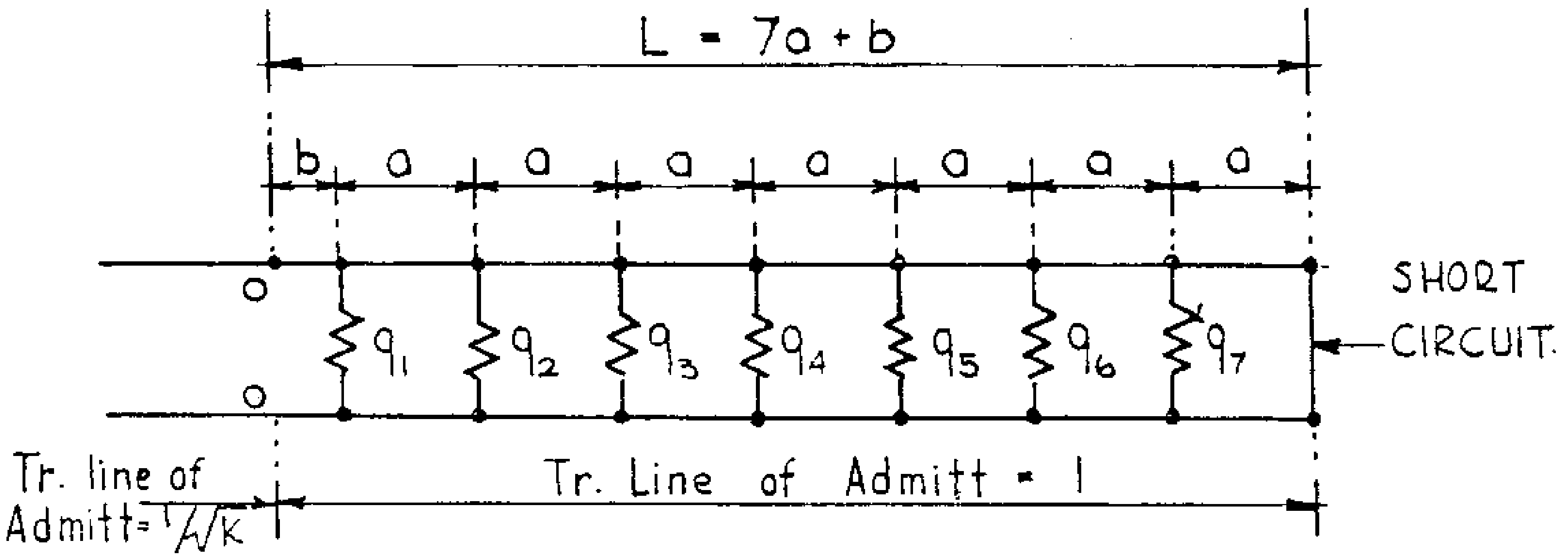


FIG. 2. EQUIVALENT CIRCUIT OF JAUMANN ABSORBER

For the sake of ease in calculating the input admittance at 00 all admittances have been normalized with respect to the wave admittance in cellular igelit.

The theoretical performance of the Jaumann-Absorber can be readily worked out using the above equivalent circuit. Figure 3 shows a rough plot of the input admittance Y_{oo} in the complex plane within the main absorption band for the service type of absorber, figure 1. The following considerations will explain it:

When the wave length, λ, in the spacing medium, is large compared with the total length of the absorber, L, the input admittance, Y_{oo}, is largely inductive and has only a very small real part on account of the short circuit. As λ decreases Y_{oo} increases in both real and imaginary parts, G_{oo} and S_{oo} respectively. As λ tends to 4L, G_{oo} and S_{oo} become comparable in magnitude. As λ increases further Y_{oo} describes a contracting spiral around the point (1.0). It makes one complete revolution each time the total phase-change through the absorber increases by 180°. Thus Y_{oo} crosses the real axis to the left of the point (1.0) roughly when

L/λ - 1/4, 3/4, 5/4, ...

In terms of the wave length, λ_o, in air that is, when λ_o = 27·9, 9·3, 5·6, 4·0, ... cms

However, the input admittance does not continue to trace out a contracting spiral as the wavelength decreases indefinitely. The limit is set by the spacing, a, between adjacent semi-conducting sheets. When a = $\lambda/2$ all the shunt conductances in figure 2 are effectively short circuited by the terminating short circuit. G_{oo} is then zero and $S_{oo} = -\cot(2\pi b/\lambda)$. In order to reach this point the input admittance must therefore trace out an expanding spiral as λ tends to 2a. This is shown in figure 3.

When the locus of the input admittance, Y_{oo}, has been calculated the amplitude reflection coefficient is readily obtained from the formula:

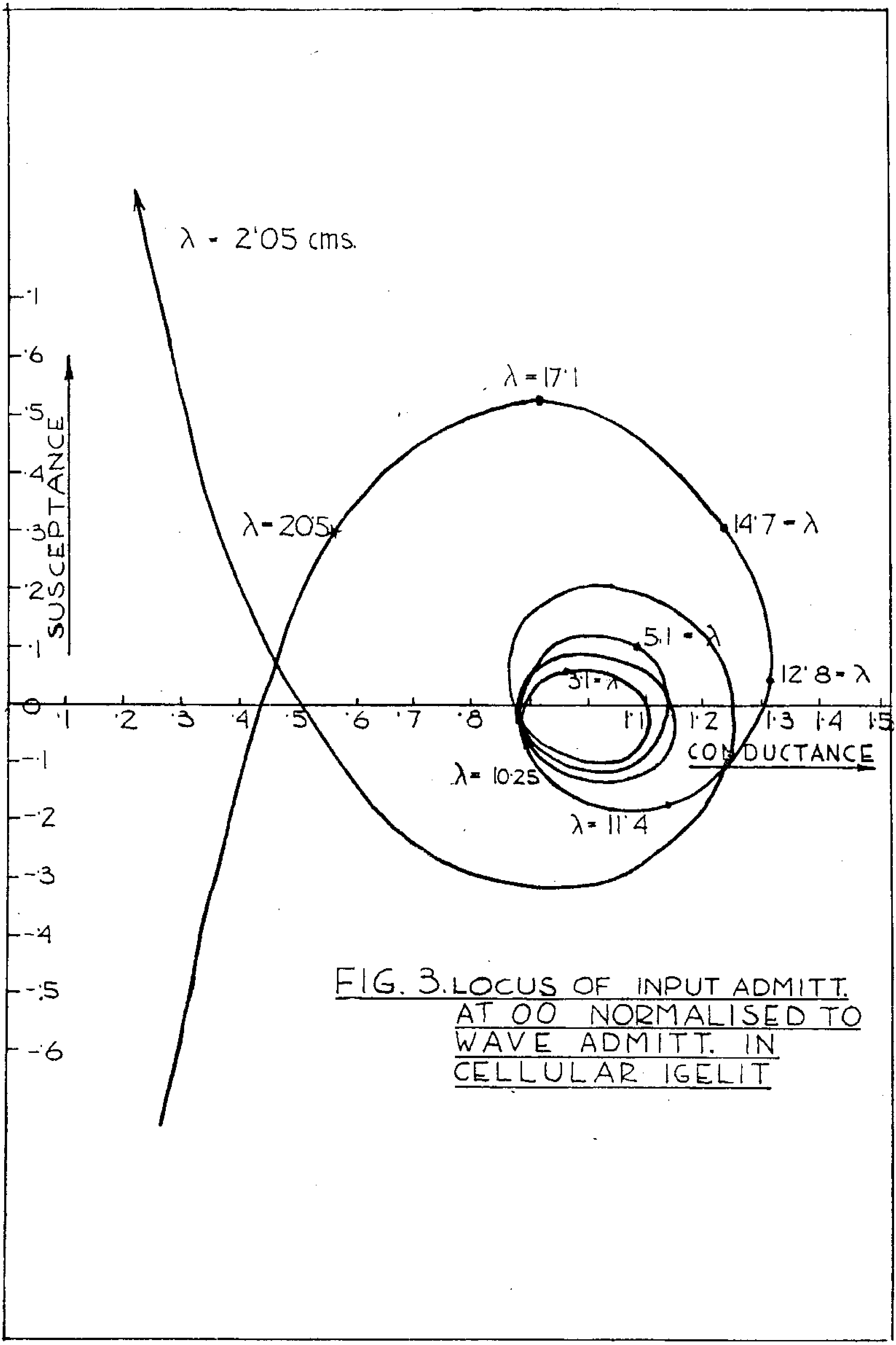


FIG. 3. LOCUS OF INPUT ADMITT. AT OO NORMALISED TO WAVE ADMITT. IN CELLULAR IGELIT

$$\gamma = \left| \frac{1/\sqrt{K} - Y_{oo}}{1/\sqrt{K} + Y_{oo}} \right| = \left| \frac{0{\cdot}88 - Y_{oo}}{0{\cdot}88 + Y_{oo}} \right| \text{ for the Jaumann Igelit absorber}$$

Figure 4 shows its general behaviour over the absorption band. It has minima roughly at 9, 6, 4, 3, and 2.5 cms. and maxima, of amplitude less than 10%, at about 7.3, 5, 3.5, 2.8 cms. It is necessary to point out that the theoretical results shown in figures 3 and 4 are the rough work of an investigator and are given only to illustrate the fundamental principles of the Jaumann-Absorber as explained to him in the course of interrogations. No write-up of the theory was discovered during the investigation. Details of asserted performance are given below in section 3.

Theory indicates that the wave impedance of the dielectric spacers should be as nearly equal to 377 ohms as possible, that is $K = \mu$. Furthermore μ and K should be as large as possible to reduce the overall thickness. On account of their inability, until very recently, to produce a material have $\mu = K$ and $\mu > 1$ the Germans were restricted to the use of cellular materials. Initially cellular Moltopren, having K = 1.15, was tried out, but, although satisfactory electrically, it was too weak mechanically for use on Schnorchels, and its properties were destroyed by salt water. Use was made of Moltopren in Jaumann-Absorbers for coating the walls of a "dark room", in which reflection experiments on absorbers were carried out. Other forms of Jaumann-Absorber for "dark rooms" were constructed with cardboard as spacing dielectric. The performance of these absorbers is not known but samples are available for testing.

An iron loaded paper, called Eisenpappe, was also tried as spacing material. For it $\mu = 5$ and K = 10, but it is sensitive to moisture and was rejected.

(c) Performance of Jaumann-Absorber

Over a frequency band 3 to 30 cms. the reflection coefficient for flat plates was claimed to be less than ten per cent. The reflection coefficient is defined as the ratio of the amplitude of signal reflected from the object, in this case metal, with and without absorbative covering. When built up of two or more cylindrical segments the joints cause electrical asymmetry on horizontal polarisation for vertical Schnorchel. The polar diagram shows

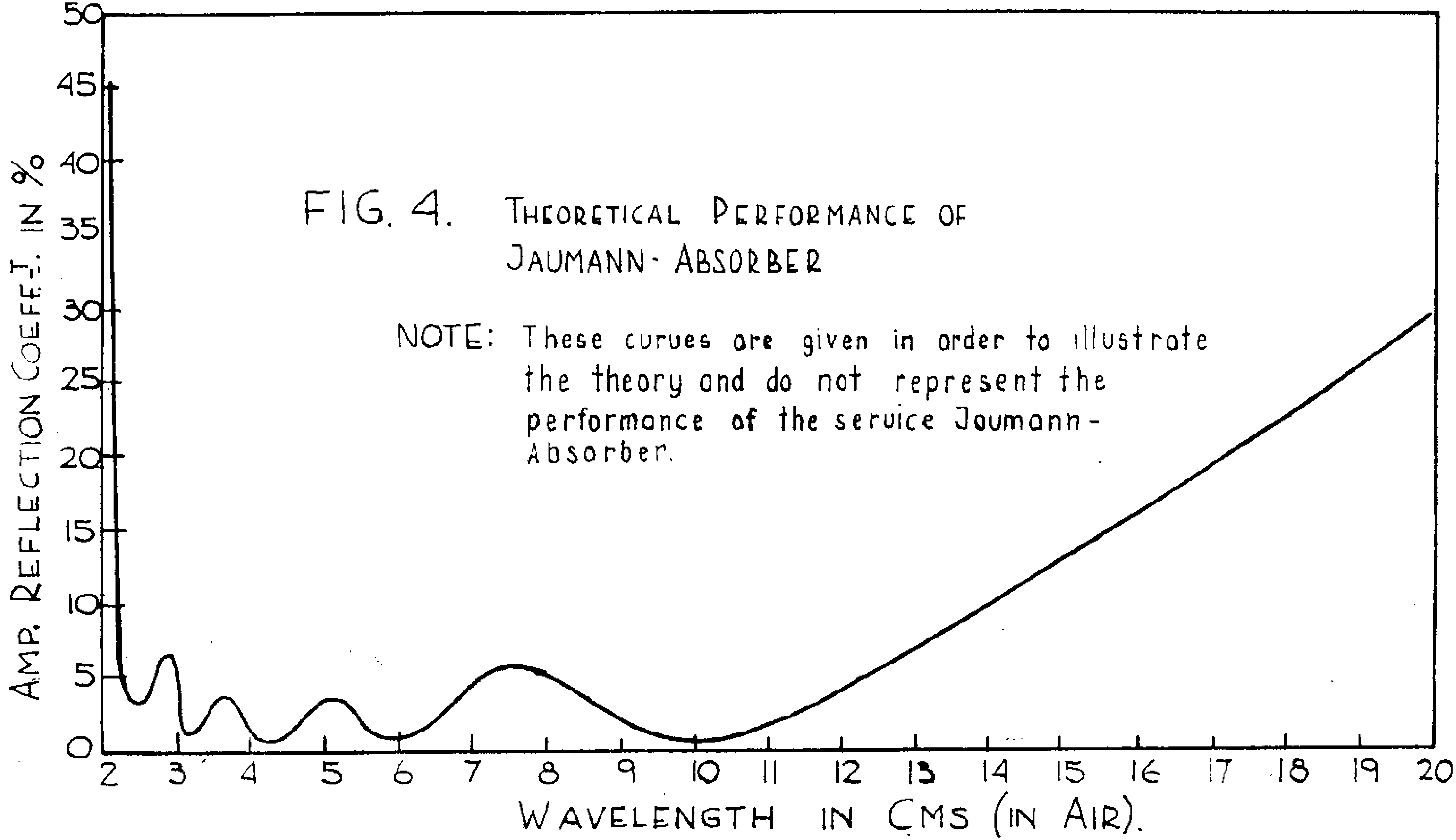


FIG. 4. THEORETICAL PERFORMANCE OF JAUMANN-ABSORBER

NOTE: These curves are given in order to illustrate the theory and do not represent the performance of the service Jaumann-Absorber.

peaks, which may be as large as 20% in amplitude of reflection coefficient. The mean value over 360° is, however, less than 10% in the band 3 to 30 cms. Samples of the cylindrical shells are available for testing.

The use of the Jaumann-Absorber in its present form is limited by the mechanical properties of cellular igelit. It can only be made up in the form of flat sheets or cylindrical segements. The thickness of each spacing layer cannot be reduced much below 7 mms. This limits the absorption band at the short-wave end to about 2 cms.

(d) Properties of Materials

Igelit is pure polyvinylchloride (PVC) without additives. It is said to be well known in America, where it was developed by Goodyear and Goodrich Rubber Cos., and in England, under the name of "Thermazote". Its dielectric constant is about 2.7.

Cellular Igelit is pure igelit, which has been specially treated in order to reduce the density by the introduction of air. There is 70% air and 30% igelit by volume. The importance of cellular igelit for this application arises mainly from the fact that the small air cells are not interconnected, and that the material is therefore, impervious to water even under high pressure. Moreover its density is about 0.35.

Cellular igelit was produced by Dynamit Nobel A.G., originally at Troisdorf near Cologne, and later at a shadow factory in Eilenburg (Saxony) after Troisdorf was bombed.

Semi-conducting sheets are made of ordinary paper, or cellulose, into which lamp-black is mixed during the manufacturing process. To one hundred parts by weight of cellulose pulp, carbon-black is added in amounts ranging from 20 to 70% by weight. Small amounts of filler are added according to normal paper manufacture procedure. The papers are finished in weights between 35 and 80 grams per sq meter and with varying glosses. Control of the conductivity of the papers was found to be very difficult and each sheet of paper fabricated into a semi-conducting section of absorber was separately measured for surface conductivity and serially numbered before shipment to the assembly plant.

Glue - Two kinds are used.

(1) For glueing layers together. It is a mixture of 5 parts of desmophen, which is a mixture of esthers (perhaps the same as moltopren) and one part of desmoduer, which is an isocyanate resin solution. This glue is paint- onto the cylindrical spacers, between which the graded perforated absorbing sheets are sandwiched. The layers are

pressed together without heat and allowed to set for two hours. Although this is the glue used in the Jaumann-Absorbers, it is not entirely satisfactory, and further work on glue was projected.

(2) "Kitt", a glue containing Kiesgluer and Kaolin, is used to glue the absorber onto the metal of the Schnorchel. For satisfactory adhesion, Schnorchel metal must be clean and dry.

Wax. The outer surface of the assembled absorbers is coated with a wax to repel water, since a film of water (K = 80) greatly increases the reflection coefficient.

(e) The process of fabrication of the I.G. Jaumann-Absorber begins with heating to a relatively low temperature, possibly 100 degrees centigrade, of the sheets of raw igelit as received from Bitterfeld. The sheets of igelit are then pressed for flatness, sawed to size and reheated. They are then stacked seven deep and rolled roughly to their intended shape between a steel cylinder and a steel band which is slowly wound on the cylinder. The igelit sheets are then sprayed with glue on both sides, interleaved with the correct sheets of paper, assembled in the proper order and clamped onto semi-cylindrical wooden forms to dry. The drying process seems not to have been critically controlled. After drying the semi-cylindrical sections of absorber are trimmed and shipped to Kiel for mounting on Schnorchels. The coated Schnorchels are subjected to final reflection coefficient tests at Heiligenburg.

(f) Recent Development of Jaumann-Absorber

Recently a new kind of Gamma iron oxyde has been produced having $K \doteq \mu = 5$. The process was invented by Dr. Huettich of Prague. A solution of ferrous sulphate in dilute sulphuric acid is precipitated with ammonium hydroxyde and then oxydized with concentrated ammonium nitrate solution. The precipitate of hydrated Fe_3O_4 is washed with hot water, dried, oxydized by heating in air at 200° C to Gamma - Fe_2O_3, and then cooled very rapidly using dry ice (solid carbon-dioxide) or liquid air. The product is ground and sifted and results in Gamma - Fe_2O_3 with about 1-2% Fe_3O_4, particle size probably about 5μ. This iron powder is used as filler in Buna-S3; the proportions by weight are 80% powder to 20% Buna-S3. Samples and further information on this new material are being sought.

So far as known this new material has not been used in any absorber, but the intention seems to have been to use it as spacing material for a Jaumann-Absorber to cover the band, 130 to 180 cms. (Note: The iron-loaded rubber mats consigned to Farnborough under ref. (f) are experimental in form. They were stated to contain an iron powder developed by I.G. Farben, and to have electrical properties which are inferior to those claimed above for Huettig's iron.)

II.

2. <u>Wesch-Absorber (Principles and Practice)</u>

(a) <u>Description of Absorber - see figure 5.</u>

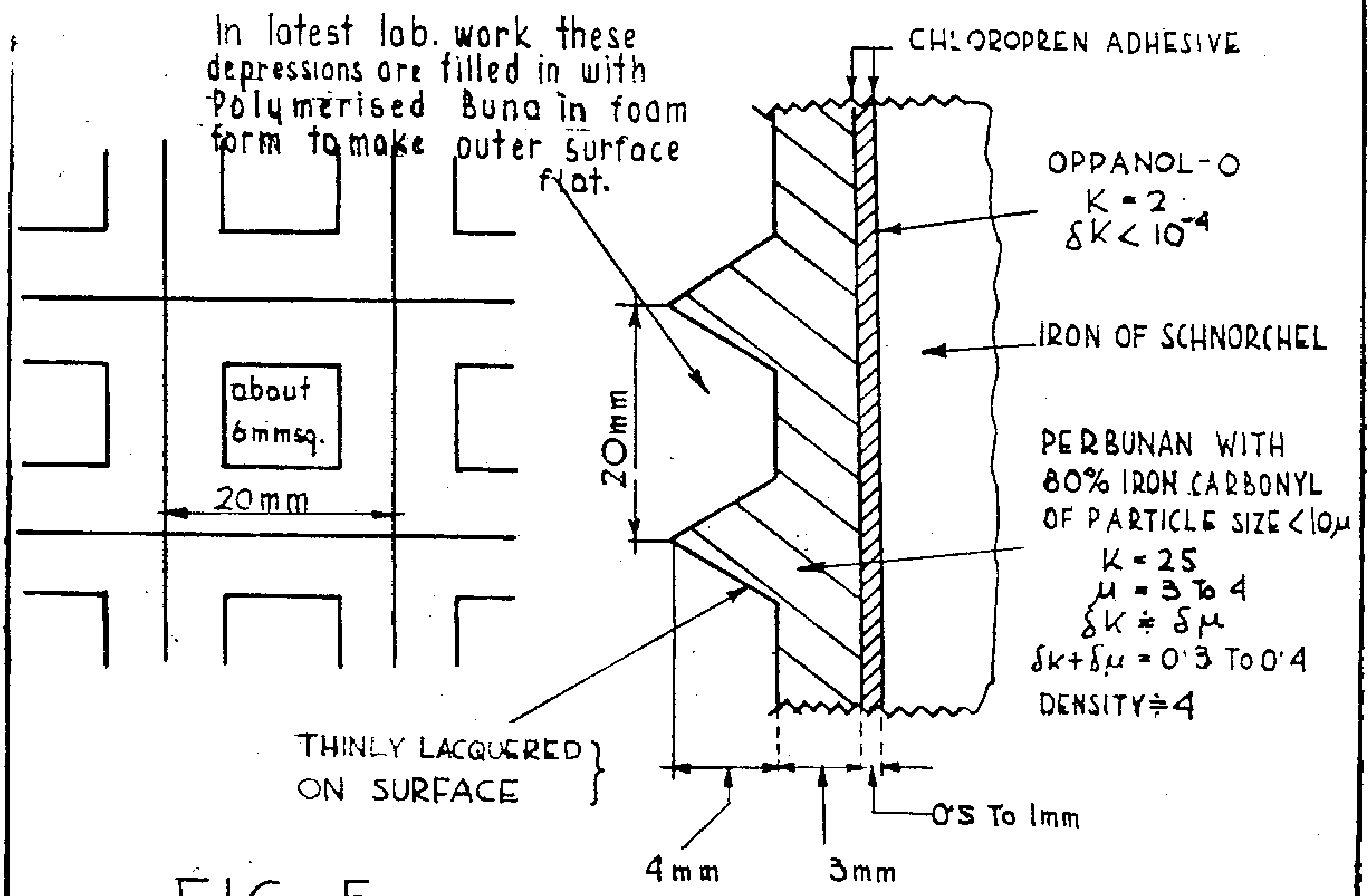


FIG. 5.

CONSTRUCTION OF WESCH ABSORBER.

The Wesch-Absorber is made up of two layers of total thickness about 8 mms. as shown in figure 5. Next to the metal of the Schnorchel comes a layer of Oppanol-O from 0.5 to 1 mm. thick. On top of this lies a thicker layer of a rubber-like substance called perbunan loaded with carbonyl iron. The first 3 mms. of loaded perbunan are solid, whereas the outer 4 mms. are moulded in the form of a waffle with ridged squares about 20 mms. wide. An adhesive called chloropren is used to stick the layers together and to the metal of the Schnorchel. The outer surface of the perbunan is protected by a thin coating of lacquer.

The absorber units are made in the form of mats, 52 cms. square. The flexible nature of the material allows the mats to be fitted to any surface of moderate curvature. No difficulty is experienced in joining mats together. The adhesive used is chloropren.

The absorber discussed above was not completely satisfactory, due to the formation of cracks at the base of the waffle wedges by wave and sea action, and work on a modified arrangement to remove this difficulty was underway. According to the new arrangement, a modified matrix with higher ridges, more closely spaced, (samples of the die have been sent to Farnborough and to NRL), was to be used, and the space between the ridges was to be filled in with a material having approximately the same electrical properties as air. Several materials were studied for this purpose, and a satisfactory one was apparently found, consisting of polymerized pure buna in a special "foam" or "moss" form. No current samples of this type were found.

(b) Theory and Electrical Properties of Materials

Two documents were secured, in which the theory and development of the Wesch-Absorber are described in some detail.

The first document is a long and comprehensive report on the reflection of a simple plane electromagnetic wave from two contiguous layers backed by a conducting plane. The outer layer is assumed to be lossy and the middle layer non-lossy. Two cases are considered

(1) Outer layer a lossy dielectric.
(2) Outer layer with iron powder.

Considerable use is made of the polar form of circle diagram for impedance, from which reflection coefficients can be read off directly. The following points are made:

(1) A single layer of lossy dielectric terminated in a conducting sheet is too frequency selective. Zero reflection coefficient can be obtained only if the material has dielectric loss angle

$$\delta \varepsilon_0 = \frac{4}{\pi} \text{ arc Tan h } \left(1/\sqrt{\varepsilon} \right)$$

Such materials are scarce.

(2) Insertion of a low loss dielectric layer between the lossy layer and the conducting sheet permits zero reflection to be achieved at one frequency, no matter what the values of $\delta\varepsilon$ and ε may be. This spacing layer acts as an inductive load terminating the lossy line. The thickness of the lossy layer is then

$$h \doteq \frac{\lambda_0}{\pi\sqrt{\varepsilon}\,.\,\delta\varepsilon} \text{ arc Tan h } \left(1/\sqrt{\varepsilon} \right) \doteq \frac{\lambda_0}{4\sqrt{\varepsilon}} \quad \frac{\delta\varepsilon_0}{\delta\varepsilon}$$

where $\delta\varepsilon_0$ is the value of the dielectric loss angle given in (1) above and λ_0 is the wavelength in air.

In spite of the reduction of the reflection coefficient to zero by this means, the selectivity is still too high.

(3) The width of the absorption band is increased by use of a dielectric loaded with magnetic iron. This reduces the reflection from the front surface. Experiments have shown that the electric and magnetic loss angles for absorbative materials, such as carbonyl iron in Oppanol, or in I-Gummi, or in perbunan, are very nearly equal. The wave impedance in the lossy layer is therefore very nearly $\sqrt{\mu/\varepsilon}$ times the wave impedance in free space. The ratio ε/μ is found to be almost independent of the amount of iron powder, provided this amount exceeds 30% by weight. For zero reflection without a dielectric spacing layer the sum of the electric and magnetic loss angles must be

$$\delta\mu + \delta\varepsilon = \frac{4}{\pi} \text{ arc tan h } \sqrt{\mu/\varepsilon}$$

and the layer thickness

$$h = \frac{\lambda_0}{4\sqrt{\mu \cdot \varepsilon}}$$

(4) Although the band width is increased by use of materials with magnetic loss and high permeability it is

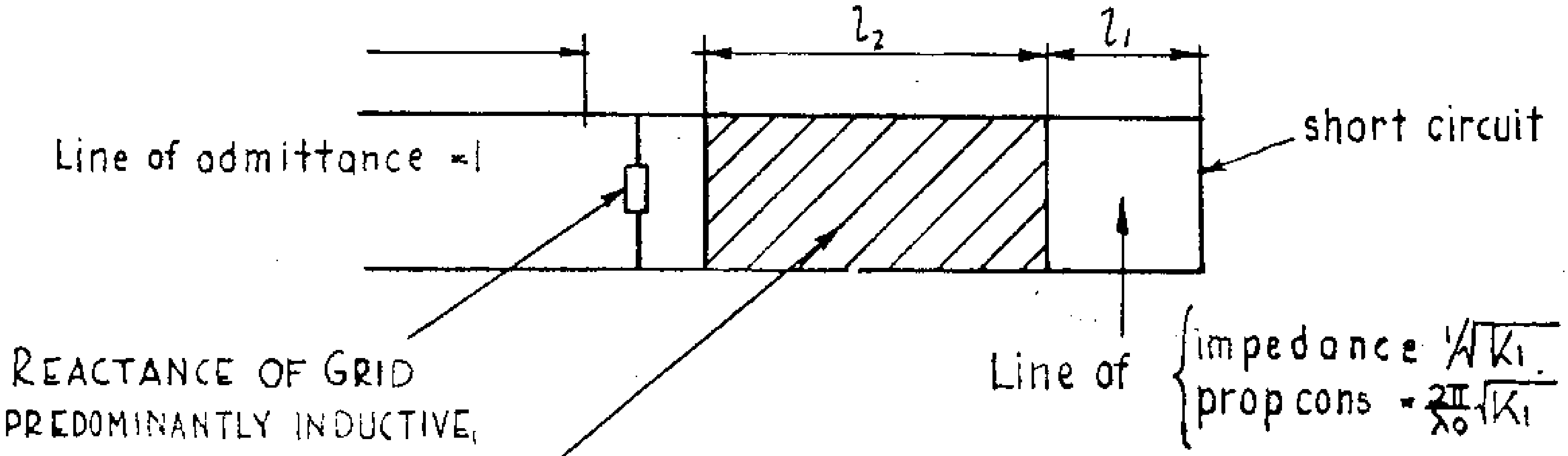
still difficult to satisfy the relationship $\delta\mu + \delta\varepsilon = \frac{4}{\pi} \text{arc tanh} \sqrt{\mu/\varepsilon}$. Just as in (2) above, a dielectric spacer eases the situation. The thickness of the spacing layer, l_1 depends on the value of $\delta\mu + \delta\varepsilon$ relative to $\frac{4}{\pi} \text{arc tanh} \sqrt{\mu/\varepsilon}$. If it is larger l_1 is less than a quarter of a wavelength in the dielectric, where as if it is amaller l_1 has to be greater than half a wavelength.

This report is profusely illustrated and should be consulted for further details and a discussion of the technique of measurements. As it is lengthy it has not been included in this report. It is available at CRB. (See Appendix II.)

The second document, Appendix III, is a research report "On the development of an Electric Absorber". Although, this report is dated July 1944, it contains descriptions of all the essential ideas. However, at that time Wesch was working on the idea of a lossy material with the product of ε and μ proportional to λ^2. Latterly he abandoned that scheme, because he could not find suitable materials.

The report reiterates the results of theoretical and experimental studies given in points (1) to (4) above. The idea of a waffled outer surface is developed from that of a reactive grating. The purpose of the waffle is to reduce the reflection from the front surface.

Mention is also made of layers about $3\lambda/4$ thick at the main absorption band. These were not used in practice. See Figure 6.



Line of { impedance = $\sqrt{\frac{\mu_2}{K_2}} \sqrt{\frac{1-j\delta\mu_2}{1-j\delta K_2}} \doteqdot \sqrt{\frac{\mu_2}{K_2}} \quad \because \delta\mu_2 = \delta K_2$

Prop. Const. = $\frac{2\pi}{\lambda_0}\sqrt{\mu_2 K_2}\,\sqrt{(1-j\delta\mu_2)(1-j\delta K_2)}$

$$\doteqdot \frac{2\pi}{\lambda_0}\sqrt{\mu_2 K_2} - j\frac{\pi}{\lambda_0}\sqrt{\mu_2 K_2}\,(\delta\mu_2 + \delta K_2)$$

FIG. 6.

Equivalent line circuit of Wesh Absorber

The equivalent line circuit of the Wesch-Absorber is shown in figure 6. The line of length l_2 is lossy. Its impedance and propagation constant are given in the figure. The spacing layer is equivalent to a low loss line of length l_1 . The waffled surface is in effect an inductive grid, at least at wavelengths long compared with the separation of the waffle ridges.

To a first approximation l_2 is the thickness which the perbunan layer would have if it were compressed into a flat sheet about a quarter of a wavelength in the medium at the longest wavelength at which the reflection coefficient is a minimum. Prof. Wesch did not know of a formula for the grid reactance. The form of waffle shown in figure 5 was found by experiment.

The absorbative material used in the Wesch service absorber is perbunan loaded with 80% carbonyl iron of particle size less than 10 μ . The dielectric constant is 25 and the permeability between 3 and 4. The electric and magnetic loss angles are very nearly equal and their sum lies between 0.3 and 0.4. The density of the material is about 4.

The spacing layer is made of Oppanol, which has a dielectric constant of about 2 and a loss angle of about 10^{-4}.

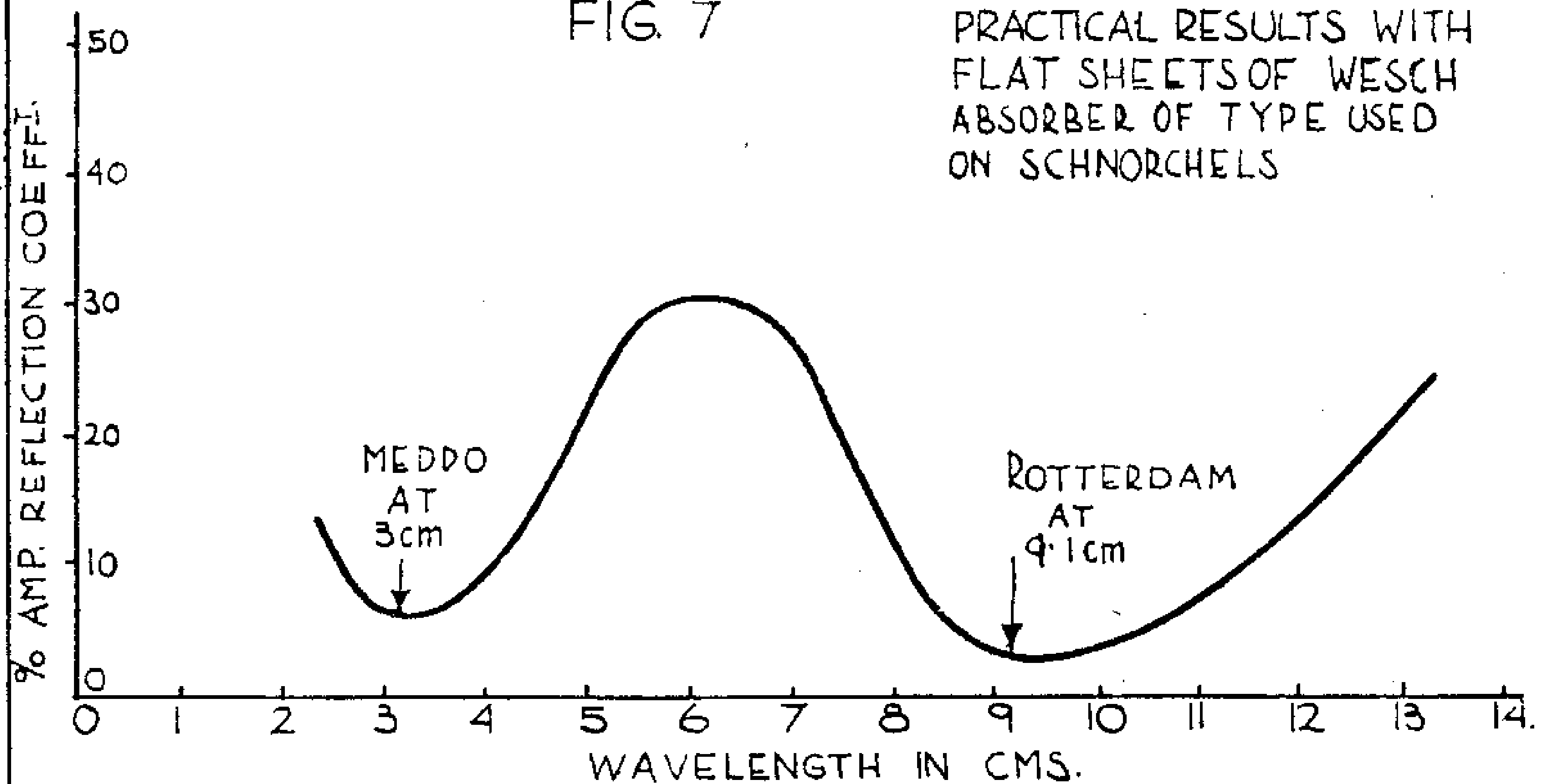
The electrical properties of the adhesive chloropren and the lacquer are not known but they are understood to have very little effect on the performance of the absorber.

In the course of the development work, many different materials were examined. Examples of these are given in Appendix III, tables 1 to 3. Oppanol figured to a large extent in the early experiments because it is soft and forms a useful base into which other materials such as iron powder and lamp-black can be worked. (A roll of Oppanol was shipped to Farnborough and NRL). I-Gummi was also used as a base and is said to be just as satisfactory electrically as perbunan. It was found, however, to be difficult to handle, and to manufacture in quantity, and perbunan was used to replace it.

(c) <u>Performance of Wesch-Absorber</u>

According to Prof. Wesch the performance of his absorber is as shown in figure 7.

FIG. 7


PRACTICAL RESULTS WITH FLAT SHEETS OF WESCH ABSORBER OF TYPE USED ON SCHNORCHELS
% AMP. REFLECTION COEFF.T
50
40
30
20
10
0
MEDDO AT 3cm
ROTTERDAM AT 9·1cm
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14.
WAVELENGTH IN CMS.

The reflection coefficient for flat plates is less than 5% in amplitude at the first minimum at about 9 cms. and less than 10% at about 3 cms. It has succeeding minima at about 1.8 cm., 1.3 cm., etc., where the thickness is roughly (2n-1) λ /4. Maxima occur between these minima at about 5 cms., 2.3 cms., etc.. At 5 cms. the reflection coefficient is about 30%. When the absorber is fitted onto a metal cylinder these minimum values are about doubled and the maxima increased by about 50%. It is interesting to observe that the Allied choice of 9 cms. and 3 cms. bands greatly assisted Wesch. In fact his absorber was originally designed to have an absorption band at 9 cms. and quite unintentionally it had a further one at 3 cms. When therefore Wesch was told of the Allied use of X band equipment, he realized that his absorber would cover that band also without further development.

A short description of measurements made on experimental production models of Wesch-Absorber is described in a report translated in Appendix IV. Wesch said that none of the curves given therein represents the quality of performance of the final product. They do, however, show the degree of non-uniformity found in production models and the approximate band width obtainable (see in particular graph Ia).

Although Wesch was not familiar with the operational performance of his absorber, he understood that the range of detection was reduced by 50%. This figure was said to apply to the Rotterdam radar on 9 cms.

(d) Production and Materials

A brief description of the production process employed in the manufacture of the Wesch-Absorber, as obtained at I.G. Farben-Oppau, is given below: (This process is illustrated by means of figures 8, 9, and 10).

(1) Ten kg. of perbunan (source: I.G.-Leverkusen) is rolled between two cylinders for about 15 minutes.

(2) Forty kg. of carbonyl iron powder (source: I.G.-Oppau) is then added slowly (about 10 minutes).

(3) Then add (about 5 min.): (500 gms. ZnO (Red label special; source: I.G. Ludwigshaven).

(4) Then add (about 5 min.): (100 gms. sulfur. 100 gms. vulkanit AZ (Source: I.G.-Ludwigshaven).

(5) The separation of the cylinders is then reduced (to about 1 mm.), and the mix is run through five times.

(6) The separation of the cylinders is now adjusted so that when the mix is fed through, the weight of a sample sheet 52 cms. x 52 cms. in size is equal to 3,300 gms.

(note figures 8 and 9).

(7) The sheet emerging from the rollers is now cut into 52 cms. squares, which are placed in matriz forms (as in figure 10), and heated at 140°C, under a pressure of 50-60 kg./cm^2.

(8) The waffle sheets were then coated with a practical lacquer, possible containing camouflage paint for near infra-red, and shipped to Kiel for fitting to the layer of Oppanol-O, and to the Schnorchel tube. (According to Dr. Kiesskalt there was a real effort to provide camouflage against near infra-red because of the belief that Allied radar was incapable of tracking on targets within ranges of 2 kms., and that near infra-red ranging devices were employed for the final approach and attack on U-boats.)

Production of the Wesch-Mats, as described above, took place originally at I.G.-Oppau, near Ludwigshaven. This production was transferred in February 1945, after Oppau was bombed, to an I.G. shadow factory at Weinheim, a few miles away.

(e) <u>Measurements</u>

(1) <u>On Materials:</u> A technique for determining the constants of lossy materials has been worked out by Prof. Wesch and Dr. Meincke of Leubus. It consists of making up a thin ring-shaped slab of the material with exactly the correct inner and outer radii to fit tightly into a concentric line. Air gaps, particularly at the inner conductor of the concentric line, must be avoided. The line is fed by a generator at one end and terminated in a short-circuiting plunger at the other. Measurements are made of the standing-wave pattern in the line for different positions of the plunger and the input impedances at the input face of the material are deduced. These input impedances are plotted in the polar form of circle diagram and they should lie very nearly on a circle. A good circle is drawn through the plotted points and the constants of the material are deduced from the coordinates of its centre point and from its radius. The report referred to in Appendix II gives fuller details of the procedure.

(2) <u>On Absorbers:</u> These were made:

(1) On flat plates. A metal sheet, coated on one side with the Wesch-Absorber, was set up at a distance from a sender and receiver. The amplitude of the reflected signal was measured from the covered side and from the uncovered side.

(2) On cylinders; Here again one-half of the

cylinder was covered and the other was not, the same measurements were made. The reflection coefficient of the coated Schnorchel was found to be as much as 100% greater than that of the flat plate at the wave-length of lowest reflection.

(3) On dummy Schnorchel. These measurements, carried out on the Kohlhof, a hill near Heidelberg, were unsuccessful because it was impracticable to set up the covered and uncovered Schnorchels nearly enough in the same position.