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FILE No. XXX-36

Physikalisch-Technische Reichsanstalt

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COMBINED INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE.

REPORT ON

PHYSIKALISCH - TECHNISCHE REICHSANSTALT

June, 1945

Reported by:

R. H. RANGER, LT COL SIGNAL CORPS U.S.

on behalf of the

U.S. TECHNICAL INDUSTRIAL INTELLIGENCE COMMITTEE

CIOS Target No. 1/441

Radar

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

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TARGET

Physikalisch - Technische
Reichsanstalt

Zeulenroda/Thuringen
and now at
Heidelberg

PERSONNEL INTERVIEWED:

Dr. A. Scheibe, Director
Dr. V. Adelsberger, Assistant Director
Dr. H. Helmholz
Dr. H. Hoyer
Dr. W. Schaffeld
Dr. Kebbel

CONDITION

100% O.K.

RECOMMENDATION

It is believed that this group is an important potential aid to rehabilitating the German equivalent of the Bureau of Standards, and should be tied in to whatever Government Institution is established to look towards the economic technical rehabilitation of Germany.

GERMAN BUREAU OF STANDARDS AT ZEULENRODA

1. Magnetrons working down to 3.7 mm and measuring equipment accurate to 10^{-4} was set up very neatly in a former school at 26 Schopper Street, Zeulenroda.

2. It was by all odds the most thorough going outfit in this line that has so far been discovered in Germany.

3. Dr. Scheibe, the Director, has been ill since last October, and is unable to walk.

4. His work is very ably carried on by Drs. Adelsberger on frequency measurement, Wolfdietrich on optical equipment for decimeter application, and Helmuth Hoyer on crystal detectors.

5. Two crystal clocks have been set up with constancies of the order of 10^{-8}.

6. A very neat geared corrector on the clock work compensates for the constant difference of the crystal frequency from even divisions of seconds. It is a motor where ther armature is geared to the stator at such a gear reduction as to make the net rotation of the rotor true seconds.

7. Low frequency crystals are used, 10,000 and 1,000 cycles.

8. For comparison, frequency division rather than multiplication is used. An oscillator corresponding to the frequency to be measured is set up, and this works down through frequency division stages to the crystal frequency.

9. He is able to work right on up into centimeter waves. For the higher frequencies, he has circuits such tha the higher frequency definitely controls the lower.

10. His whole plan is to get oscillators which are extremely constant in frequency, by temperature and voltage control, as well as using very stable circuits, and then he compares the sub-harmonics of such, with the standard clock.

11. The stability of the circuits he states is of the order of 10^{-5} and the over all accuracy of the measurements even on the centimeter frequencies is of the order of 10^{-4}.

12. Complete schematic diagrams and a description of this work will be included with this report.

13. Resonant line adjustable wave meters have been made in this laboratory. They can be measured by the clock system down to 8 cm. and from there frequencies down to 3 cm

14. An entirely different approach to wave length measurement has been accomplished by Dr. Schaffeld. This consists essentially in setting up radio interferometers.

15. A large one set up in the small school auditorium, where it is relatively free from extraneous wall reflections gives accuracies of the order of 10^{-4} in relative measurements of two or more frequencies. These may again be referred back to the clock system of course.

16. Small compact interferometers have also been built which make it possible to get measurements of a high order out in the field.

17. Another interferometer setup is organized with one path such that synthetic materials may be placed in it to determine their electrical characteristics by the path change that they make with their introduction in that path.

18. He also worked with calite lenses for decimeter applications.

19. Dr. Helmuth Hoyer has specialized in crystal detectors, and has been able to work down to 3.7 mm. It is definitely a watchmakers art.

20. Dr. Koops working under Dr. Smakula at Zeiss has furnished Dr. Hoyer with new crystals of silicon "112" which designates the crystal formation. It seems that these new ones working with wolfram whiskers are twice as good as what they had before.

21. They were unable to tell whether they considered the new ones equivalent to the American, but they believed that they were of the same order by comparison with the few samples they have had of the latter.

22. One final measurement device that Dr. Schaffeld had was a grid of parallel piano wires strung vertically in a frame about 4 x 5 feet. By observing the angle that this frame had to be turned from being head on to the radiated energy, to obtain a maximum response in the wires of the screen separated by a certain distance, a geometrical determination of the wave length could be obtained.

23. The leaders of this group are now at Heidelberg with their essential equipment. They may be found through the Military Government, and are at present in the Landschule at Heidelherg.

24. Messrs. McCarthy, Townsend, and Mertz have added further observations to this.

CENTIMETER AND MILLIMETER WAVE LENGTH RADIO RECEIVERS DEVELOPED IN THE HIGH FREQUENCY LABORATORIES OF THE GERMAN REICH PHYSICO-TECHNICAL INSTITUTE

Range 23 mm. to 3.7 mm.

The receivers cover the following wave length ranges:

1. 24 mm. to 15 mm.
2. 15 mm. to 8 mm.
3. 8 mm. to 5 mm.
4. 8 mm. to 3.7 mm.

These are all of the detector type. Types 1 to 3, radio detectors of the E.D. 704 type are used. Type 4 was furnished with an air detector developed in our laboratories.

Figure 1 gives full details of the plan of construction of Type 2. A round brass tube is carried over into a rectangular conductor. The fixtures for the two detectors are located in the conudctor (a) and are screwed into the holder (b). The terminal sockets (c) are screwed into the fixture from beneath. The current bushing (d) is on springs, to avoid danger of breaking the detector. The adjustable short circuiting slide (d) serves to match the inpedance of the tubular conductor with that of the detector. Different diameter "cats whiskers" (not shown in the diagram) can be pressed into the round conductor.

Receivers 1 and 2 - apart from proportional increase in size for the partioular wave band used - are exactly similar in construction. For these two low-frequency parallel detectors are used. As the two detectors have slightly different peak tuning points together they will cover a wider band and accommodate frequency changes. Because of the screening influence of the porcelain envelope of the detector at shorter wave lengths, set 3 is only furnished with one detector. As, however, the effect of the porcelain becomes even too serious on the very short wave lengths. Set 4 was made without porcelain. This air detector, shown in Figure 2 (scale 2:1) was likewise evolved in our laboratories; its essential element is shown in Figure 3 (scale 4:1). It is only adapted to a fixed frequency on account of the rigidity of the cavity.

The sensitivity of the detector, especially in the short wave range, is as high as 50 times that of the E.D.

704 type. For checking, therefore, and for the 3.7 mm. wave lengths the air detector is decidedly to be preferred. In the experiments so far made, it has been possible, with selected detectors (E.D. 704) to get an idea of the effective wave lengths which it could deal with and to make rough measurement of these. In order not to be too restricted in wave length coverage attempts were made to use type ED 704 further reduced in size. While experiments have enabled us to improve it noticeably in this regard, still we did not succed in bringing the sensitivity up to the standard of the air detector.

Construction of the receivers 3 and 4 is the same as that of 1 and 2, apart from the aforementioned reduction in scale.

In Figure 2 a part of the rectangular conductor for set 4 is shown.

Experiments proved that below the 15 mm. wave length the cavity requires and interior coating of silver.

REPORT CONCERNING MAGNETRONS DEVELOPED IN OUR HIGH FREQUENCY LABORATORIES AND THEIR USE -- By W. Schaffeld

A. Magnetron Types

I. a) Double -slot magnetrons, fixed frequency. For lambda = 7.4 cm; 6.8 cm; 6.0 cm; 5.4 cm; 4.5 cm; 4.0 cm; 3.0 cm; 2.5 cm; and 2.0 cm.

b) Double-slot magnetrons with several discrete frequencies for the wave band lambda = 1.4 cm. to 0.37 cm.

c) Double -slot magnetrons for pulse operation at appr. 7 cm. and 4 cm.

II. Multi-slot magnetrons with fixed wave at lambda = 5.4 cm; 3.5 cm; 2.9 cm; 2.7 cm; 2.0 cm; 1.68 cm; and 1.3 cm.

III. Multi-sphere magnetrons (wheel-form) for selection operation with permanent direction (Dauerstrich) and impulse.

B. Operational Properties and Usages of the Magnetrons.

I. a) Illustration #1 shows the basic construction of the magnetrons. A band conductor of Molybdenum screened off by a short-circuit plate 'p' on one side, is shaped like a circle on the other side to form the anode. The width of the band conductor is marked 'h', the clearance is marked 'd', the thickness 'c', and the diameter of the anode tube is marked 'a', it has a length factor of e and vibrates in 3/4 lambda. A tungsten filament is used as a cathode. The whole is housed in a sealed glass container, the shape of which is shown in Illustration #1. The magnetron drawn to scale in the illustration is used for operation on the lambda = 6.8 cm. wave. For shorter wave operation the system must be reduced in proportion.

b) We are unable to come on the written details concerning valves lambda = 7.4 cm to lambda = 2 cm. The approximate data of these are: Anode voltage U_a appr. 1,700 - 2,000 volts. Filament current 3 A to 4 A according to magnetron type. The factor of magnetic field strength can be read as: lambda = $\frac{11{,}000}{H}$. The angle of the axis of the anode tube to the direction of the magnetic field is to be arranged between 5 and 10° - according to the anode load. In Illustration (table) 2a and 2b the different discrete vibrations of valves 227 and 237 with their relevent data will be found. Over and above the types dealt with several other types in the band of lambda = 1.5 cm. to lambda = 0.5 cm. were constructed and tested. They were, however, not found satisfactory in their qualities. They were constructed according to the same principles as those in Illustration #1, but with this difference that the band conductor in these types vibrated on a higher ratio than 3/4 lambda.

c) Impulse magnetrons were built on the double-slot principle for lambda appr. 7 cm. and lambda appr. 4 cm. On account of the high interior resistance of such magnetrons the anode voltages used are very high (appr. 40 Kv.). These valves were not used when testing was carried out.

II. Illustration #3 shows the construction of the double-slot magnetron built in our laboratories. Illustration #3a shows a 12-slot magnetron drawn to scale - for lambda = 3.5 cm. Similar to the double-slotted type, a 'Lecher' (a name) band conductor of molybdenum is short-circuited on one side. However, in contrast to the double-slotted type - the vibrational system consists of several segments, located on either side of the Lecher conductor and placed at such an angle that each segment fits into the other when the conductors are integrated. Illustration #3b gives an enlarged side view of the anode system, and Illustration #3c a sectional view (marked 'b'). The segments vibrate in self-resonance. The distance of the segments from the short-circuited side of the band system is $\frac{\text{lambda}}{2}$ and from the open side $\frac{5}{4}$ lambda.

A Thorium cathode is used in our laboratories as source of emission (600up) for all our slot valves. For tubes of the type used on the shorter wave lengths the segment system is likewise reduced (more than proportionally). The size of the gap separation 'd' and the segment width 'f' can be approximately calculated - on condition that the angle of transit interval is $\text{alpha}_1 = 150^\circ$ for $f \neq d$, and $\text{alpha}_2 = 45^\circ$ for 'd'. Likewise, the magnetic field strength can be reckoned by the formula:

$$H = \frac{1}{\frac{Z \times \text{lambda}}{a} - \frac{r_k}{b}} \sqrt{U_a}$$

In this 'Z' stands for the number of slots; r_k the cathode radius; and U_a the anode voltage, 'a' and '6' are constants. In the case of most magnetrons, 'a' approximately equals 4 x 10^4 and 'b' approximately equals 4.5. In Tables 4a and 4b are given the operating characteristics and the most important dimensional data for these tubes.

III. Illustration #5 shows the construction of a 'wheel-form' type. The system itself is of copper. All odd segments, segments 1, 3, 5 etc. are linked electrically on one side by a coupling ring, and all even segments are shorted similarly on the other side. An indirectly heated Barium cathode is used as emitter. Neutralization of the high frequency output takes place inductively with the assistance of a concentric 'Lecher' system. The vibrational or 'swing' system of such a tube is capable of several degrees of 'hunting'. Operational data regarding the magnetrons shown in Illustration #5 are:

Lambda = 8.2 cm; U_a approximately 1,000 volts; magnetic field strength H = 500 - 650 Oerst.
Lambda = 6.5 cm; u_a = 10 Kv-18 Kv; magnetic field strength H = 1,500 - 2,000 Oerst.

Experiments with shorter wave 'wheel' magnetrons were not completed.

The double-slot magnetrons are not very stable in their behavior on account of return heat phenomena. Auxiliary devices for stabilizing are not very trustworthy and are a bit clumsy. For this reason, all double-slot magnetrons produced in our laboratories are operated on alternating current. By this device, and with the help of a resistance bias, about 20,000 ohms in the anode load, stable vibratory conditions and long life of the magnetrons are attained. The discharge of the high frequency output takes place, as illustrated in Illustration #6 by means of a tubular conductor.

In order to achieve a high degree of anode discharge, approximately 100-150 W at lamba = 6.8 cm, the anode load for these magnetrons must be about 2 Kvs., on account of their high interior resistance. With the use of alternating current for magnetrons lambda = 6.8 cm. magnetron peak tensions of up to 10 watts can be achieved but for magnetrons lambda = 3 cm. the useful peak delivery is only 0.25 watts. For those tests made by us on the shortest waves (lambda = 3.7 cm.) the estimated high frequency output should lie between 10^{-4} and 10^{-5} watts. For reception of waves from 8 mm. to 3.7 mm. a special type of receiver apparatus must be used, which we describe in a short report. We have carried out tests with these valves regarding detector quality, frequency, consistency of materials, diffusion, reflection, etc. Multi-slot magnetrons are much more stable in their behavior than the two-slot type. Return heat effects are very much less and are of little significance for the stability of the vibration on account of the great independence of the cathode emission from the vibration process. The anode tension and the magnetic field strength are much less dependent so far as stability is concerned than are the double-slot type. Dependence, however, becomes more pronounced the slighter the ratio of vibration.

Frequency stability of a transmitter with an 18-slot magnetron for lambda = 2.04 cm. was tested for an hour with stable operational tension and permanent magnets at, at least, 5×10^{-5} of operational frequency. The frequency stability of the corresponding 2-slot magnetron is inferior by more than one order of magnitude.

As a result of the much slighter interior resistance high outputs of anode loss can be produced with considerably lesser anode loads, approximately 300 v - 500 v. The greatest was 1 watt for lambda = 3 cm., and from 0.25 to 0.5 watts for several magnetrons which were constructed later on.

Such diffusion might possible be traceable to unsymetrical build. Outputs have not been measured on shorter wave lengths, but at a rough estimate high frequency output for the earliest magnetic field valves developed (later forms are not yet forthcoming) lies at lambda = 1.3 cm. 10 milliwatts.

Tests regarding modulational capacity were carried out on the magnetic field magnetrons for lambda = 2 cm. In contrast to the two-slot type this form of magnetron could be modulated down to 70% on low frequency without any appreciable chatter factor. In this case, the low frequency voltage was about a tenth of the anode direct voltage. Corresponding tests were made with the double-slot magnetrons on a wave length of lambda = 6.8 cm. Clear modulations of amplitude could only be achieved through the medium of rectified absorbing layers (gaseous conduction lamps) which, however, exclude any high frequency modulation.

Further experiments were directed towards constructing magnetrons with a much larger number of slots, in order to diminish the necessary diminsions of the magnetic field strength. A 36-slot magnetron was built with a cavity resonator with the following characteristics:

Lambda	H Oerst.	U_a
6	300	140
9	150	appr. 60

The aim of this further development was to replace the exterior magnetic field by the interior one of a specially evolved heat filament on the cathode. Research work on this has not yet been completed but the prospects are not unfavorable.

Multi-slot magnetrons were subjected to the same tests as were the two-slot type, and should ultimately do away altogether with the two-slot types after they have been brought to a higher state of perfection as a result of their greater stability and the greater accuracy in the tests attained thereby.

The aim of the work carried out on multi-sphere "wheel" magnetrons was finally to be able to utilize the same type as oscillator and impulse generator by having several searching grades in the self-resonance of any given radius of vibration. With this, as already mentioned, the magnetic field for long length usage would be located in the heat conductance of the valve itself. This would be achieved through adapting the shape of the heat filament and in certain circumstances by the use of an additional coil in the heat conductor, and the magnetic field for impulse operation would be created through a system of coils on the outside. In this way, the impulse wave for return ray work would be overlaid and received by a suitable displacement of the harmonic vibration adapted to the intermediate frequency. The stability of frequency which might be expected in the whole system would be much greater than it would be with the use of separated manipulation valves and oscillators. The width of the channel in the receiver could be made as narrow as the transmission of an impulse of the desired time and form would allow.

The experiments are not yet completed, and the prospects, as we said already, are favorable.

N.B. Three pages of tables in the German original have not been copied for want of time and pressure of work.

TARGET:

PHYSICO-TECHNICAL REICHSANSTALT
Zeulenroda, Germany
(Report Regarding Quartz Crystal Clocks & Frequency Measuring Equipment at the High-Frequency Laboratories - By U. Adelsberger)

QUARTZ CRYSTAL CLOCKS AND THEIR FURTHER DEVELOPMENT

I. Summary - In the Physico-Technical Institute, A. Scheibe and U. Adelsberger have been occupied since 1931 with the development and improvement of the quartz crystal clock, their efforts having been directed towards diminishing the time-error, greater dependability for longer periods, and towards the elimination of sources of change.

These clocks have attained the following frequency accuracies: Constant to ± 5×10^{-8} per year as a monthly average accuracy of single-second contact in the synchronizing motor, 2×10^{-4}, normal frequencies for testing purposes with an accuracy of approximately 2×10^{-8} per year with a variation from the average value between 0 and 2×10^{-5} frequency constancy of the oscillator for several hours $1 \times 5 \times 10^{-9}$.

II. Controlled Oscillator: The quarts crystal has a natural period of 60 Kcs. and is held at the nodes by springs.

It is placed in a vacuum or alternatively in H_2 under a pressure of 17 mm. With a length of 91 mm. in the direction of the electrical axis and width of 11 mm. it has a zero temperature coefficient at approximately 36°C. In order to eliminate the effect of change with tubes the control tube RE 134 is operated at 2.7 v filament voltage and 10 v. anode voltage. Adjustment is carried out by a quartz insulated grid-anode and grid-cathode condensors, which have fine and coars adjustment. The grid-leak resistance is 20 to 50 megohms.

The interior compartment has a thermostat at 36°C with a mercury contact thermometer sensitive to one-thousandth of a degree Centigrade and has a heat insulation composed of an eider-down layer 4 cm. deep between a layer of copper and one of aluminum both one centimeter in thickness. Near the head end of the thermostat is located the vacuum tube chamber, next to the leak-resistance and parallel capacities. Here the exterior thermometer of 30°C takes over the task of regulating the temperature. The regulation of these new types of clocks is relatively insensitive to brief stoppages, whereas such stoppages, in the earlier forms, led to marked disturbance of accuracy.

III. <u>Frequency Division</u> - (See Figure #2). For operation of the 100 pole synchronizing motor, frequency-dividing stages of 10 and 1 kc. and 250 cycles are obtained from a three-stage amplifier. To eliminate back coupling a non-resonant repeater (2 x RE134) is interposed before the synchronization motor. Furthermore, the rather large jump between stages 10 and 1 is improved between 10 and 1 kc. by using a two tube parallel arrangement in the 1 kc. stage. The control voltage is not taken off inductively but by means of a capacitative voltage divider. It consists of two series capacities connected across the anode tuning condensor. These are of 50 and 100 pF, and their mid-point is directly connected to the grid of the 1 kc. stage.

The critical affect caused by tube change was eliminated in the newer types of clock by reducing the anode voltage through a high series resistance. The result is that the interlocking of the stages could be depended upon for a period of at least a year without tuning. The series resistance of about 40,000 ohms makes alterations of the interior resistance of the tube of no consequence automatically; the operational voltage for the anode is still only about 20 volts, the anode current averages about 0.5

milliamps and the grid current about 0.2 milliamps per stage. A limit is set to the latter through a grid-circuit arrangement of a fixed resistance of approximately 50 k. ohms with parallel capacity which automatically creates a high negative grid bias and also by a fixed resistance in series directly to the grid of the tube of 1 - 8 k. ohms. This improves synchronization by improving the wave form. In this way, the dependence of locking in on the filament voltage of the divider stages was eliminated, something which otherwise would have occurred with the slightest changes. In the present improved form of the quartz clock the filament voltage of all the divider stages can be altered from 2.9 to 4.4 volts, without the synchronism of the stages falling out or the motor stopping.

IV. The Synchronous Motor. Improvements in this are primarily the greater safety factor with prolonged operation in the bearings and contacts. Two motors were furnished with phase shifting couplings which enabled the clock to be adjusted by fixed amounts as determined by its natural rate without stopping the clock. Discreet corrections could in this way be made ahead of time in order to avoid corrections later on. In the case of a clock with a relatively large permanent correction factor the motor was provided with an intermediate gear change placed between rotor and a slowly advanced or retarded stator running on ball-bearings. By means of this automatic adjustment of the stator, the rotor runs true so as to enable exactly correct seconds to be given our. By means of a 10 second contact on this motor, a special wall clock was synchronously driven so that the time recorded by the quartz chronometer could be read at a glance.

V. Reliability with Long Period Operation of the Quartz Crystal Clock.

This becomes an important factor with the recent increases in accuracy of quartz crystal clocks over protracted periods, and also is important for determing the accuracy of measurements made by reference to the normal rates of quartz crystal clocks. For scientific uses, such as questions regarding the variations in terrestrial rotation, and preservation of a time unit and the second in the standards set for quartz crystal clocks, such points as the qualities achieved in the overall behavior over long periods of working are of great significance.

VI. Literature on the Subject - "Technical considerations of quartz crystal clocks at the Reich's Physico-Technical Institute. Hochfrequenztechnik u. Elektroakustic "' 43; 37 - 47, 1934, by A. Scheibe & U. Adelberger. "Confirmation of Variations in the Astronomical Diurnal Period" (See Physikalische Zeitschrift 37, 185 and 415, 1936).

GENERAL PLANT (ILLUSTRATION 1) AND ACCURACIES OBTAINED IN MEASUREMENTS MADE WITH BEAT FREQUENCIES AND SOUND FREQUENCIES ON HIGH AND ULTRA-HIGH FREQUENCIES.

I. Summary - The quartz crystal clocks produced by the Reich's Anstalt give a normal frequency of 10 and 1 kcs. brought by repeater and filter to the frequency divider setup for testing. Here the difference or beat frequency is brought into relationship with the frequency to be measured which is reduced to a definite sub-multiple of its original frequency (Fx). The total dividing factor is known as m/n (these are integers). For the exact counting of the beat frequency in the output of the frequency divider, the quartz clocks furnish one and ten second contacts as time signals for the high-speed moving coil, and likewise 250 cycles for the synchronous drive of the motor which advances the recording tape at a constant speed of from 100 to 300 mm/s selected as desired. The accuracy of stroke on the tape band amounts to approximately 0.2 mm. or 2 x 10^{-4}s in time, so that within a time interval of 20 s. beat frequencies up to 50 cycles can be determined to $2x10^{-5}$ of their true value. Furthermore, the 250 cycles of the clock also drive an electric stop watch or clock having a synchronous motor, so that only the personal reaction time enters into the measurement of slow beats.

II. Dividing Factor. If the division factor is greater than 1 - i.e., if the frequency to be measured, fx, is greater than 1 kc. then the frequency x can be connected directly into the dividing set. For this, the unnecessary stages which have frequencies higher than fx are cut out. On the other hand if fx is smaller than 1 kc., or in other words, when m/n is less than 1 the tone-frequency multiplier is used to create a suitable testing frequency above 1 kc. (See Figure #4).

What we have called a high frequency multiplier serves also to create a more suitable frequency for testint when fx is at an unfavorable value for exact measurement of beat as compared with the normal frequencies at our disposal. In this case, fx is first connected to the multiplier. The number of different divider factors m/n which may be chosen is therby greatly increased.

III. Accuracy of Measurement by Frequency Division, Up to 5 x 10^{-7} - (See Figure #3) All frequency measurements, so far as accuracy and required measuring time are concerned depend on the position of the unknown frequency x with respect to the controlled frequency spectrum, or in other words, on the value of the ration m/n k cycles. In twenty seconds and with frequencies under 5 x 10^{-7} cycles accuracies of the order of 10^{-6} are usually to be expected using the stop watch to count the beats. With the use of the recorder 10^{-7} can be attained. Greater measuring intervals make it possible to take full advantage of the clock accuracy - namely 2 x 10^{-8}.

IV. Accuracy of Measurement with Frequency Division up to 10^{-9} Cycles. For measurement of frequencies above 5 x 10^{-7}, or 6 meters wave length, a special lower frequency generator is locked in on one of its harmonics and then this generator is again measured by the frequency division method. An oscillator at 50 Mc. can, for instance, be locked in to a frequency in the neighborhood of 1,000 Mc = 32 cm., and the locking into synchronizm is audible. Since the generators used are constant to 10^{-5} of their frequency, we can consider the possible accuracy as approaching a limit of 2 x 10^{-5}. If we use generators more constant than that given, correspondingly greater measurement accuracies can be achieved.

V. Measuring Procedure with Harmonic Generators Up to 3 x 5 x 10^{-9} Magacycles (See Figure V) - If sensitive resonant cavity wave meters are available, then the harmonics of a 32 cm. oscillator can be used (i.e. 16, 11 and 8 cm. harmonics) for calibration with accuracies of the same order 2 x 10^{-5}. Likewise a 40 cm. oscillator may be used with the harmonics at 20, 13 and 10 cm. As each of the above oscillators is continuously variable, there will be a very complete coverage below frequencies of 32 cm. As the harmonic generator is continuously variable from about 80 to 150 cm. with a variable capacitor this takes care of harmonics down to 10 cm. Likewise, another oscillator is available from 23.5 to 29 cm. which carries the harmonics down to 8.5 cm.

VI. Measuring Procedure with Resonant Cavity Meters Up to 10^{-10} cycles (See Figure #6) - For measurement of still shorter waves with the clock a special extrapolation process is used aided by 2955 and 2960 which reach a degree of accuracy of approximately 3 x 10^{-4}. Calibration curves shown in Figure #9 are practically straight and independent of frequency. It was possible in our testing to verify the final values of the quartz crystal clock down to 2.7 cm. wave lengths or approximately 10^{-10} cycles using a Michelson type of interferometer.

VII. Checking with an Interferometer - Up to 4 x 10^{-10} Cycles. We had at our disposal standard cavity meters for use between 3 and 0.8 cms. which could be compared with the interferometer. The degree of accuracy thus attained is of the order of one in a thousand. Experiments with special cavity wave meters for still higher frequencies have been started, the first operated at 0.6 cm. The stub in this equipment has a diameter of 1 mm., the exterior tube is rectangular with a cross section of 1.8 cm. x 1.8 cm., 80 mm. in length made of silver, highly polished plates. Using the large Michelson interferometer the measuring line is 300 meters long, the relative accuracy, with the use of a Zeiss precision lead screws for moving the plates about 1 x 10^{-4}. The middle plate of the interferometer which is semi-transparent to electrical waves, consists of a strong mirror-glass plate with a surface of approximately 1/4 sq. meter, and alternatively 5 or 3 mm. thick. To do away with stray reflections, it is set up in a large room, adjustments are observed optically. For detection, sensitive horn receiver with detector, amplifier, and oscillograph is used.

THE FREQUENCY DIVIDER TEST EQUIPMENT OF THE PHYS. TECH. REICHSANSTALT (See Figure 1)

I. General - The frequency testing apparatus used has a range of from 1 to 50,000 kilocycles and fully exploits the accuracy of the quartz crystal clock. For dividing the fx frequency, five divider stages are available, which are turned on and synchronized with fx. The new frequency which is then set up and which is of course controlled by fx and is between 1 and 10 kcs. is compared with one or the other of the suitable normal frequencies of the quartz clock by noting the beat frequency. To determine whether the unknown frequency is above or below the standard, it is best to compare the beat measurements, if only for greater exactness, with first one and then the other of two distinct frequencies from two quartz clocks. With precision measurement the total degree of accuracy comes to 2 x 10^{-8} of the frequency value.

II. Construction - The frequency division equipment consists of two parts - one at audio frequency, and the other at high frequency. Each of these is furnished with a three-stage low frequency amplifier and a loud speaker to allow the synchronism of whatever stage is being dealth with to be heard by ear. Switching off and on of each individual unit is accomplished by a multipolar change-over switch which puts the anode voltage on the unit used. In this way, the high frequency connections to the other units are neither interrupted nor disturbed.

In the audio frequency section, two quartz clock frequency dividers of 10 and 1 kc. are connected to a beat registering apparatus to which the normal frequencies of 10 and 1 kcs of two quartx clocks are supplied through special change-over switches with indicating lights which preclude error. The beat frequency can be brought out at the output terminals in either sine or rectangular wave form in case simple estimate of the beat with a stop watch is either not possible or not sufficiently accurate. If this is the case, pulse measuring equipment with built-in stop watch and recorder synchronized by the quartz clock frequency of 250 kcs. is available. The high frequency divider works in three divider steps - for 2,000, 500, and 100 kcs., which are used when measurements are to be made for various corresponding values of fx. These steps are designed to have a very distorted wave form which aids in synchronizing the harmonics. It has been mentioned that in each of the steps from two to three RE 134 valves must be used in parallel in order to match the internal impedance to the load which diminishes at high frequencies.

III. <u>Properties</u> - Each of the frequency divider stages has reactive coupled tube oscillators tunable within narrow limits by a circuit such as is shown in Figure #2. They are supplied with loud-speaker tubes RE 134 - load 10%, output 2 Ma/V. The operating characteristics are filament voltage - 3.5 volts, anode voltage supply 100 volts, anode voltage (according to stage) from 3 to 6 milliamperes. A good frequency divider has the following characteristics - high anode tuning, very strong inductive back coupling, an automatically high negative grid bias potential realized by a grid capacity coupling with parallel resistance of from 3,000 to 2,000 ohms. For this reason, as large a size of air corps inductance as is feasible is used. In the best type of multiplier the harmonics carry up to the 200th. If the division factor, that is to say, the relationship of fx to the frequency of the highest frequency divider stage used m/n approximates a fraction of simple whole numbers, good synchronization is achieved. M x n should be less than about 150. The auditory note coupled by small capacities may be tuned to 3 x fx to 7 x fx. For example, m/n = 1 1/9 = 10/9; m x n = 90: m/n = 201/2 = 4 1/2: m x n = 82.

FREQUENCY MULTIPLICATION BY RECTIFIERS

I. Further Points Requiring Development. Greater ease of calibration processes in the realm of high frequencies by diminution of the frequent changes in oscillator and frequency. Extension of the range of measurement of the frequency divider arrangement down to very short waves so that precision measurements can be there undertaken with the quartz clock. A lessening of undesired sensitivity to hand capacity and vibration in testing and long duration measurements. The creation of a uniform distortion spectrum for the purposes of full coverage.

II. Further Results Achieved - Increase in the number of frequency divider stages improves synchronization when the frequencies involved are not such as are related by whole numbers. It also increases the exactness in the measurement of natural periods by luminous resonators. Likewise it enables longer waves to be used with relation to the short wave lengths with higher natural oscillations and much higher constancy. If the ratio of the two frequencies approaches a fraction m/n, in which m and n are whole numbers, then the extent of the multiplication which we may use which we shall designate as k to k x m/n. If k goes into n, p times then the possible multiplication factor is increased to m/p, and thus is brought nearer to an integer ratio, inasmuch as p is smaller than n. This results in an appreciably improved synchronizing force. When luminous resonators are used for the purposes of measurement, a much finer division of a longer basic wave ensues as with the aid of the multiplied frequency - the luminous quartz can still be directly excited. This energy is in fact at our disposal and it transpires that as the frequency constancy of the long wave oscillators is so much better, athe accuracy in the measurement is greatly favorably influenced.

Short wave resonant circuits can be produced with a very high constancy in which a material such as "Calit" or similar ceramic is used. Coating and windings are mostly baked right in the ceramic as silver. If the multiplied frequency is connected to a circuit of this sort, the fundamental frequency can in this way be as exactly measured as the circuit warrants.

III. Frequency Multiplier - This consists of a powerful double diode tube (RGN 2004) - a center tapped coupling coil, and seven output circuits with a rotary condensor for the short waves produced(Figure #3) the range of the output circuit is 2,000 to 2 m wave length. With sinusoidal input voltage the tube output is: I = 2/K (cos. x/1 x 3 + cos. 4 x/ 3x5 + cos. 6 x/ 5 x 7 + ...). Because of the very gradual decrease with the order of the harmonics, because of the presence of the direct current a notable rise in the amount of energy available in the short waves is accomplished. This is carried out with variable resistance and a condensor connected in parallel, such that with increased resistance a counter e.m.f. is created. The result is in the deformation of the sine oscillations, gaps are created in the basic impulses of the order of one or more harmonic wave lengths (phase angle).

Only a filament voltage of 4 volts is required for operation. The anode input voltage is furnished by the 10 W test oscillator (appr. 120 volts).

The input circuit can be connected to only one side of the rectifier, so as to produce the odd harmonics. An audio frequency multiplier is available giving harmonics from 800 to 8,000 cycles, which may be connected in ahead of the frequency dividing unit.

HARMONIC WAVE TRANSMITTER FOR THE MEASUREMENT OF VERY HIGH FREQUENCIES.

I. Summary

a. Aim - Extending the range of application of the quartz clock. Calibration of wave meter by harmonics.

b. Construction - A triode is excited with two or even only one lambda/4 oscillators in such a way that with very short cathode leads to the tube strong over modulation sets in up to the point of being pulse operation.

c. Results - In the meter and decimeter ranges the harmonics are so strong that wave meters immediately register, and synchronization takes place for the through short wave oscillators. In the centimeter wave band the sound can be heard in the headphones, since the constancy of the harmonic generator is greater than 10^{-5}. Even the fourteenth harmonic can be used for measurement.

II. The harmonic generators (Figures #4 & #5) are oscillators variable over a wide frequency range and with very high constancy for use with direct or alternating current. They were used in the band from 23 to 940 cm. wave lengths for the fundamental, and this means that the harmonics used reached from 6 to 470 cms. If 50 to 10,000 cycles is used as plate supply, the harmonic content may be raised further.

III. Tuning is carried out by means of a rotary condensor placed close to the tube (LD 1, or LD 5 for the longer waves). It is advisable to use symmetrical rotary condensors such as shown in Figure #6 with screening and short connections. In the case of single circuit oscillators which connects a tube to a stub resonator, rough and fine tuning can be carried out in turn by moving the interior stub and a wire placed at its side.

IV. This setup with each change of wave length, higher distortion and higher constancy is of great advantage in measurements in the decimeter and centimeter ranges. With a filter of a special type inserted a filtered harmonic tuning can be realized. The filter likewise consists of a lambda/4 resonators with capacitative loop couplings on each side to earth (Figure #7).

The frequency spectrum has no gaps. By swinging over the band by the aid of the regulator an intensity curve in the form of a sine wave is obtained. This is explained by the absence of any chokes in the conductors.

V. A special adaptation of this oscillator makes possible directly controlled frequency division - satisfactory synchronization with the quartz clock can be made.

DESCRIPTION OF CONSTRUCTION OF THE HARMONIC OSCILLATORS USED AT THE REICHSANSTALT

I. Ksl - Two concentric conductors (closed at one end) of 20 cm. length, 46 mm. exterior and 3 mm. interior diameter are connected to rotary air condensors of from 10 to 100 cm. capacity. This resonator is connected in to a tube LD 5 between anode and grid by the aid of a strap conductor 12 cm. in length, 10 mm. wide, and with a clearance of 8mm. The tube is placed close to the open end of the conductors so that the cathode can be linked along the shortest path with the central point of two series capacities of 2,000 pF each which loop over the exterior tube of the conductors at their open ends. The condensor on the grid side of 2,000 pF is connected to regulating resistance through a hollow conductor. This resistance is of 3,000 ohms while the hollow conductors of the condensor on the anode side lead to two terminals to which the anode voltage is applied.

The band covered by this oscillator is from 5 to 9 meters. The rotary air condensor for capacitive coupling is connected between anode and cathode, and there is also a replacable fixed condensor of from 25 to 200 cm. between cathode and grid. The oscillator furnishes strong harmonics for calibration purposes. These are marked directly on the wave meter down to less than 1 meter. It is possible to synchronize the oscillator to another of 40 or 32 cm. wave length. It is possible to hear synchronization take place by a three stage low frequency amplifier at the input of which a short uni-directional serial is set up. However, this calls for skill and practice. To make the task easier, it can be said that when synchronization takes place between the two oscillators a peculiar echoing sound (Microphone effect) is heard in the headphones if anyone in the room speaks or the table is rapped slightly.

The energy of the fundamental is taken from the output terminals of the oscillator through a flexible concentric cable 5 mm. long to the frequency dividing unit, 2,000 kcs. stage, for the purposes of synchronization and further division down to the normal frequencies of 1 to 10 cycles. The output voltage at KS 1 is taken through a wire loop which is coupled at the closed end of the conductor linked to the anode of the tube magnetic ally with the supply lines aroung the interior conductor. In the case of the harmonic wave oscillator KS 1 very many different divisional possibilities exist (m/n).

II. <u>UKS 6</u> (Figure #4) The conductors are 8 cm. long, 32 mm. exterior and 18 mm. interior diameter. The tube used is the LD 1 (special short wave triode) its tuning range is from 80 to 150 cms. with symmetrical twin rotary condensors with very short leads to anode and grid with a capacity of from 1.5 to 10 cms. The harmonic is in the neighborhood of 11 cms.

The type of circuit is the same as in KS 1 with the exception that both series capacities of 2,000 pF are replaced by a small piece of brass shaped to both sides; and surrounds the two conductor tubes near their open ends like a polar magnet and acts as cathode point in the circuit. With the use of a layer of triacetate foil 0.07 in thickness on both sides, effectively double the capacity is realized. A more effective type of harmonic oscillator for the shorter decimeter waves is the single resonator. It only has a lambda/4 dipole like that of a standard wave meter. Its dimensions are: exterior diameter of tube 44 mms., interior 22 mms., with centimeter scale divisions 30 cm. in length. Two coupling loops which extend 18 mms. in an exial direction along the interior conductor and are placed as close as possible to the latter and are fixed at their outer ends by means of surface condensors to the outside walls. They lead, near the middle, to the grid and anode connections of a short wave triode. The cathode of this tube is connected by the shortest path possible with the outer walls of the tube. Owing to the magnetic or reactive coupling of the interior conductor and the definite reference potential of the cathode, a very tight coupling takes place which causes strong distortion. While the grid surface condensor is bridged by an adjustable resistance to create a suitable initial negative grid bias, the voltage for supplying the anode is led to the anode surface condensor directly, that is to say, without the use of a choke. It passes through a hollow double conductor. In the opposite wall of the tube a loop is inserted to draw off the high frequency energy.

Generally speaking, this oscillator possesses two modes of vibration, corresponding to an excitation of a lambda/4 or 3 lambde/4 for the conductors used. The wave lengths of both these, therefore, differ by the factor.

III. If the interior conductor, as in the case described, is comparatively large then the multiplication factor as a result of the influence of the coupling of the tubes is very slight. It can be reckoned as four times the value of the interior conductor. The first oscillating mode comes into play when the interior conductor is slowly pushed forward and its forward end is over the coupling loop. The second made starts somewhere about the triple value point. It is not always possible to excite both modes. This harmonic oscillator has a range of from 31 to 35 cms. and from 80 to 115 cms. wave length.

IV. DS 4. This is similar in construction to the above. Its dimensions are: diameter of exterior tubes 52 mms., interior 22 mms, length about 35 cms. Both the coupling loops have a total length in both axial directions of approximately 65 mms. The oscillating mades of this oscillator lie somewhere in the neighborhood of 36 to 41 and 90 to 130 cms. wave lengths.

V. DS 2. Special type of construction for ultra-short waves. The diameter of the exterior of the tubes is 18 mms. Both the coupling loops consist of metal strips 6 x 1 mm. and run for a length of 12 mm. in a parallel direction with the interior conductor. They are bridged over to the tubes by a miniature porcelain condensor of 2 pF. The range extends from 23.5 to 28.5 cms.

THE ROD OR STANDARD WAVE METER OF THE REICHSANSTALT

I. Summary - Long concentric tubular conductors with several resonance points. A rod is pushed into a hollow tube (spindle drive with a double nut with a certain amount of play, and a lever operated by hand) in which the length of the rod is shown on a dial divided up into units of 1/10th mms. Nodal gaps are not to be found and in the precision form of construction the total error in measurement is limited to 2×10^{-4}, down to wave lengths of approximately 8 cms. and 4×10^{-4} at 1.5 cms. Additional tubes which may be inserted extend the range of measurement and enable the "order-figure" of the resonant points to be determined.

II. In this way, it is also possible to construct single tube wave meters which when the long rod is used attain an accuracy of 2×10^{-4} for 7 cm. wave length and of 3×10^{-4} for 2.5 cm. These wave meters possess an almost straight line curve of correction as a function of the wave length. With their aid, it was possible after calibration of the longer waves to carry by extrapolation of the quartz clock method to 8 to 2.5 cms. Checking the wave length with the interferometer showed the correctness of the wave lengths thus extrapolated to be of the order of 5×10^{-4}, when the form of the correction curve for these ultra-short waves was taken from a similar type of wave meter with measurements three times as great. This was done by extending the short lines in the scale, 3:1 (See Figure #9).

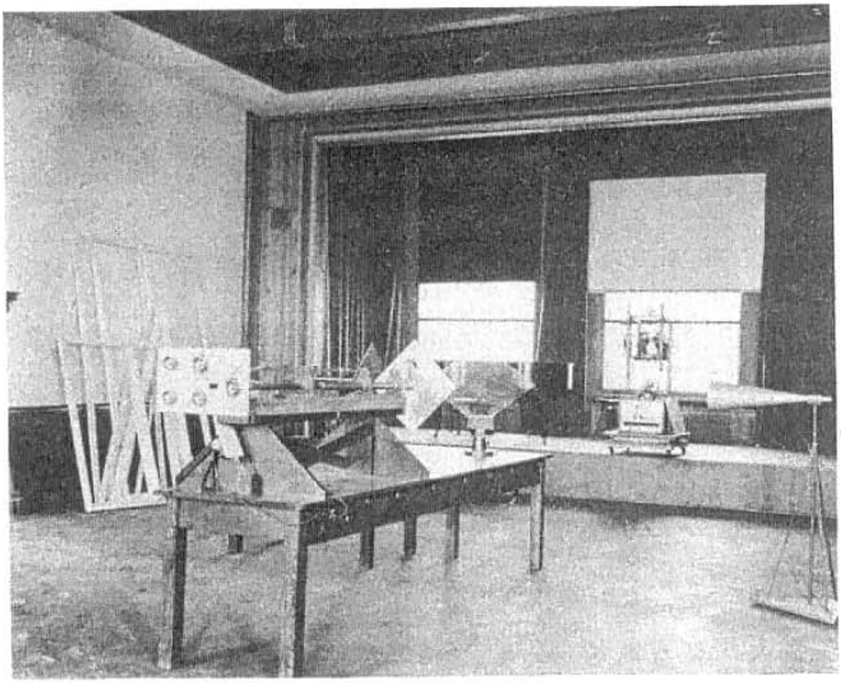
III. Contact between movable interior conductor and the hollow tube is not flexible and is not to be depended on for long periods. Only the interior conductor is silver which means that the attenuation comes down to half the initial value. The interior diameter of this conductor is accurate to 1/100 mms.

IV. It is of the greatest importance that in the single tube wave meter the apparatus is built in such a way that the hollow interior conductor is extended into the measuring chamber, inasmuch as the spindle inside it ends in a smooth guiding piece.

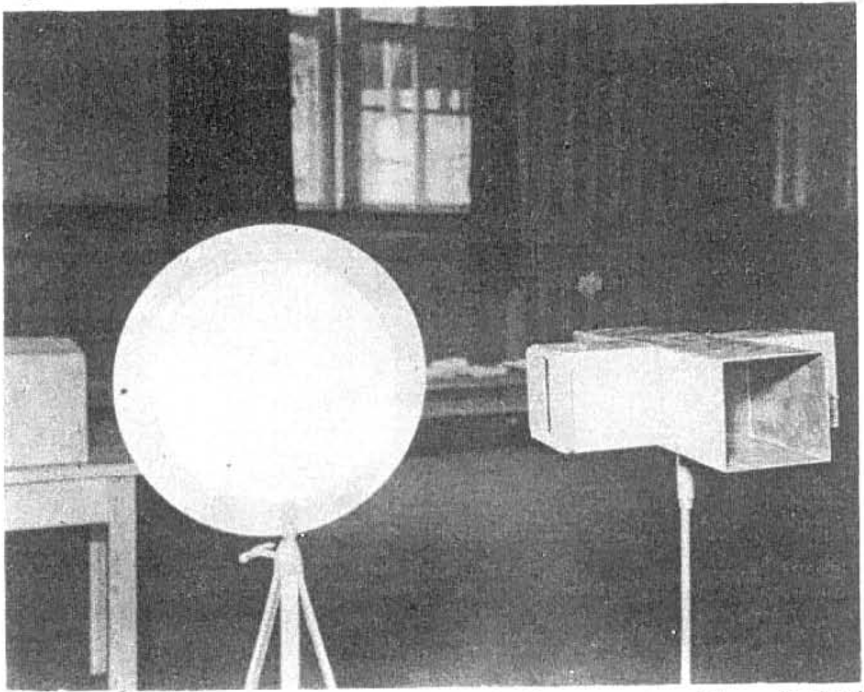
V. It was not possible to follow this construction in the type used for the ultra-short waves. In the latter, the spindle and the rod are arranged behind one another with means of a flexible coupling. Inasmuch as this increases attenuation, the necessary correcture also increases. The accuracy of measurement attained in the region of 0.8 cm. is about 5 x.10-4.

VI. Since rod wave meters are portable, they can be set up on a wooden platform free of stays or guys. For this, it is usually sufficient to have two points of support.

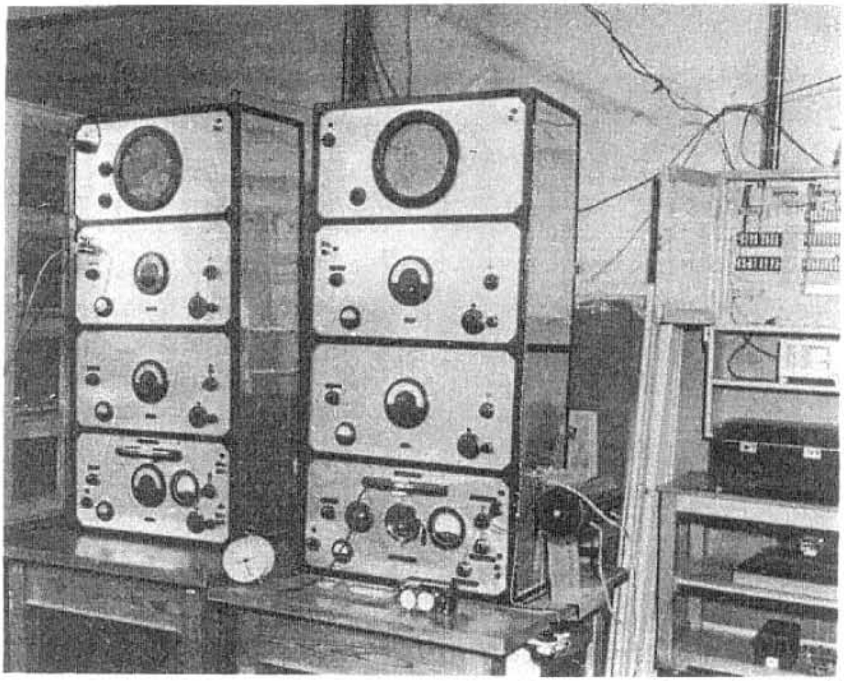
VII. Detector and galvanometer of 2 x 10^{-7} amperes serve to indicate the resonance points. These meters are so highly sensitive that even the weakest harmonics are clearly indicated. For coupling to the oscillator simple metal strips are sufficient - metal or wire hooks will also do, and broadband knobs are also used some times. In the hollow tube, quite close to its wall, two very small inductive coupling loops are placed diametrically opposite to each other, and the coupling attenuation is made equal to that of the natural attenuation of the conductor. The total range of the single tube meter is one octave less than that of the rod wave meter which is about 4 octaves.



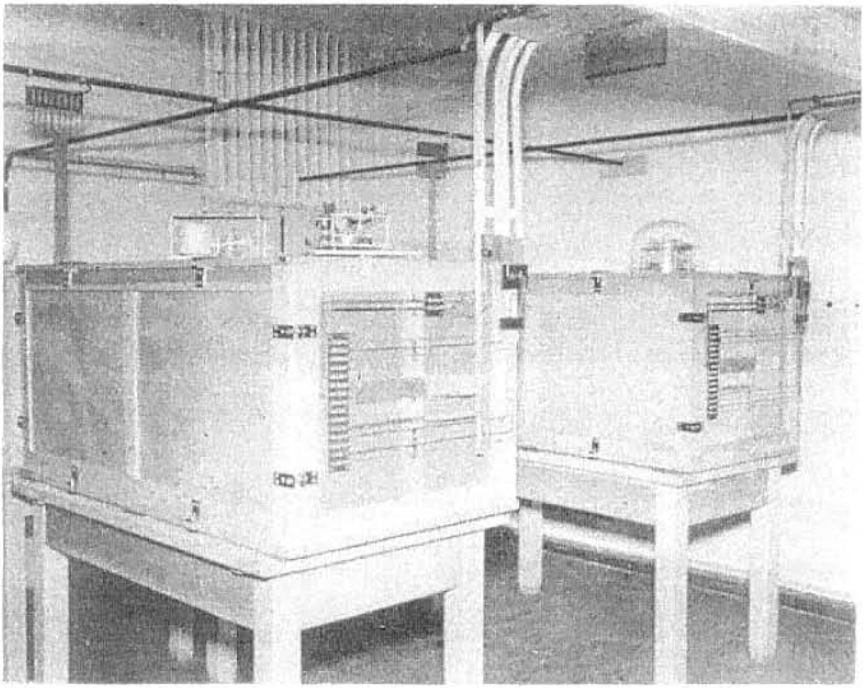
Michelson Interferometer applied to electric waves, generator in rear. Half reflector in center, forwarding waves to complete reflectors, which in turn combine to transmit to horn pick-up right. Adjustments at left move center reflectors accurately and produce interferances and co-incidences as relative path lengths are changed.



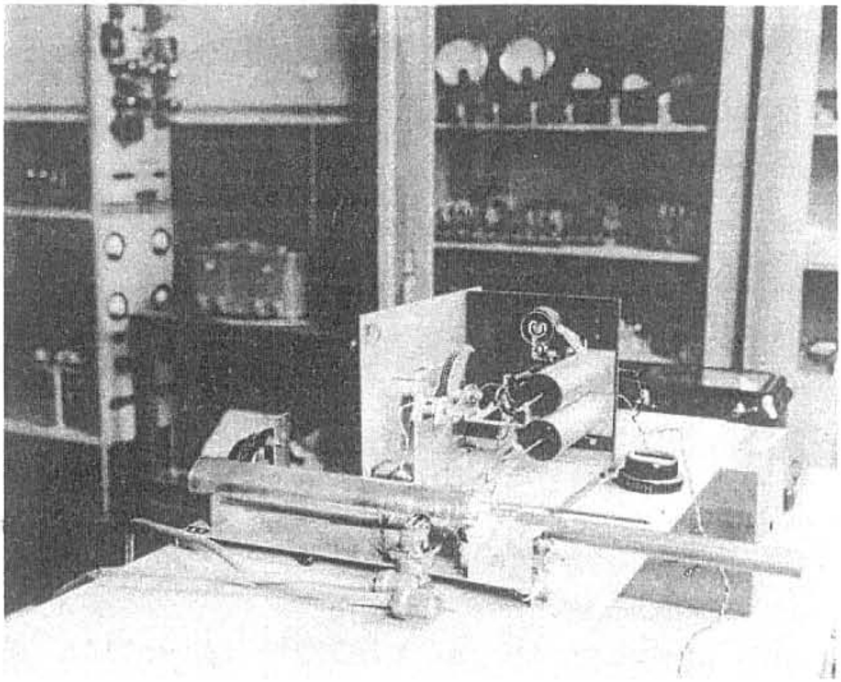
Left - Sample of cait disk placed in one path of interferometer to determine change in apparent path length giving measure of refraction. Right - Light portable interferometer for field use.



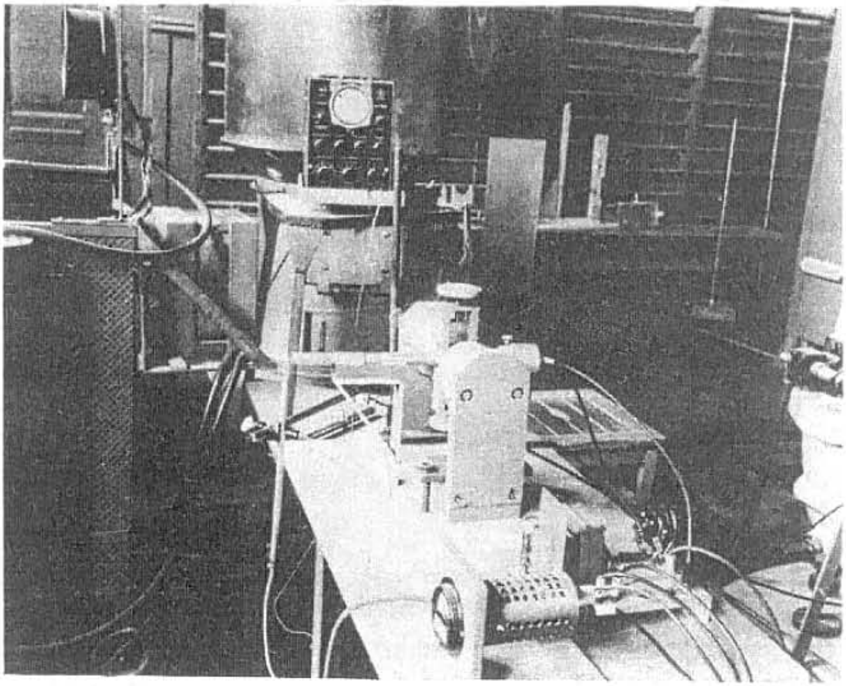
Two Multivibrators working off clocks. Note stop-clock in foreground. Also very neat double dial stop watch. Loud speakers to note beats at top.



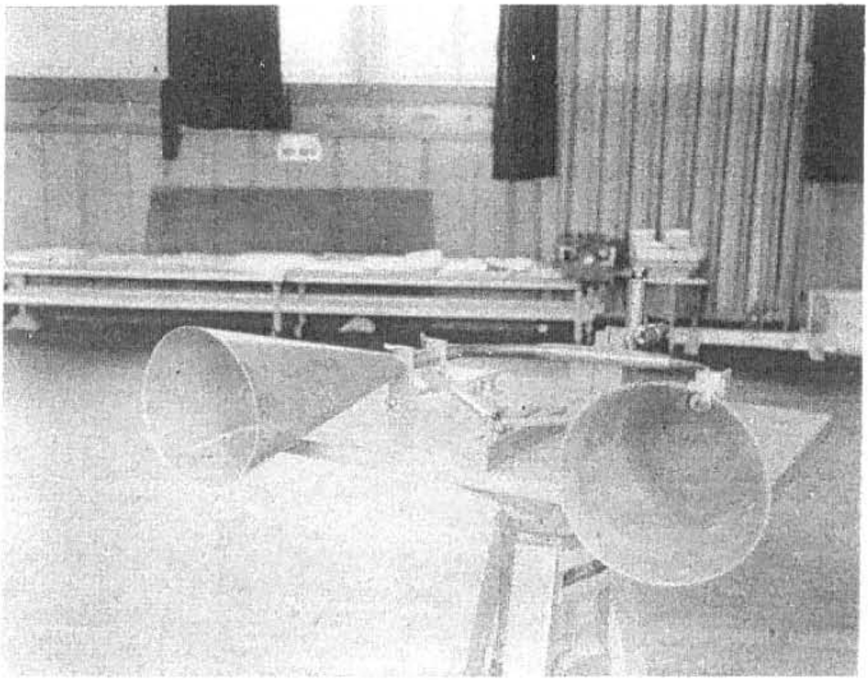
Two temperature controlled crystal oscillators set up in basement. Synocloronous motor has moving stator geared down from rotor to correct permanent set of crystals to beat even seconds.



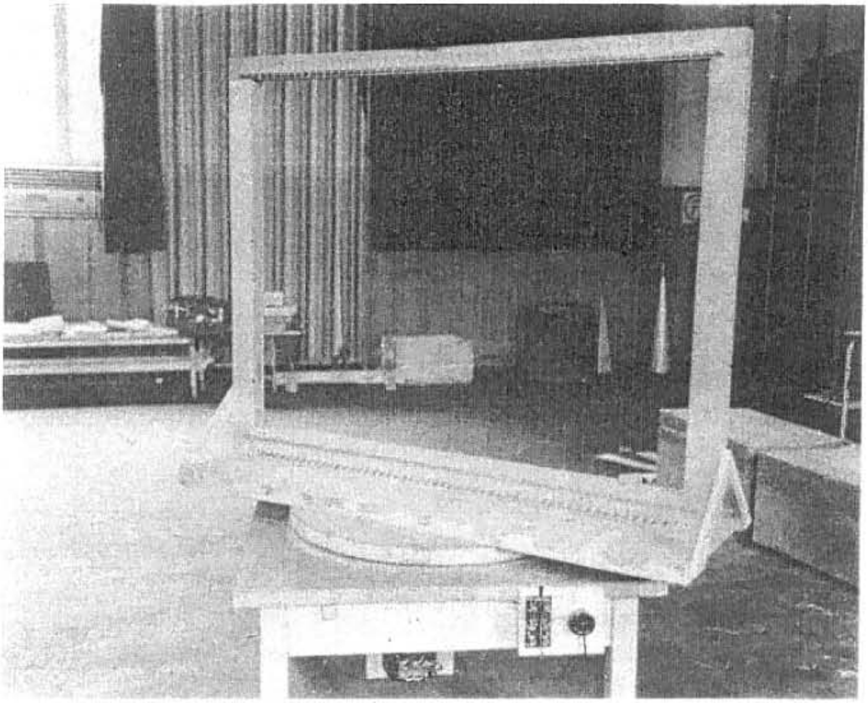
3 cm extension oscillator - note headphone - When oscillator is in step with a harmonic of 30 cm cavity oscillator(front) the rushing noise in headphone stops.



Magnetron oscillator working in neighborhood of 4 mm. Pulse can be seen on scope.



Balanced **horn pick-ups** to get accurate **direction** of reflected wave from grid below.



Centimeter grid used for electric wave measurement exactly as light waves are analyzed by a Michelson grid. Geometry of wire spacing and angular pick up from perpenducular transmission to grid gives measure of wave length.

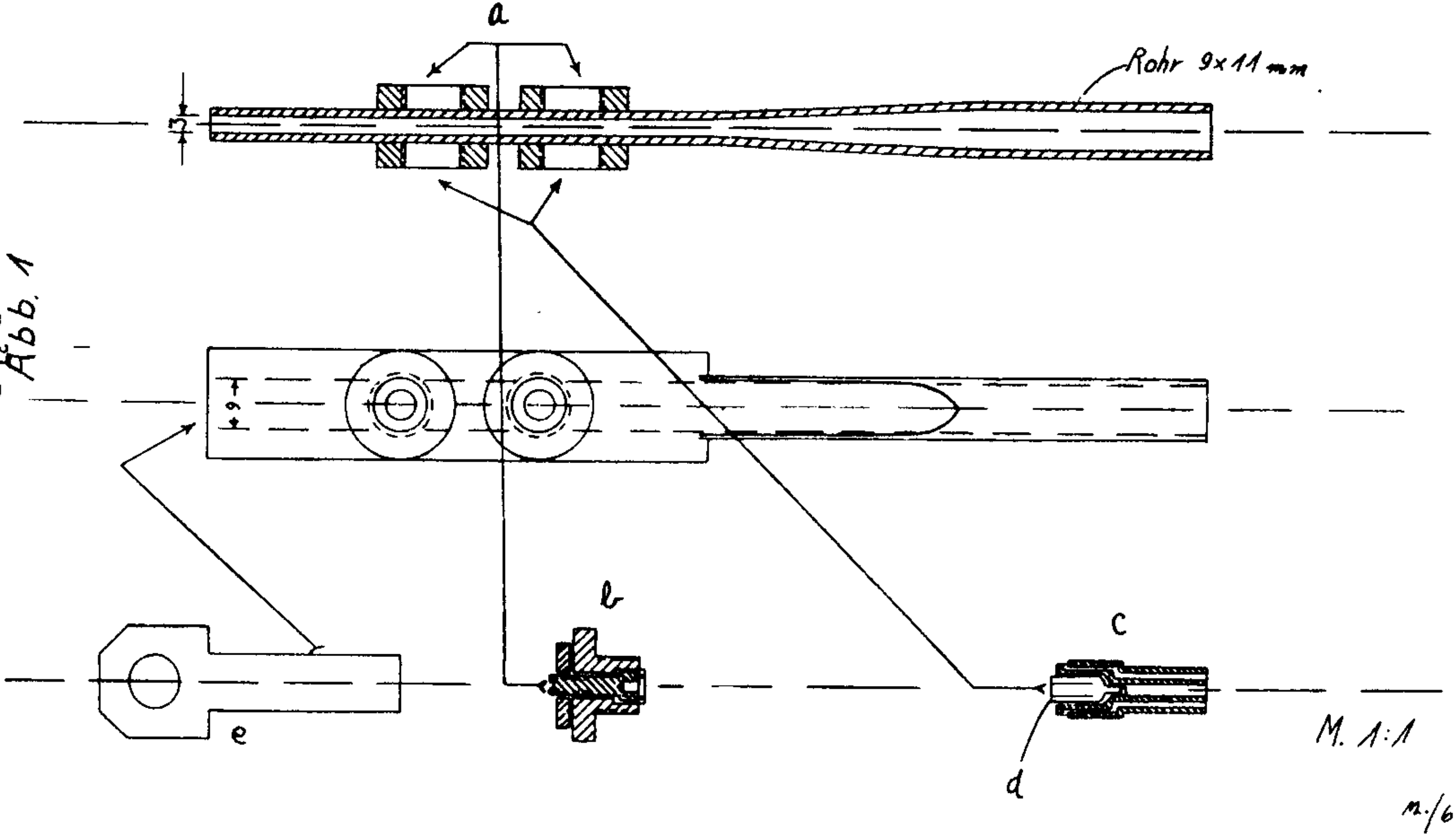


Abb. 1

Abb. 1

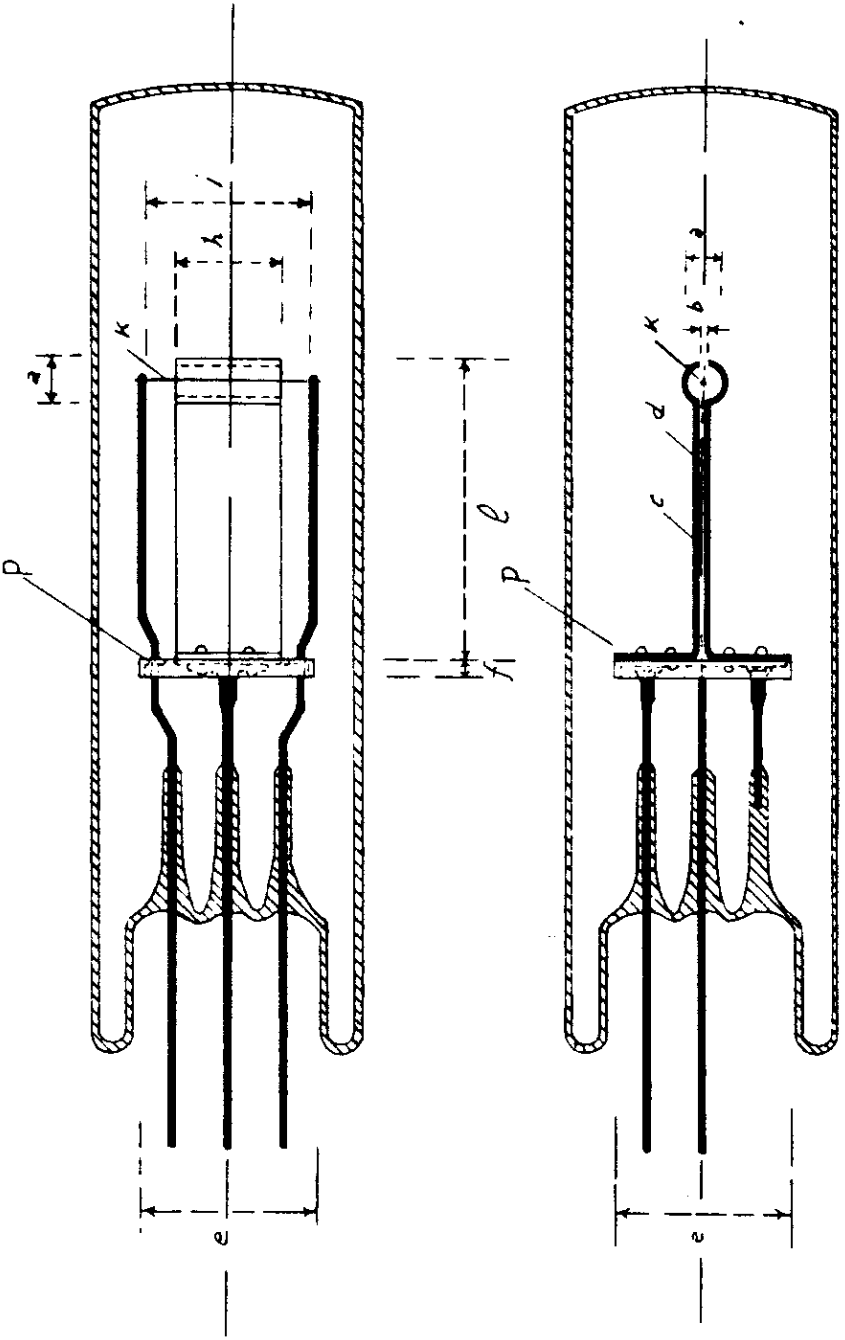
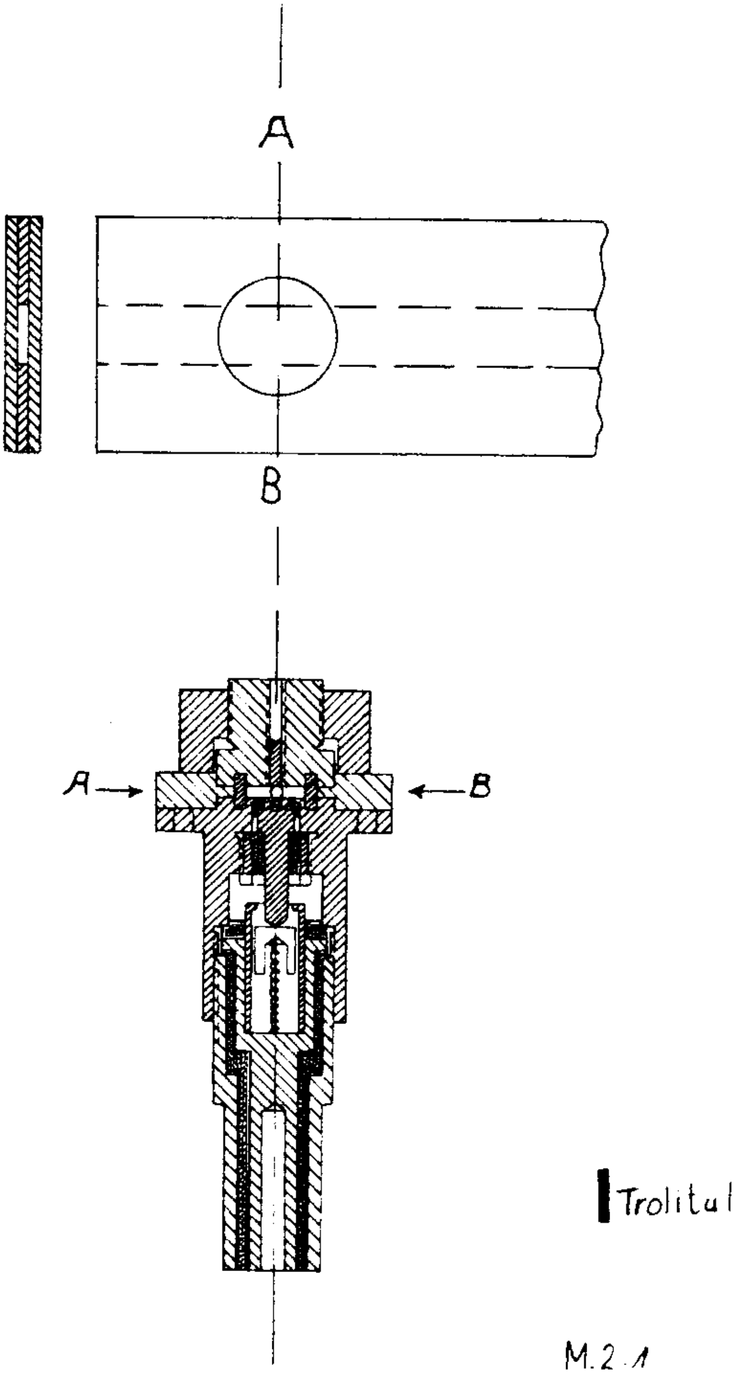


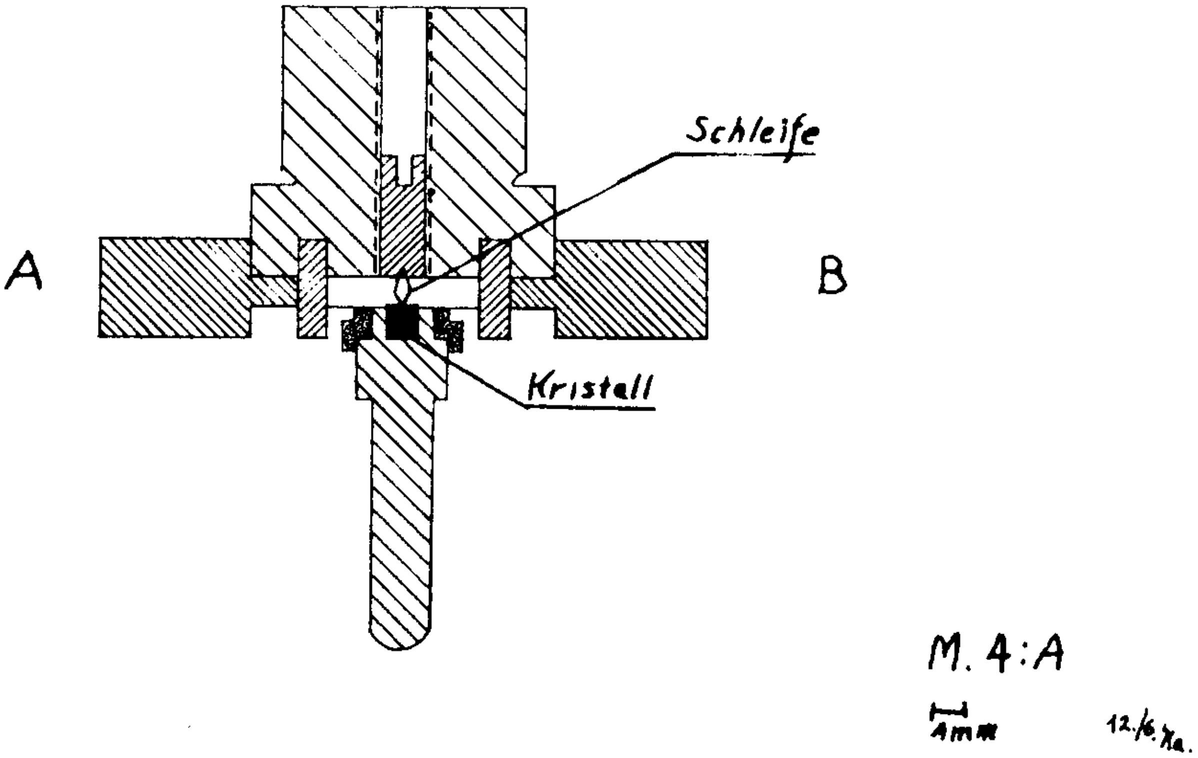
Abb. 2



M. 2:1

12/6. Ka

Abb 3



13./6 4a.

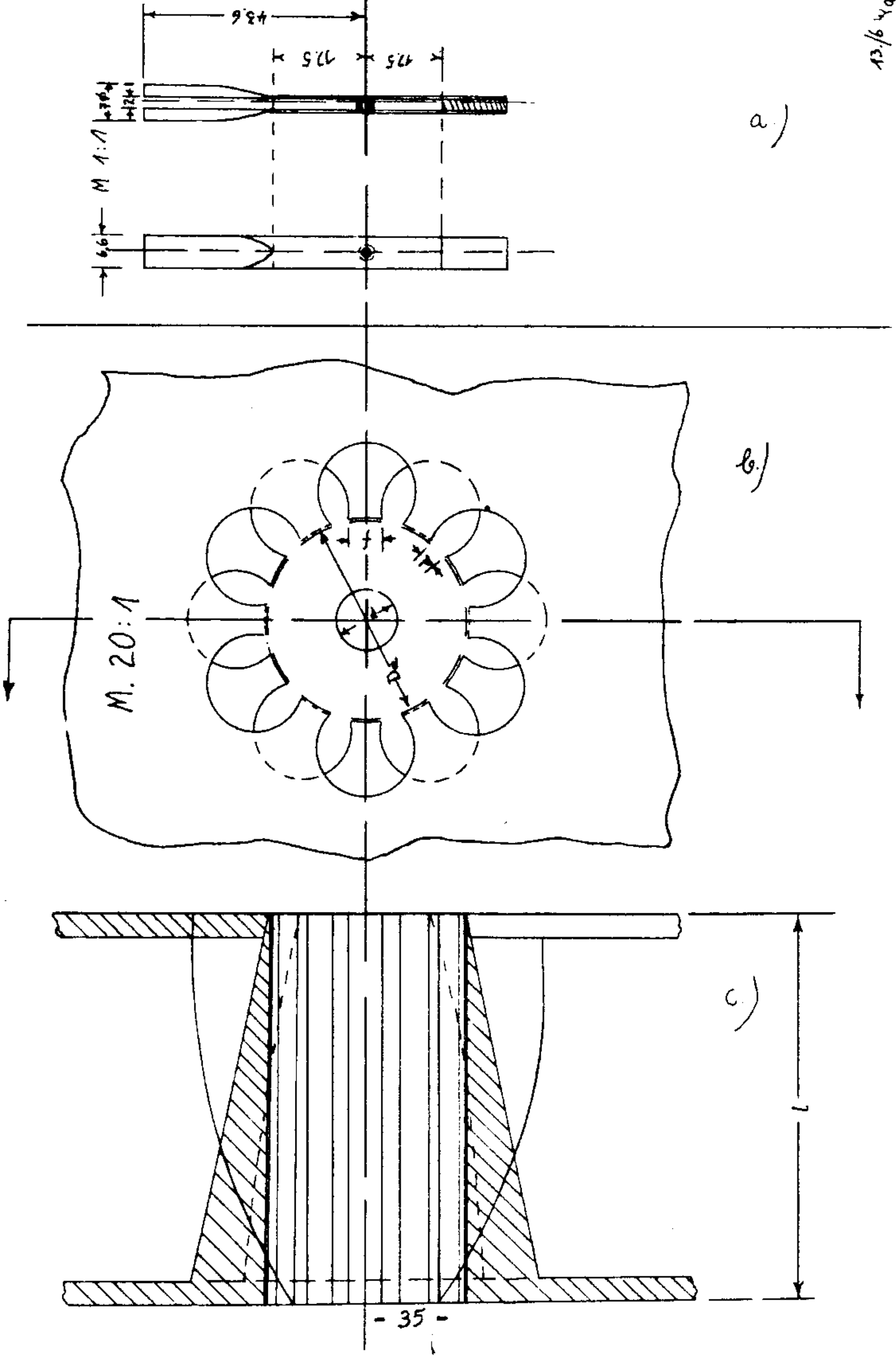


Abb. 3

M 2:1

Abb. 5

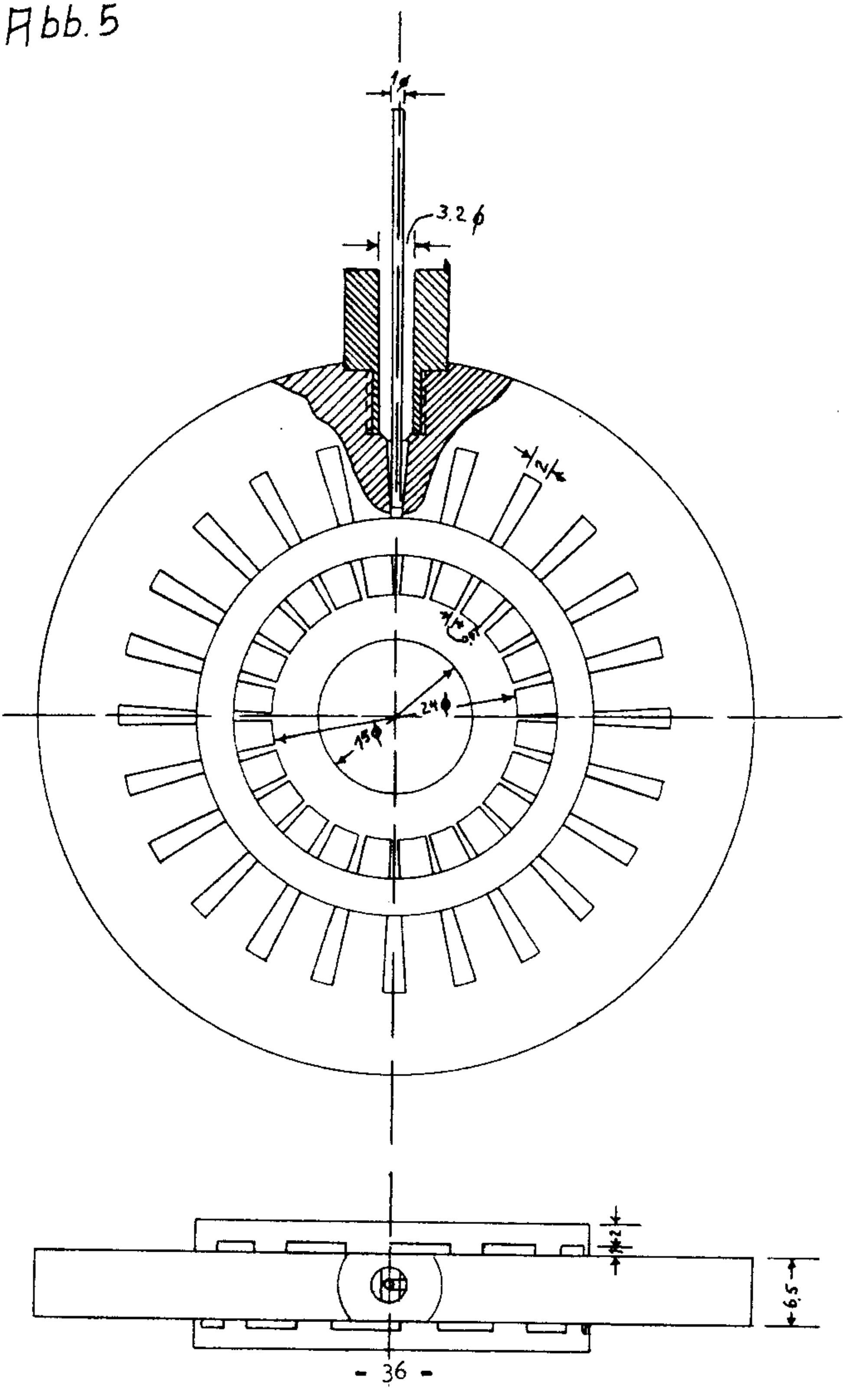
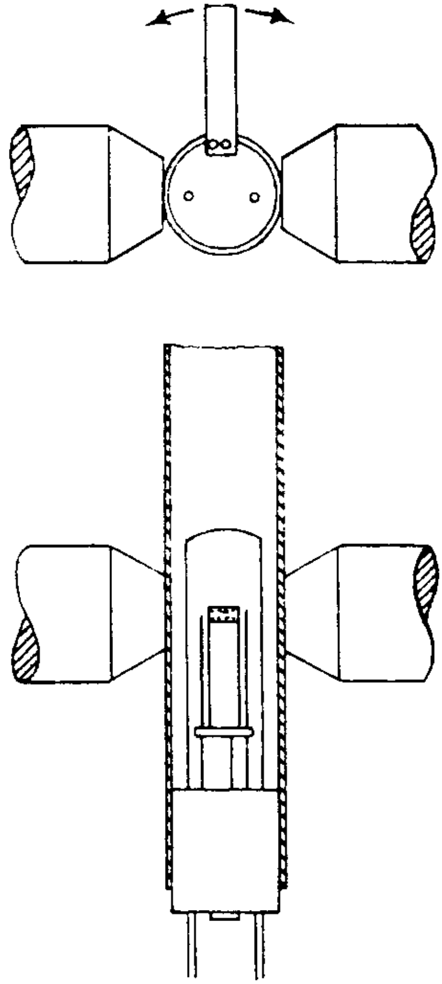


Abb. 6



Schematische Darstellung des Frequenzteilungsgerätes der. Phys.-Techn. Reichsanstalt

(U. Adelsberger)

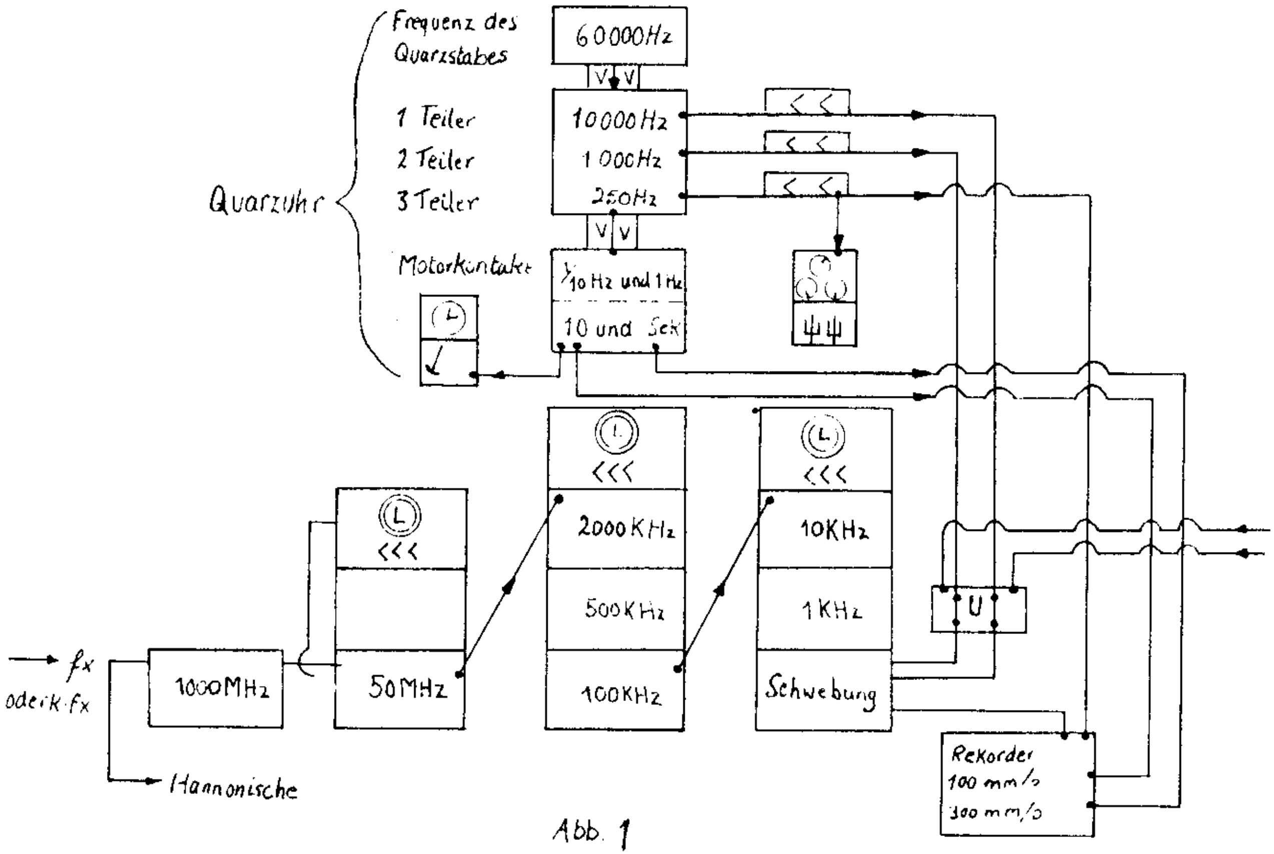
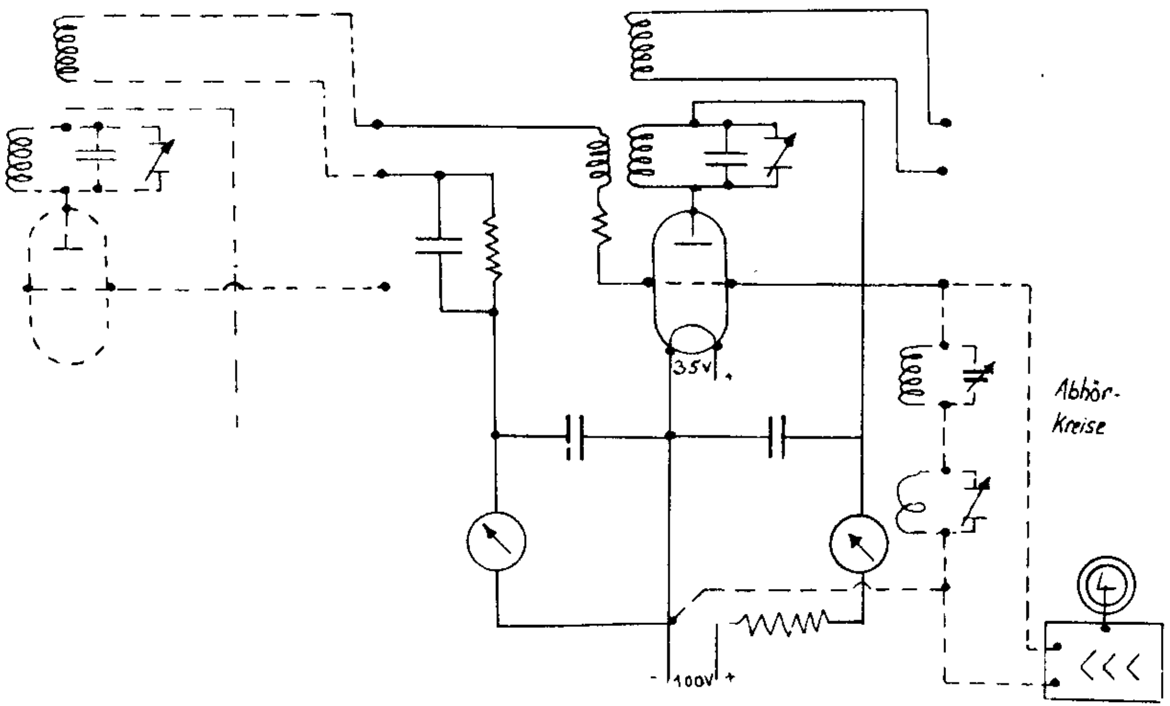
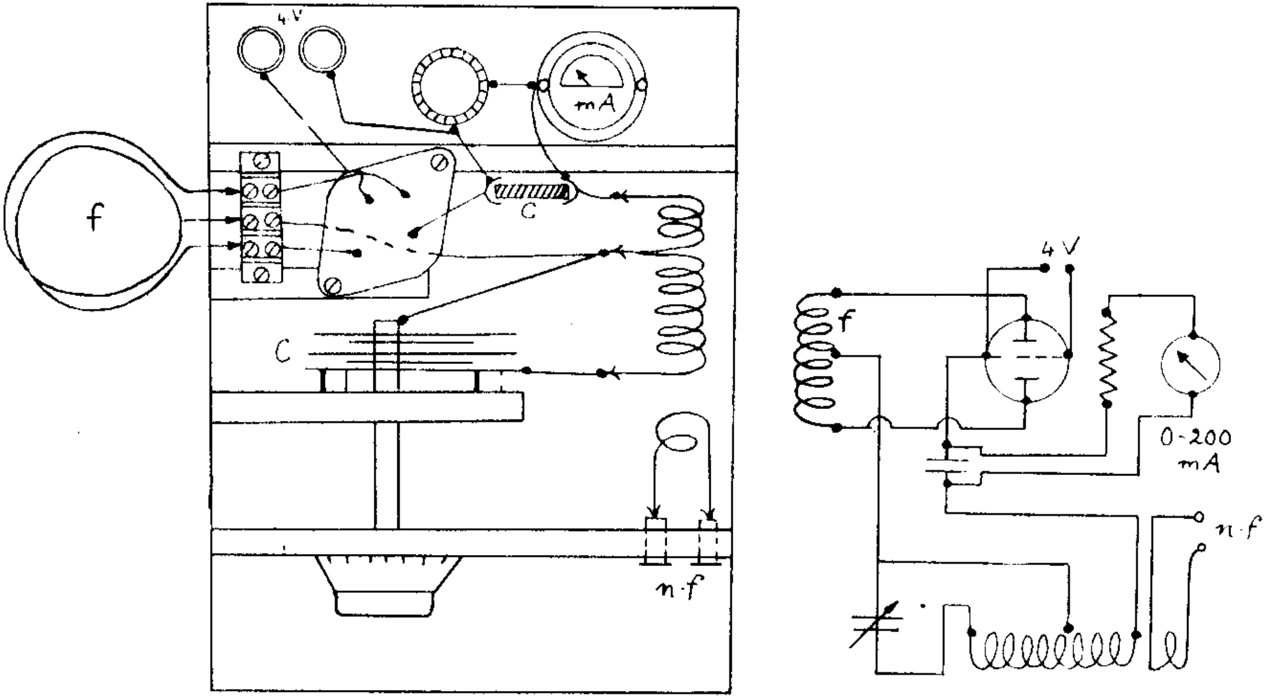


Abb. 1



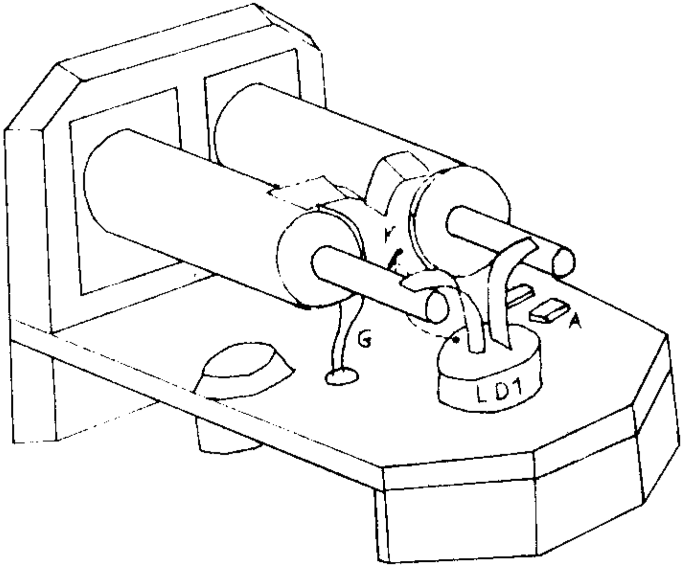
Frequenzteilungsstufe	Abb. 2	Physikalisch-Technische Reichsanstalt (V. Adelsberger)



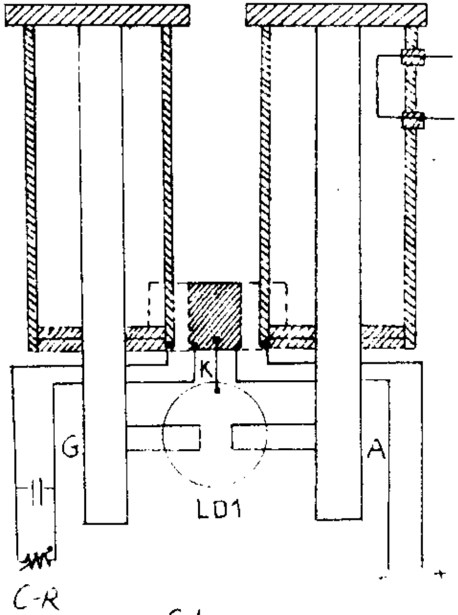
Frequenzvervielfacher

Abb. 3

Physikalisch-Technische
Reichsanstalt
(U. Adelsberger)

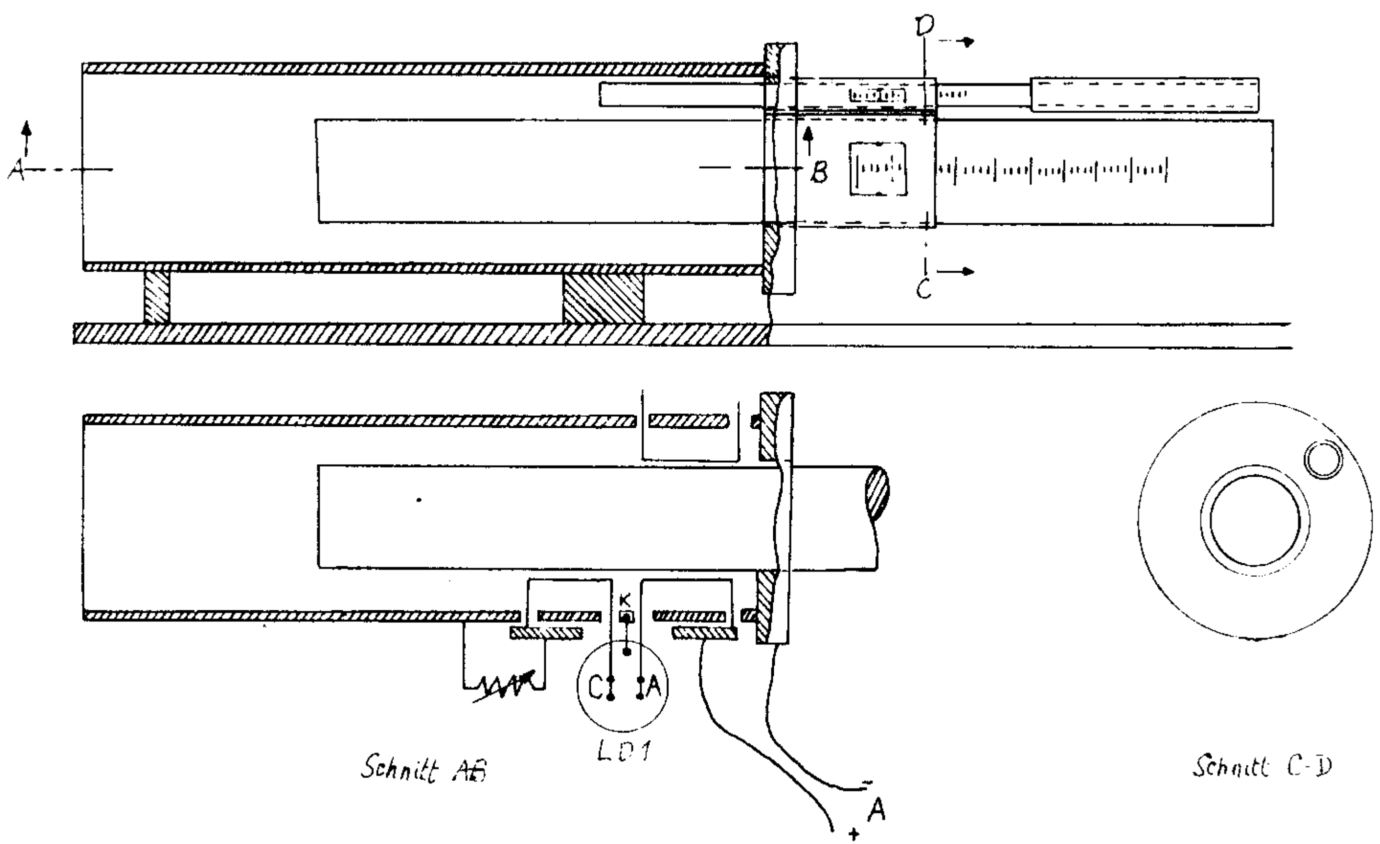


Ansicht



Schema

Oberwellensender UKS 6	Abb. 4	Physikalisch - Technische Reichsanstalt (V Adelsberger)



Dezimeter - Oberwellensender
für Frequenzanschluß DS3

Abb. 5

Physikalisch-Technische
Reichsanstalt
(U Adelsberger)

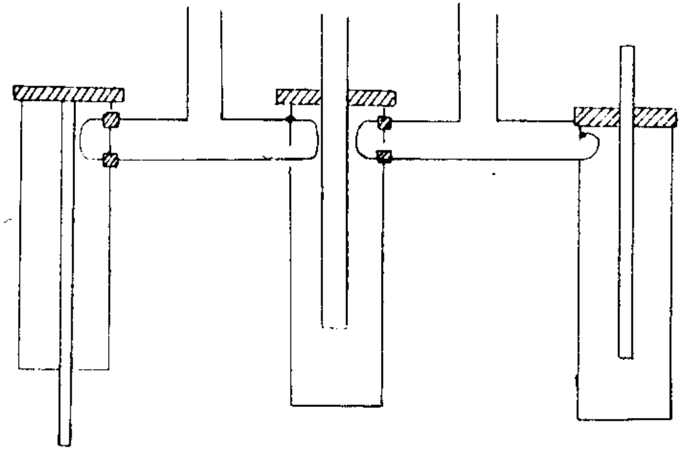
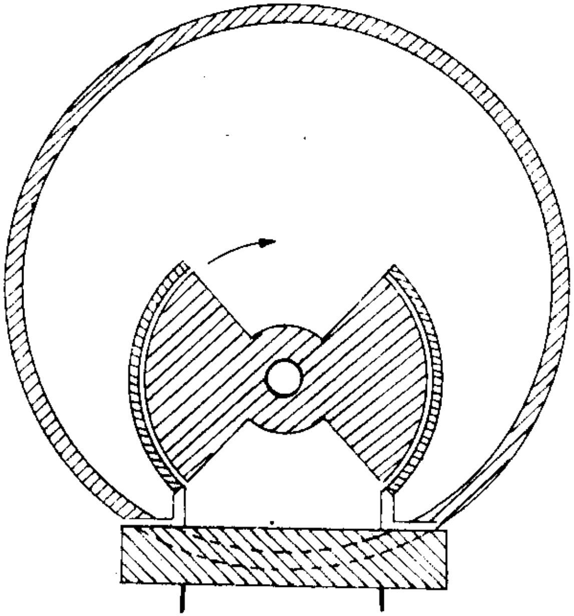


Abb.7



Symmetrischer Drehkondensator

Abb.6

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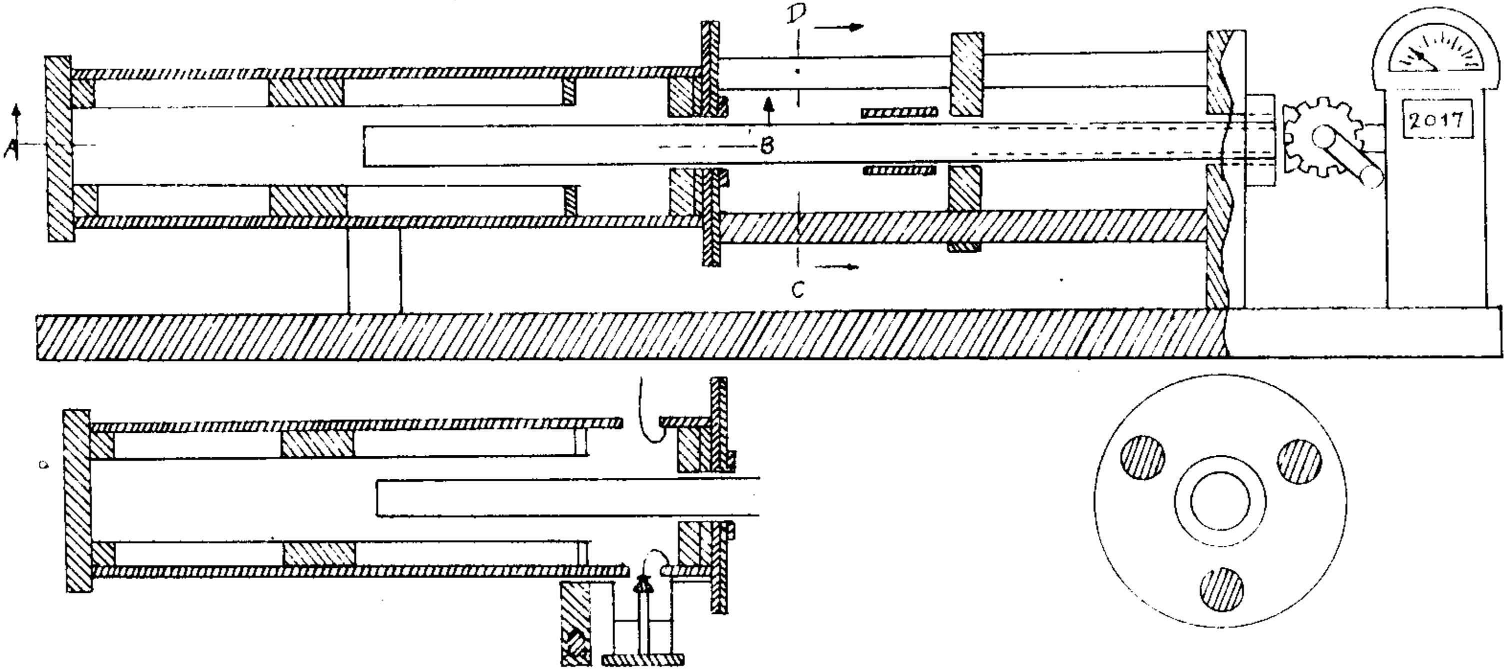
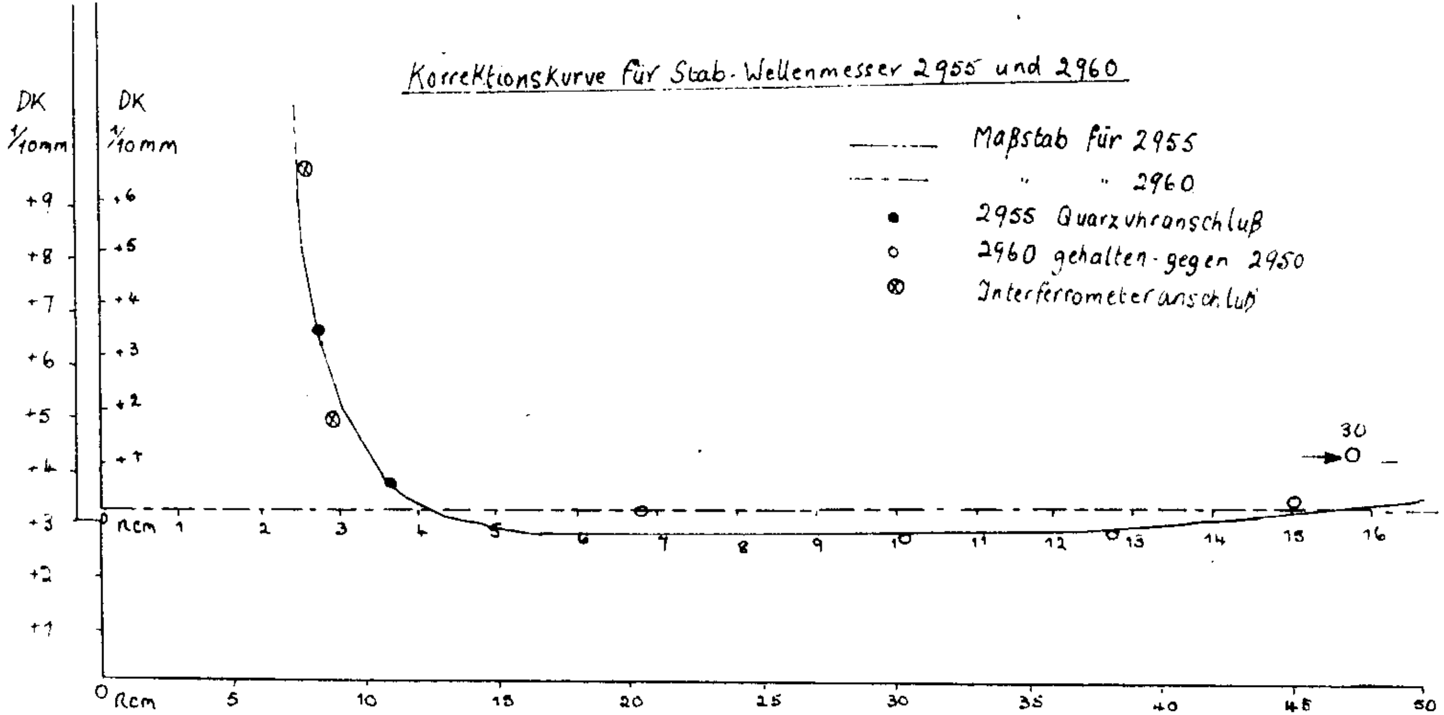
Reichsanstalt
(V. Adelsberger)



Schnitt A-B

Schnitt C-D

Stabwellenmesser 2953	Abb. 8	Physikalisch-Technische Reichsanstalt (V. Adelsberger)



Korrektionskurve für Stab-Wellenmesser 2955 und 2960

Abb. 9

Physikalisch-Technische
Reichsanstalt
(U. Adelsberger)