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RESEARCH ON NOISE IN CROSSED FIELD DEVICES

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~~Second~~ quarterly report.

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C O N T E N T S

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I. SUMMARY

The program of work of this trimester was the following :

1. continuation of the tests in order to reduce the amplitude of the fast mode,
2. first results on the operating tube.

As far as the first point is concerned, attempts were ~~have been~~ made to achieve an attenuation of the fast mode having the required characteristics for use in a tube. For reasons ~~which will be~~ shown, the interdigital line, initially designed, was replaced by a meander line. No radiation measurement was ~~has been~~ done so far on this structure.

Hot tests have begun. The first results show that the tube amplifies. For an electronic gain of 22 dB, no oscillation is observed in the absence of signal which makes the tube readily usable for noise measurements.

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II. FAST MODE ATTENUATION.

II.1. TESTS WITH THE INTERDIGITAL LINE.

In the last report we described a method which allows to measure the coupling due to stray radiation between input and output of the tube. This method has the advantage to be applicable to the tube under its final shape without introducing any modification of the tube structure which might perturb the measurement. On the other hand, the coupling measured that way is only due to the radiation of both ends of the structure, the coupling resulting from reflections on the ends of the line being determined by VSWR and attenuation measurements.

Here is briefly summarized the principle of this method :

the slow wave is strongly attenuated (for instance attenuation larger than 80 dB achieved by the use of carbon papers). Once the sole and cover are in the final position, the measurement of the attenuation between input and output shows a succession of maxima and minima. These are resonances either of the fast mode between line and sole or of the whole cavity which constitutes the body of the tube.

Let us put : $\left|\frac{V_o}{V_i}\right|_{max}$ the transmission in voltage for one of these resonances,

ρ the reflection coefficient of the input and the output (input and output being identical, one supposes equal reflection coefficients),

A the attenuation in voltage of the line.

In the last report it has been shown that the maximum gain beyond which the tube becomes unstable is given by :

$$G_{osc} \sim \frac{1 - \left|\frac{V_o}{V_i}\right|_{max}}{\rho^2 A + \left|\frac{V_o}{V_i}\right|_{max}} \sim \frac{1}{\rho^2 A + \left|\frac{V_o}{V_i}\right|_{max}}$$

The measurement of ρ and A on the one hand, of $\left|\frac{V_o}{V_i}\right|_{max}$ on the other hand, gives information about the relative importance of the two factors - reflections and radiation - which limit the stability. Thus illusory improvements may be avoided. For example, if one finds that $\left|\frac{V_o}{V_i}\right|_{max} \ll \rho^2$ A, it is useless to try to decrease the coupling due to radiation between input and output. In that case, the main point is to improve the matching of the structure and to increase the attenuation.

Let us consider the interdigital line described in the last report. The VSWR is about 1.5 (see fig. IV.1 of last report). Let us suppose the natural plus lumped attenuation of the structures is of the order of 10 dB. Hence $\rho^2 A \sim \frac{1}{25} \times \frac{1}{3.16} \sim 1.3 \times 10^{-2} \sim 40$ dB. The coupling due to radiation is of the same order of magnitude as shown by fig. I.1. In that case it is reasonable to try to reduce it. The reduction of this coupling can be obtained either by acting on the excitation of the fast mode at the input and output transition (taper) or by attenuating it. We have chosen this last method. In the case of fig. I.1, one can see that the coupling due to radiation has been reduced by about 6 dB. The results of fig. I.1. correspond to an attenuation obtained by stacking teflon sheets and carbon paper. These measurements have been interrupted because they have only a qualitative value. Further more the achievement of the attenuator which will be used in the tube has suffered delay. Also interdigital line has lost for the time being some interest, since it is replaced by a meander line.

II.2. FAST MODE ATTENUATOR.

In order to be usable in a tube, this attenuator should satisfy the following requirements :

1) breakdown voltage higher than 10 kV,

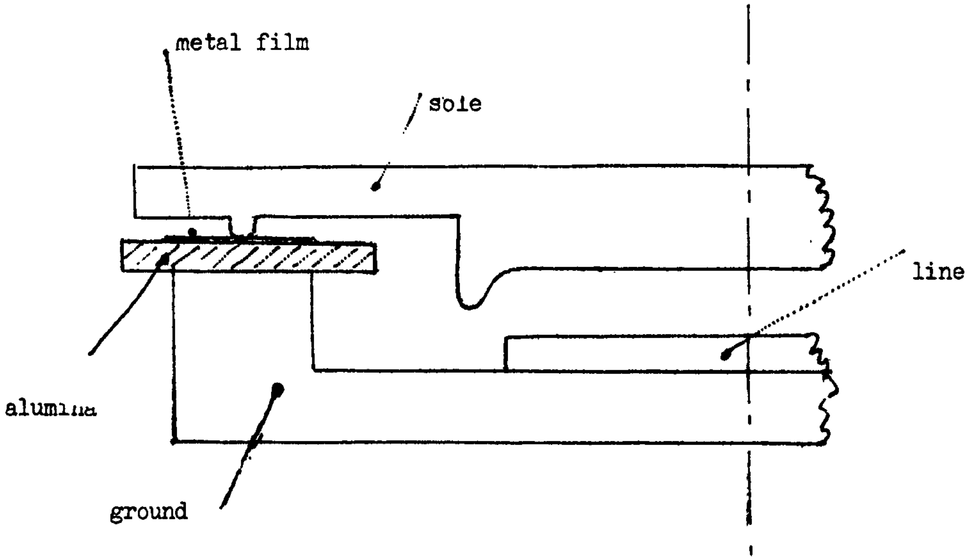
2) the attenuator should stand at temperatures of the order of 100° C without gassing,

3) attenuation of the order of 10 dB for the length of the line (= 35 cm).

In order to achieve this attenuation, the metal losses of a thin film have been used. An attenuation based on the dielectric losses of barium titanate is on the study.

II.2.1. Attenuation by metallic losses.

The principle is shown on the figure below :



A thin slab of alumina, 30 mm wide, 0.6 mm thick, is metallized on one face by evaporation under vacuum over a width of 20 mm. The thickness of the metal film is much less than the skin depth. The contact with the sole is achieved by a wire of 1 mm diameter. This system is equivalent to a transmission line with two conductors of low impedance, one of the conductors being very lossy.

The attenuation constant is given by :

$$\alpha_{Np/m} = \frac{\sqrt{\varepsilon}}{120\,\pi} \; \frac{1}{2\,\sigma\,\delta\,e}$$

where :

ε is the dielectric constant

e is the thickness of the dielectric

σ the conductivity of the metal film

δ the thickness of the metal film

Alumina slabs 0.6 mm thick, $\varepsilon \sim 9$, are used :

$$\alpha_{Np/m} = \frac{6.6}{\sigma\delta}$$

Value of α is adjusted by measuring the d.c. resistance : the metal film has a length of 40 cm, a width of 2 cm, a thickness δ . The resistance of the ribbon is then $R = \frac{40}{2} \frac{1}{\sigma\delta} = \frac{20}{\sigma\delta}$. Hence $\alpha = 0.33\ R_{Np/m} = 2.86\ R_{dB/m}$, hence for the length of the line : $0.35\alpha_{dB} \sim R$ expressed in Ω .

The first samples have been achieved using copper. The resistance of the film varies during time because of oxydation. Copper has been replaced by palladium which is perfectly stable. The resistance has been fixed at a value of 20 Ω which corresponds to an attenuation of 20 dB.

The breakdown voltage between the metal film and the other electrodes is sufficient, but the contact between the film and the sole is not sufficient. Breakdown occurs between sole and film, destroying the latter. Tests are under way to solve this difficulty.

II.2.2. Attenuation by dielectric losses.

The dielectric should have on the one hand a high dielectric constant as well as high loss angle, on the other a very high d.c. leakage resistance. These characteristics belong to barium titanate. Fig. II.1 shows the variation of ε and tg δ versus temperature for the type HK N° 420 which was chosen for hot tests because of the very small variation of these two quantities in a temperature interval of 0° C to 200°C.

Let us point out that these curves are valid for a frequency of 1 Mc/s, in the absence of d.c. electric field. After the data given by the manufacturer, ε decreases by about 50 % for fields of the order of 1000 V/mm, and tg δ increases by a factor 2 for frequencies around 1000 Mc/s.

In order to compute the losses we will put $\varepsilon = 500$, $\text{tg}\delta = 2 \times 10^{-2}$. For f = 1300 Mc/s, one obtains :

$$\alpha = \frac{1}{2} \frac{10^{-8}}{3} \sqrt{\varepsilon}\ \omega\ \text{tg} \ = \frac{10^{-8}}{6} \sqrt{500} \times 2\pi \times 1.3 \times 10^{9} \times 2 \times 10^{-2} \sim 6 \text{ Np/m}$$

For the total length of the attenuator :

$$\alpha L = 6 \times 0.4 = 2.4 \text{ Np} \simeq 20 \text{ dB}$$

The slabs have been designed with a width of 30mm. They are metallized in the middle over a width of 10 mm. The areas of the slabs in contact with the sole and ground respectively are limited to the metallized part in order to avoid high electric fields at the surface of the ceramic which might cause arcing.

The impedance of the "line" thus constituted is $\frac{120\pi}{500} \frac{3}{10} \simeq 3\ \Omega$. It is of the same order as the impedance of the strip of alumina with metallic losses ($Z = \frac{120\pi}{3} \frac{0.6}{20} \simeq 4\ \Omega$).

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III. CHARACTERISTICS OF THE MEANDER LINE.

This line was considered previously relative to another contract. Its characteristics being definitely superior to the interdigital line, it was decided to use this line as a first step for the hot measurements, especially since the tube lends itself particularly well to such rapid modifications.

This line is obtained by brazing a meander onto an alumina slab which is in turn brazed to a copper ground plate (fig. III.1). The dimensions are given in fig. III.2.

Fig. III. 3, III.4, III.5 and III.6 represent respectively, as a function of the wavelength, the dispersion curves, the coupling impedance, the match and the insertion loss. A comparison of these curves with those relative to the interdigital line (see preceding report) shows the superiority of the meander line :

Wider pass-band with no low-frequency cut-off which, in the case of the interdigital line, is bothersome in virtue of the possibility of oscillation on the m = - 1 space-harmonic. On the other hand, the dispersion is of the same order as that of the interdigital line, the delay ratio is smaller (18 to 20 in the frequency band as opposed to 21.5 to 22.5 in the case of the interdigital line).

Higher coupling impedance with much less variation.

Better match. The match is easier to obtain, the impedance of the meander line being of the order of 40 Ω and practically constant in the band.

The insertion loss is more uniform, however its value is greater by a factor of two approximately.

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IV. TESTS ON THE TUBE IN OPERATION.

Fig. IV.1 shows the tube in its magnet.

The replacement of the interdigital line by the meander line is the only modification effected on the tube whose description is given in the preceding report.

Since it is not baked, the tube outgasses for a considerable length of time. The limiting pressure is of the order of 10^{-6} mm Hg. Until now, the lowest possible voltages were used. The tube amplifies under the following conditions :

- line voltage V_L = 3050 V
- sole voltage V_s = 850 V
- line current I_L = 135 mA
- sole current I_s = 0
- magnetic field B = 380 gauss
- frequency f = 1300 Mc/s
- electronic gain G_e = 22 dB
- gain G = 16 dB
- output power P = 19 W
- applied power P_o = 410 W
- efficiency η = 19/410 ~ 4.5 %
- line-sole distance d = 6 mm
- critical magnetic field B_c = 396 B/B_c = 1.04
- electronic delay ratio τ_e = 17.5
- cold delay ratio τ = 17.3

Observations :

The efficiency is very low, the input power being only 475 mW; the tube is far from being saturated. Operation of the tube at higher levels of input power raises equipment problems whose solution is being investigated.

The electronic gain of 22 dB corresponds to operation without simultaneous parasitic oscillations at a frequency different from the signal frequency and without preoscillations in the absence of a signal, within the limits imposed by the precision of our measurements. Were a preoscillation to exist, its level would be at least 30 dB below the signal level.

Oscillations definitely start for an electronic gain of the order of 27 dB (G = 21 dB), obtained by increasing the current. As has been already pointed out, no radiation measurements have been carried out on the meander line. However, it is certain that the radiation of this meander line is less than that of the interdigital line. Since the measurements carried out on the latter have shown that the term $\left|\frac{V_o}{V_i}\right|_{max}$ is greater than 40 dB, it is probable that in the case of the meander line, start of oscillations is due to reflections, especially since there is only 6 dB of attenuation. Under this hypothesis, it may be possible to increase the gain without the risk of oscillations by adding a localised attenuation to the intrinsic attenuation of the line.

The tube amplifies in the entire frequency band, however it has not been possible up to now to carry out systematic measurements because of arcing in the vicinity of the attenuating slabs. While this problem is being solved, the tube will be tested without attenuating slabs; these tests will allow one to evaluate directly the importance of the radiation.

The experimental value of the electronic gain is not in agreement with the theoretical value. The theory, taking space charge into account, gives G_e = 40 dB. The disagreement may possibly be explained by the low value of B/B_c which leads one to suppose that the beam does not travel the entire length of the line.

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V. PROGRAM FOR THE COMING PERIOD.

Tests on the tube, without attenuation of the fast mode, will begin shortly. The orientation of future work will depend in part on the result of these tests. We shall endeavor to elucidate the following points :

1) conditions of operation of the tube,

2) limits and possible improvements of the stability of the tube,

3) measurement of the noise factor.

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LIST OF FIGURES.

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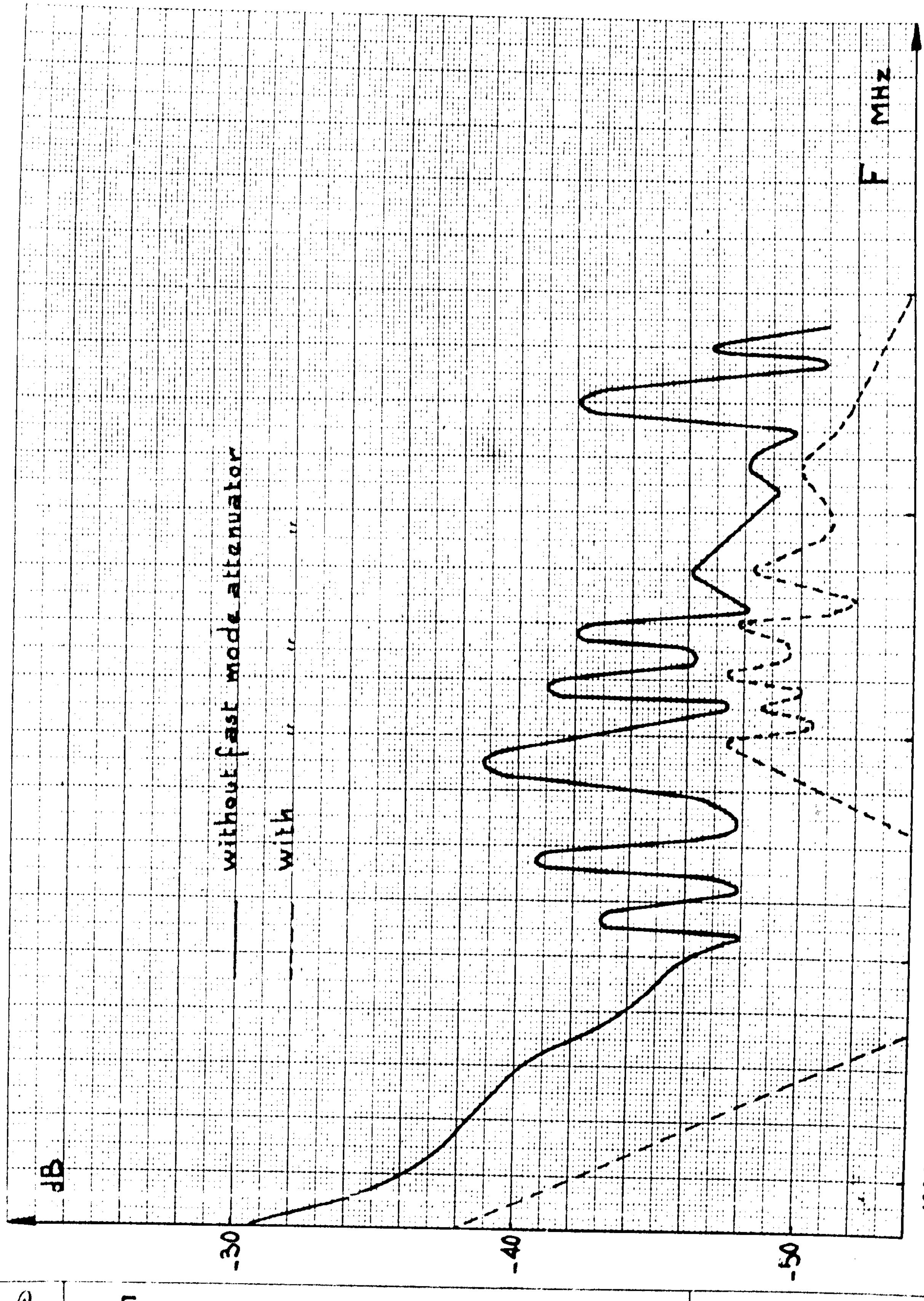
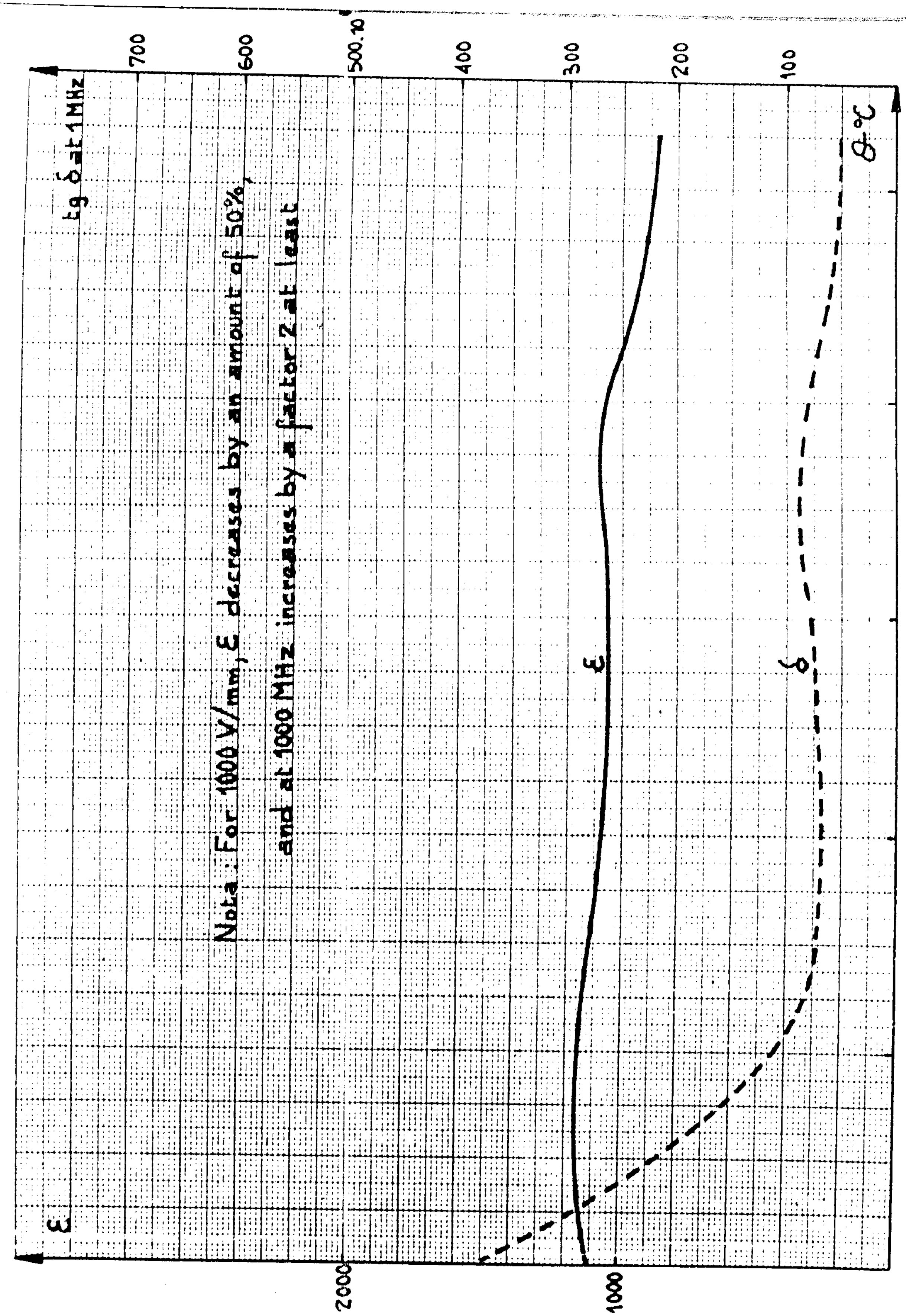


Fast mode transmission of the interdigital line

Fig. I - 1



CSF	Ceramic HK N°420 Variation of ε and tg. δ versus temperature	Fig. II - 1

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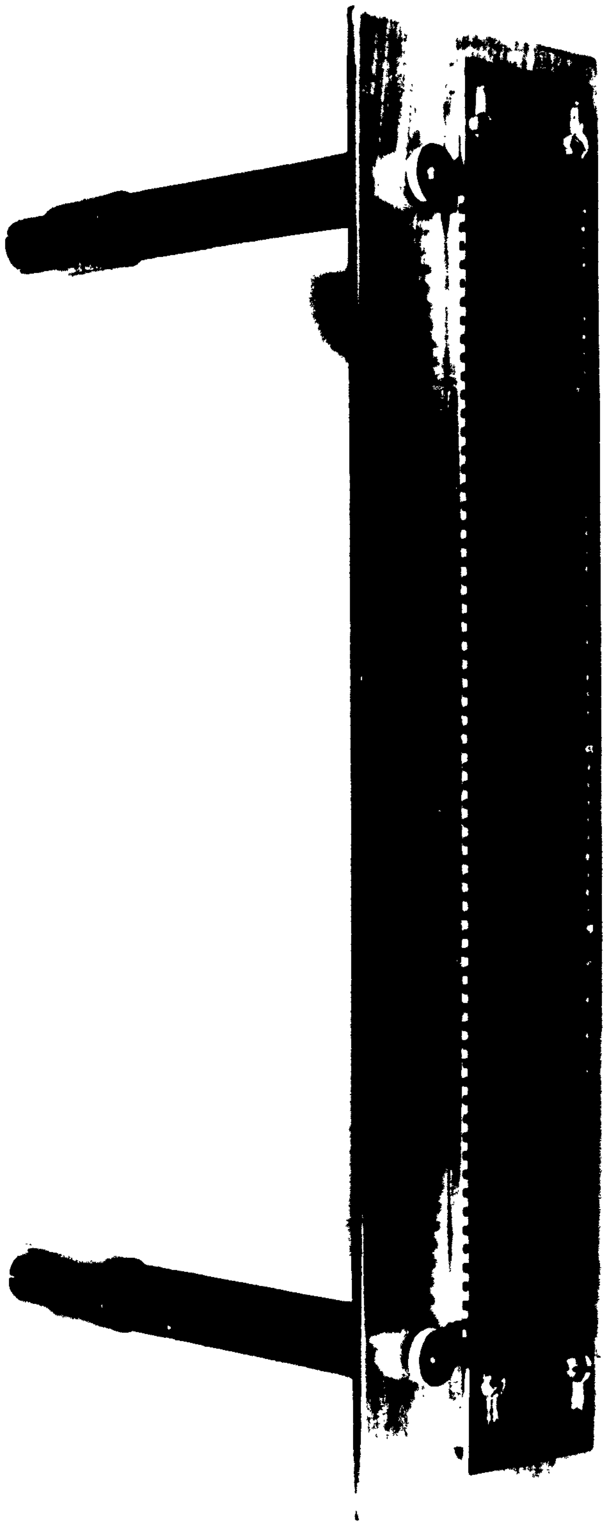

FIG. III 1

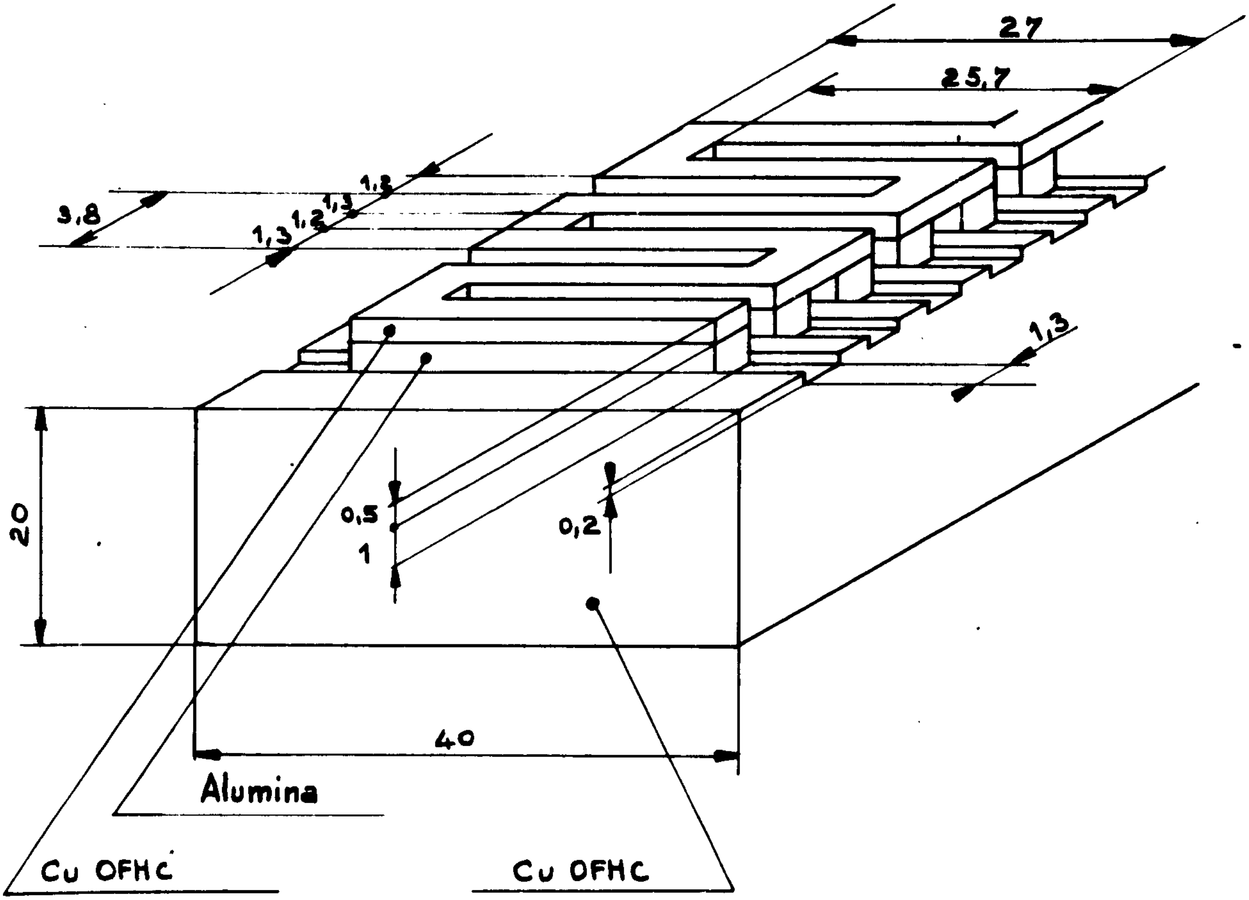

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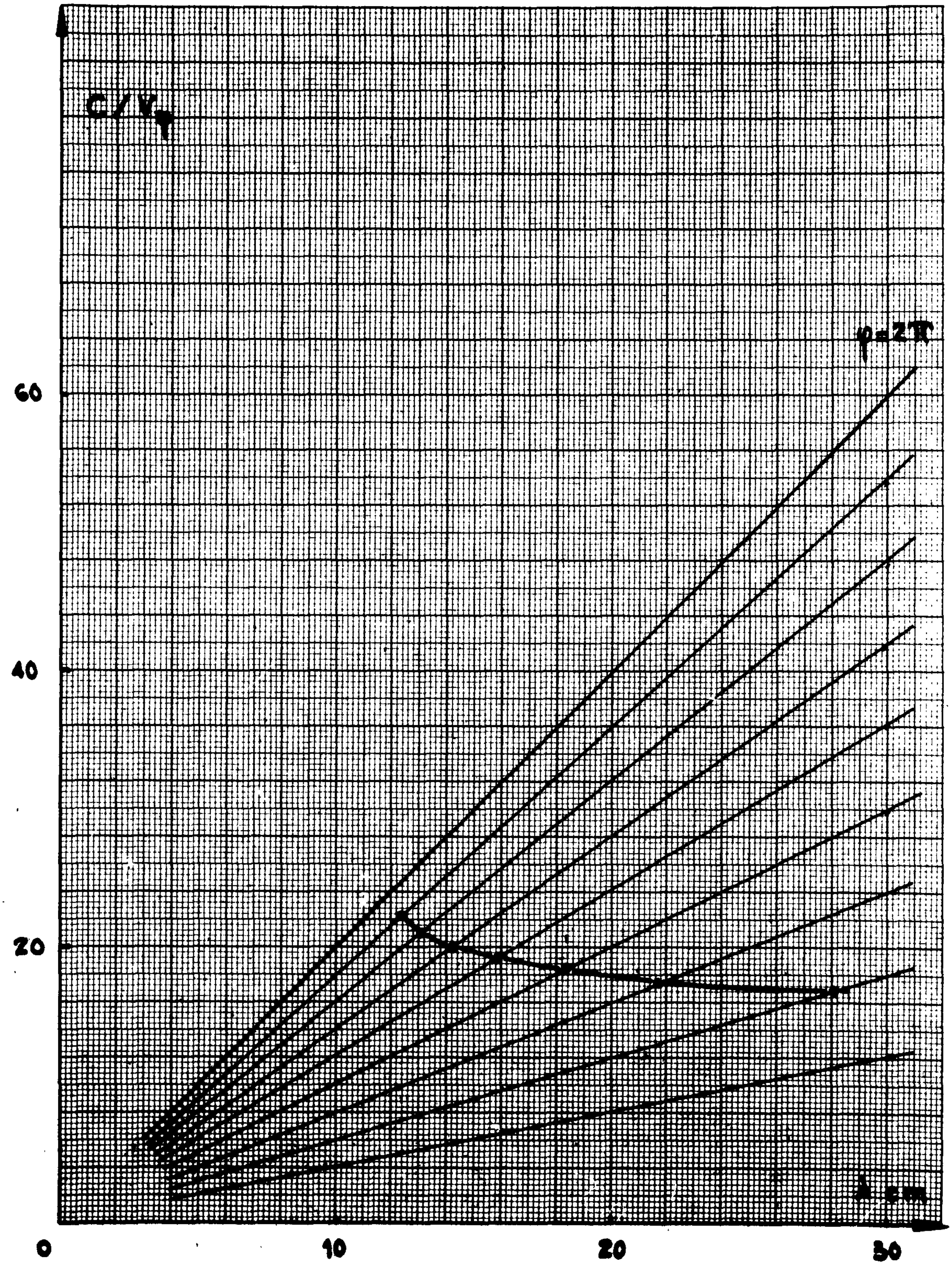
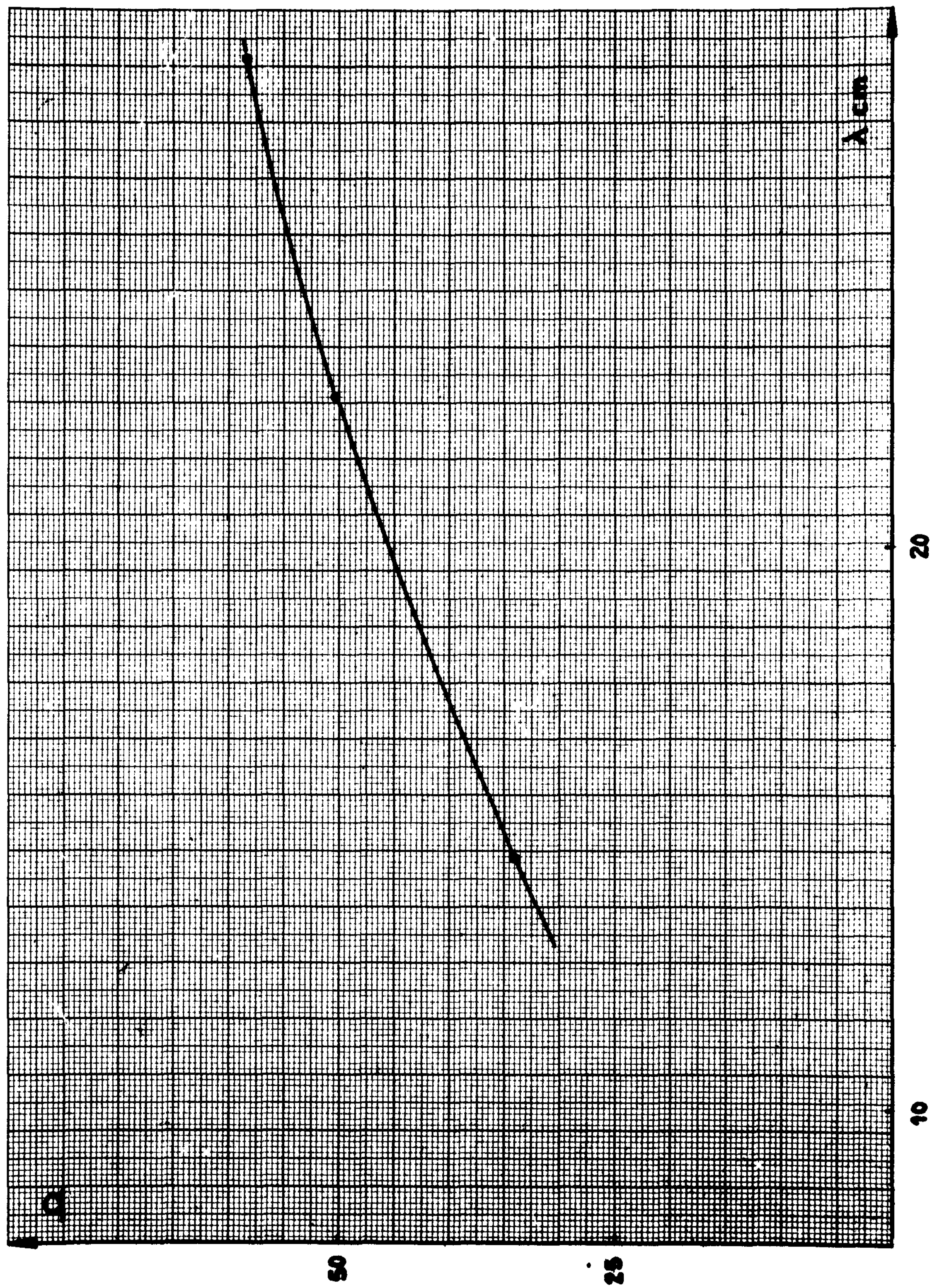
Fig. III_2



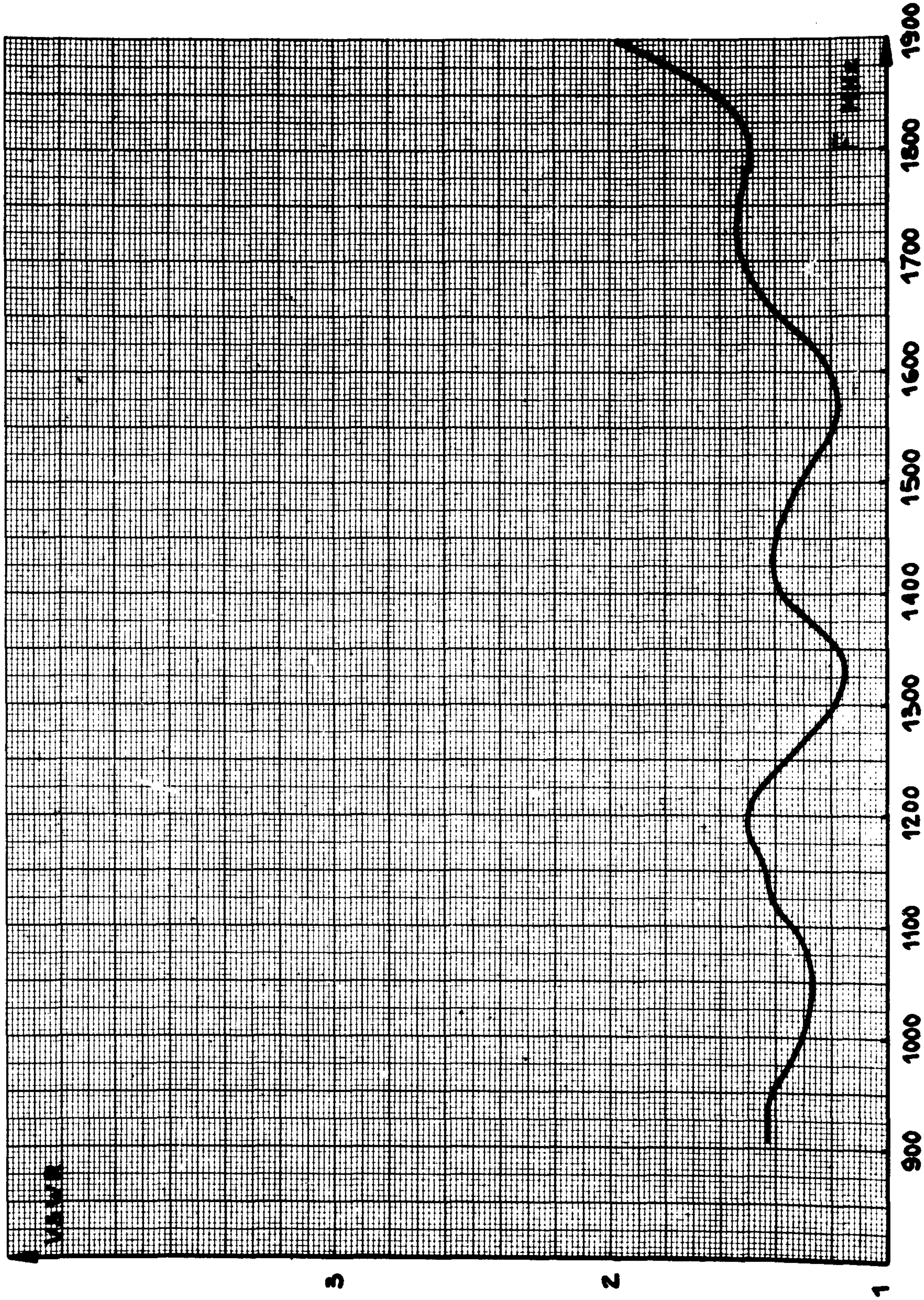
Dispersion curve of the meander line

Fig. III_3



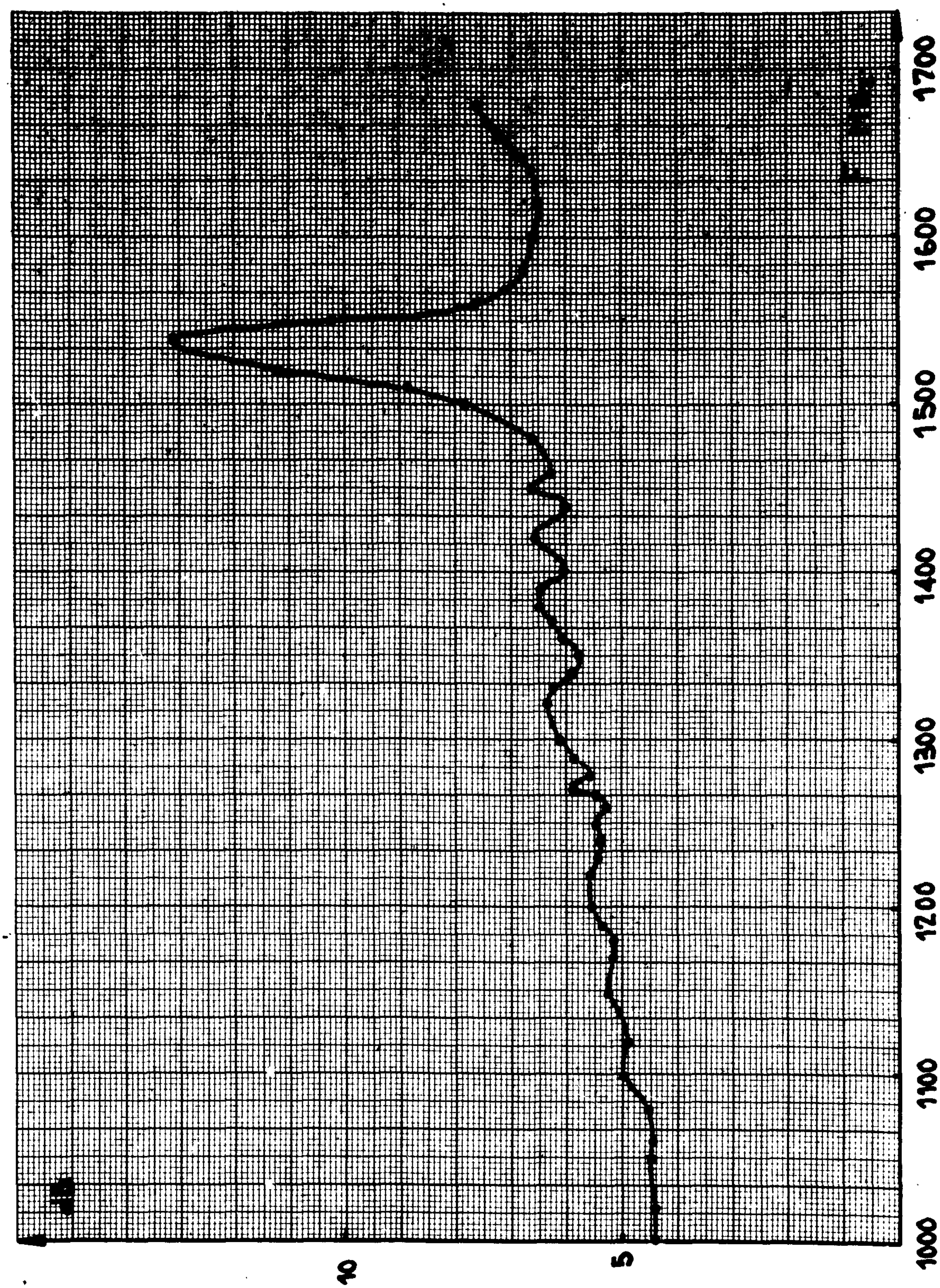
Coupling resistance of the meander line

Fig. III - 4



Matching of the meander line

Fig. III_5



Transmission of the meander line with sole and cover

Fig. III_6

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