7

ON NATURE OF DYNATRON TYPE NEGATIVE IMPEDANCES AT FREQUENCIES FROM 1 TO 40 MEGACYCLES/SECOND

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ABSTRACT. The paper relates to investigations on the nature of dynatron type negative impedances obtained from screen-grid tubes operated under secondary emission condition over the range 1-40 Mc/s and forms an extension of a previous work by the first author.

A suitable method for the measurement of "$-R_a$," "C_a" and "C_{af}" has been evolved. Measurements of "$-R_a$," "C_a" and "C_{af}" have been carried out over the range 1-40 Mc/s and discussion as to the nature of variation of $/R_a/$ and C_{af} with frequency has been made. Dependence of $/R_a/$, C_a and C_{af} upon the amplitude of the operating h.f. voltage (*i.e.*, that applied between anode and filament) or superimposed h.f. voltage has been shown.

A discussion on the nature of variation of $/R_a/$ of screen-grid tubes under secondary emission condition with frequency over a large frequency range has been made. Considering a substantially large frequency range and allowing for the effect of the amplitude of impressed or superimposed h.f. voltage, it has been found that the mean curve derived from the experimental curve indicates the law that the internal resistance decreases in general with increase of frequency from very low to very high frequencies.

Further, a discussion on the dielectric constant K of electronic medium between anode and filament of screen-grid tubes under secondary emission condition and its dependence upon the amplitude of impressed or superimposed h.f. voltage as well as upon the frequency has been made. Allowing for the effect of h.f. voltage amplitude, it has been found that the curves of variation of 'K' with frequency are wavy showing peaks and depressions and that the values of 'K' are less than unity at frequencies greater than 11 Mc/s for some tubes and 14 Mc/s for others.

Linearity of the negative impedance element (taken as a whole) has been investigated since this forms the essential requirement for the use of the element in circuits and networks.

Phase shift caused by the negative impedance element (as a whole) has been calculated from measurement of $/R_a/$ and C_a as well as measured directly by cathode-ray oscillograph method.

INTRODUCTION

In a previous work the first author (Chakravarti, 1940) has made comparative studies of "stability," "magnitude and angle of impedance," "linearity" and "phase-distortion" for dynatron, transitron and feed-back types of negative impedance element over the frequency range, 0.5 Kc/s to 1.0 Mc/s.

From stability point of view, the transitron type has been found to be the best of the three. The dynatron type obtained from screen-grid tube can be maintained stable by keeping plate and screen-grid voltage variations as well as filament current variations within limits and suppressing the oscillations set up by closing the negative element terminals through network or apparatus or any impedance, as discussed in previous works (Chakravarti, 1938 and 1940). The feed-back type of negative impedance can be made stable by proper adjustment of the amplifier performance.

The negative impedance element of any type cannot be regarded as non-reactive except at very low frequencies. In the first author's paper (Chakravarti, 1940) entitled 'On Nature of Negative Resistance Sections,' the dynatron types of negative impedance element have been taken more or less non-reactive up to 50 Kc/s. A good agreement of the results calculated on that basis with the actual measurements has confirmed that the above view point could be maintained without much error up to 50 Kc/s.

The correct equivalent of the negative impedance element (of dynatron and transitron types) at a higher frequency will be a negative resistance $(-R_a)$ shunted by the effective capacitance (C_a) equal to anode-filament capacitance (C_{af}) added on to self-capacitance of choke as well as other stray capacitance in wiring, valve base, etc., and by an inductance (L) inserted to block the a.c. from traversing the path of H.T. source. As impedance due to 'L' is very large, the (effective) equivalent of the negative impedance element untuned to any frequency will be $-R_a$ shunted by C_a. For all types of negative impedance over the range 0.5 Kc/s—1.0 Mc/s the impedance magnitude has been found to decrease in general with increase of frequency though not in a smooth curve.

From the linearity point of view, the dynatron type has appeared to be best suited for use in a.c. circuits over the range 0.5 Kc/s—1.0 Mc/s. The transitron type has been more of non-linear nature, whereas the linearity of the feed-back type has been found to depend upon that of the amplifier.

For dynatron and transitron types the angle of phase-shift has been proportional to $1/\omega$ up to 0.5 Mc/s but varies in a non-linear way with $1/\omega$ between 0.5 and 1.0 Mc/s.

Before proceeding to the scheme of measurements undertaken at present, it is desirable to survey the works of various authors on internal (a.c.) resistances and interelectrode capacitances of thermionic tubes as well as on dielectric constants of ionized medium therein.

The problems relating to (*a*) variation of dielectric constant (*vide* Bergman and During, 1929; Benner, 1929; Benham. 1931; Sil, 1932; Prasad and Varma, 1936; Imam and Khastgir, 1937; Hollmann and Thoma, 1938; Khastgir and Serajuddin, 1939, and Basak, 1941) of electronic medium in diode, triode, and screen-grid tube (operated under normal condition) with frequency and agreement or otherwise of the measured values with Eccles-Larmor, Benner and Lorentz theories and (*b*) variation of internal resistance and interelectrode capacitances (*vide* Benner, 1929; Hartshorn, 1931; Mitra and Sil, 1932; Baker, 1933; Hollmann and Thoma, 1938: Rao, 1940; Khastgir, 1941, and Basak, 1941) of triodes (operated under normal condition and also as dynatron) and screen-grid tubes (operated under normal condition) with frequency have received attention of the majority of workers. A few workers, however, have interested themselves on the dependence of the interelectrode capacitances of thermionic tubes upon the operating conditions (*vide* Moullin, 1933; Dye and Jones, 1933; Bell, 1935; Moullin, 1937, and Jones, 1937).

It will be noted that none of the above studies has related to internal resistance, anode-filament capacitance and dielectric constant of ionized medium for a screen-grid tube operated *under secondary emission condition*. The first author in a previous paper (Chakravarti, 1940) has measured among other things the variation of the magnitude of negative (internal) resistance as well as negative impedance with frequency over the range 0.5 Kc/s—1.0 Mc/s for screen-grid tubes under secondary emission condition.

The present paper relates to extension of work on the nature of dynatron type negative impedance obtained from screen grid tube over the range 1-40 Mc/s, since this alone of all types of negative impedance has proved suitable from all points of view for use in communication circuits at frequencies up to 1 Mc/s.

The work undertaken has consisted of the following:—

(*a*) Measurements of $-R_a$, C_a and C_{af} over range 1-6 Mc/s.

(*b*) Measurements of $-R_a$, C_a and C_{af} over range 6-15 Mc/s.

(*c*) Measurements of $-R_a$, C_a and C_{af} over range 20-40 Mc/s.

(*d*) Measurements of the effect of h.f. voltage amplitude (applied to negative impedance element) on $/R_a/$ and C_{af}.

(*e*) Discussion on variation of $/R_a/$ with frequency for screen-grid tube under secondary emission condition.

(*f*) Discussion on dielectric constant of electronic medium under secondary emission condition and its dependence upon frequency and h.f. operating voltage.

(*g*) Measurements of the linearity of the negative impedance element at 3, 10 and 30 Mc/s.

(*h*) Determination of phase-shift caused by the negative impedance element over range 1-17 Mc/s by cathode-ray oscillograph method developed by the first author.

Four screen-grid tubes of British, American and Continental makes worked under secondary emission condition have been employed for (*a*), (*b*), (*c*), (*d*), (*e*) and (*f*) measurements, while only AC/SG tube has been used for (*g*).

METHOD OF MEASUREMENT OF NEGATIVE RESISTANCE, EFFECTIVE CAPACITANCE AND ANODE-FILAMENT CAPACITANCE

The negative resistance and the shunting effective capacitance of the negative impedance element at a desired frequency (the parallel inductance of choke being of such impedance as to cause no appreciable error when neglected) could be obtained by two measurements of impedance magnitude of the element, one at the desired frequency and another at slightly higher or slightly lower frequency such that values of negative resistance and effective capacitance at this second frequency could be regarded same as those at the first frequency. The impedance could be obtained directly by observing the h.f. voltage drop across the negative element and the h.f. current flowing into the element.

For instance, if negative resistance and shunting effective capacitance at 3 Mc/s ($\omega = 2\pi \times 3 \times 10^6$ r.p.s.) are desired, the impedance of the element (Z) at 3 Mc/s is first obtained. We then have the equation

$$\frac{1}{Z^2} = A^2 = \frac{1}{R_n^2} + \omega^2 C_n^2, \qquad \ldots \quad (i)$$

'A' being the admittance.

Next, the impedance of the same element (Z′) is measured at slightly higher frequency, say, 3.005 Mc/s ($\omega = 2\pi \times 3.005 \times 10^6$) so that the values of the components may be regarded almost the same. Then the new equation will be

$$\frac{1}{Z'^2} = A'^2 = \frac{1}{R_n^2} + \omega'^2 C_n^2. \qquad \ldots \quad (ii)$$

From (i) and (ii), $|R_n|$ and C_n can be obtained.

For this method, (a) the number of observations required is doubled, (b) the h f source must be able to give the value of desired frequency f (Mc/s) *plus* or *minus* 1 to 5 Kc/s accurately over the whole range; and (c) input impedance of the valve voltmeter must be very large compared to the impedance of the element at all frequencies over the range 1-40 Mc/s.

Due to difficulty of obtaining a suitable thermionic voltmeter which would fully satisfy the condition (c) above for the frequency range 1-40 Mc/s, this method was abandoned in favour of a new method evolved by the authors for the purpose.

Fig. 1 shows the circuit diagram and the equivalent circuit. The blocking condenser (C) and shunting choke (L), being of negligibly small and considerably large impedance respectively at the frequencies concerned, have been left out in the equivalent circuit. The impedances of the measuring instruments I_1, I_2 and I_3 are negligibly small at the frequencies concerned.

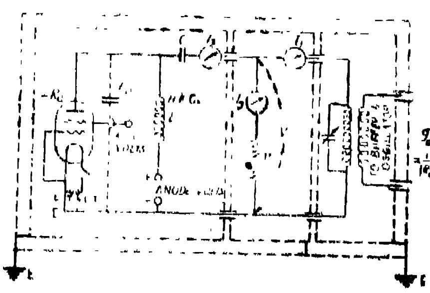

FIG. 1(a)

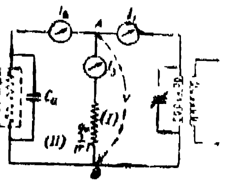

FIG. 1(b)

Let V = voltage between points A-B in the circuit ; g = conductance (magnitude) of arm I of the parallel impedance A-B ; g_a = conductance (magnitude) of negative resistance portion of arm II of the parallel impedance A-B; and C_a = total effective capacitance shunting the negative resistance.

Conductance is ordinarily a scalar quantity, but when negative resistance is involved, the idea of the direction of conductance cannot be avoided. For instance, if a voltage V be applied to terminals 1-2 of a positive resistance 'R' with 1 positive and 2 negative, the direction of current is from 1 to 2 and if the same voltage be applied to terminals 1-2 of negative resistance of the same magnitude 'R' with 1 positive and 2 negative the direction of current is from 2 to 1. The direction of conductance is also reversed in the two cases. In the following calculations, only magnitudes and not directions have been considered for all quantities and consequently the same applies to the case of conductance.

Then
$$V=\frac{I_3}{g} \qquad \text{. (1)}$$

$$V=\frac{I_2}{\sqrt{g_a^2+\omega^2C_a^2}} \qquad \text{... (2)}$$

$$V=\frac{I_1}{\sqrt{(g+g_a)^2+\omega^2C_a^2}}. \qquad \text{... (3)}$$

From (2) and (1),
$$g_a^2+\omega^2C_a^2=\frac{I_2^2}{I_3^2}.g^2 \qquad \text{.. (4)}$$

From (3) and (1),
$$(g+g_a)^2+\omega^2C_a^2=\frac{I_1^2}{I_3^2}.g^2. \qquad \text{... (5)}$$

Subtracting (4) from (5),
$$g^2+2gg_a=\frac{g^2}{I_3^2}(I_1^2-I_2^2)$$

$$2gg_a=g^2\left[\frac{I_1^2-I_2^2-I_3^2}{I_3^2}\right]$$

$$\therefore \quad g_a=\frac{g}{2}\left[\frac{I_1^2-I_2^2-I_3^2}{I_3^2}\right] \text{ in magnitude} \qquad \text{... (6)}$$

and from (4)
$$C_a=\frac{1}{\omega}\sqrt{(I_2^2/I_3^2).g^2-g_a^2}\,. \qquad \text{.. (7)}$$

The value of 'r' and therefore of 'g' at frequencies involved can be accurately known. I_1, I_2 and I_3 can be accurately measured up to 40 Mc/s by Sullivan u.h.f. thermo-milliammeters. Hence the magnitude of g_a and R_a can be known with accuracy. C_a depending on g, g_a, I_2, I_3 and ω can be determined accurately.

Since self-capacitance of the choke together with stray capacitances of wiring, tube base, etc., can also be determined by similar arrangement after removing the tube from its base, C_{af} which is the (hot) anode-filament capacitance can be found out. H.F. power to the measuring arrangement has been supplied from a suitably controlled master oscillator through a buffer stage to obtain stability of the source frequency. The voltage output of the master oscillator decreases with increase of frequency. Great deal of care has been taken in the lay-out of the circuit and screening the different portions and leads as well as the measuring instruments at high and ultra-high frequencies.

MEASUREMENTS OF "$-R_a$," "C_a" AND "C_{af}" OVER RANGE 1-6 Mc/s

Measurements were carried out on dynatrons obtained from four different screen-grid tubes—(1) SG 215 (Mazda), (2) AC/SG (Mazda), (3) A 442 (Philips) and (4) 32 (RCA-American)—over the range 1-6 Mc/s working under conditions set forth in the next paragraph. The tubes SG 215, AC/SG and 32 were new whereas A 442 was in intermittent use for last few years. SG 215, A 442 and 32 were battery-heated tubes whereas AC/SG was an indirectly heated type. Table I gives details of the anodes (from which secondary emission takes place) and anode-cathode distances collected from broken specimen.

TABLE I

Tube	Type of anode structure	Approx. anode dimensions	Approx. width between plates if rectangular	Anode material	Anode-cathode distance (cms)
SG 215	Two rectangular plates	1¼″ × ½″ each	1/8″	Pure nickel	0.51
AC/SG	Do	Do	Do	Do.	0.46
A 442	Do.	5/8″ × 3/8″ each	3/16″	Alloy of iron, nickel molybdenum and cobalt found on spectroscopic analysis	0 64
32	Circular plate	diameter 1″, length 3/4″	,,	Pure nickel	0.88

For SG 215 the screen-grid, plate and control-grid voltages were 80, 40 and 0 volts respectively, the filment current was 0.15 A and a.c. resistance from static characteristic was $-{}_0R_a = -22.86 \times 10^3$ ohms; for AC/SG the screen-grid, plate and control-grid voltages were 60, 28 and 0 volts respectively, the filament current was 1.0 A and a.c. resistance (static) was -15×10^3 ohms; for A 442 the screen-grid, plate and control-grid voltages were 100, 50, and 0 volts repectively the filament current was .06A and a.c. resistance (static) was—69.23×10^3 ohms; and for 32 tube the screen-grid, plate and control grid voltages were 68, 22 and 0 volts respectively, the filament current was .06 A and a.c. resistance (static) was -150×10^3 ohms.

Table II shows the values of $-R_a$, C_a and C_{af} obtained at different frequencies from observations of various currents and known conductance 'g.' Measurements on each tube were made at a constant h.f. voltage at all the frequencies,

TABLE II

Frequency in Mc/s.	SG 215 H.F. Voltage = 12.5'			AC/SG H.F. Voltage = 12.5'			A 442 H.F. Voltage = 12.5"			32 H.F. Voltage = 8.0"		
	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}
	ohms	μμF	μμF	ohms	μμF	μμF	ohms	μμF	μμF	ohms	μμF	μμF
2	−12500	60.6	48.3	−15620	40.5	37.7	−4250	97.7	85.9	−8410	52	40.2
3	−5210	74.0	35.0	−5430	68.0	29.0	−3125	82.2	43.2	−5710	57	18.0
4	−2070	70.6	34.3	−1390	66.3	30.0	−1835	72.5	36.2	−3700	43	6.7
5	−512	65.5	27.7	−868	53.4	15.6	−567	79.8	42.0	−2580	22	10.0
5.5	−735	37.6	2.6	−1100	35.6	0.6	−1100	79.1	41.1	−2500	22.1	11.0

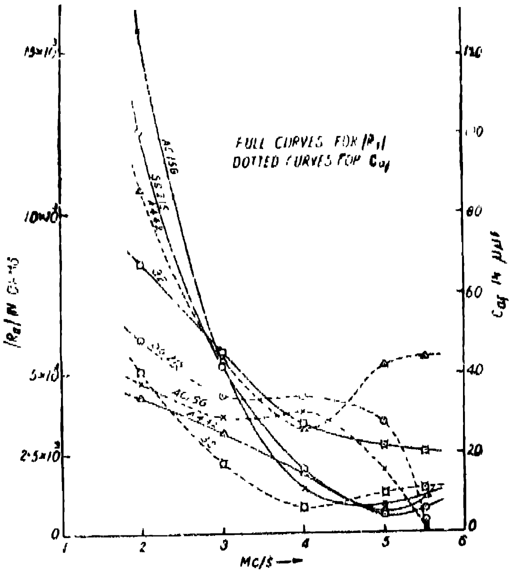

FIG. 2

Variation of R_a and C_{af} with frequency.—Fig. 2 shows the variation of $/R_a/$ and C_{af} with frequency for all tubes over the range 1-6 Mc/s. It will be seen that for all tubes $/R_a/$ decreases smoothly with frequency up to 5 Mc/s and for three of them (except 32) it tends to increase again between 5 and 5.5 Mc/s. It will be observed that for SG 215 and AC/SG C_{af} decreases at first slowly up to 4 Mc/s and then rapidly between 4 and 5.5 Mc/s; and for A 442 and 32 it decreases smoothly up to 4 Mc/s and then increases subsequently.

MEASUREMENT OF "$-R_a$", "C_a" AND "C_{af}" OVER RANGE 6-15 Mc/s

Measurements were made on dynatrons obtained from the four tubes mentioned in Section 3 over the range 6-15 Mc/s. The working conditions and a.c. resistance (static) were the same as those mentioned in Section 3.

Table III shows the measured values of $-R_a$, C_a and C_{af} at different frequencies. Measurements on each tube were made at a constant h.f. voltage at all the frequencies.

TABLE III

Frequency in Mc/s	SG 215 H.F. Voltage=4.1"			AC/SG H.F. Voltage=3.2"			A 442 H.F. Voltage 4.1"			32 H.F. Voltage=2.74"		
	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}	$-R_a$	C_a	C_{af}
	ohms	μμF	μμF	ohms	μμF	μμF	ohms	μμF	μμF	ohms	μμF	μμF
6	− 980	39	1.5	−2360	50.7	13.2	−3330	54.6	17.1	− 720	50.3	12.8
8	−2700	42.5	4.5	−1300	45.2	7.2	−1770	42.4	4.4	− 260	41.8	3.8
10	−1180	46.7	8.5	−1040	62	23.8	−1560	47.2	9.0	− 360	45.2	7.0
12	− 310	37.8	2.6	− 220	40.1	4.9	− 328	43.3	8.1	− 880	39.4	4.2
14	− 310	33.8	8.3	− 250	26	0.5	− 230	32.0	6.5	−1110	26.8	1.3

Variation of $/R_a/$ and C_{af} with Frequency

Fig. 3 shows the variation of $/R_a/$ and C_{af} with frequency for all tubes over the range 6-15 Mc/s. It will be seen that $/R_a/$ for A 442 and AC/SG decreases more or less smoothly with increase of frequency, for SG 215 it increases to a maximum value at 8 Mc/s and then decreases smoothly with increase of frequency and for 32 tube it decreases to a minimum value and then increases smoothly with increase of frequency. The variation of $/R_a/$ with frequency for SG 215 appears to be exactly opposite to that of 32.

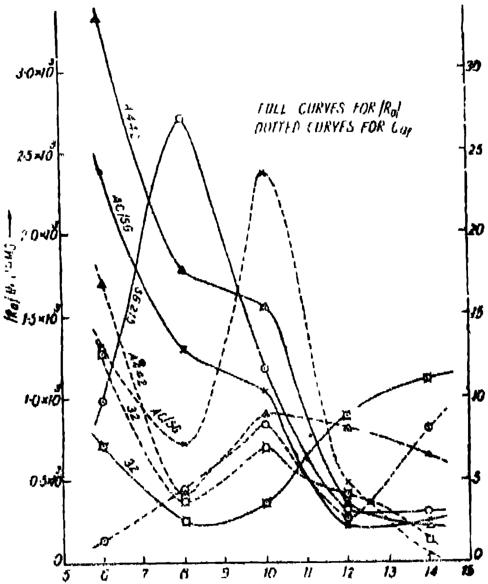

FIG. 3

It will be observed that the nature of variation of C_{af} with frequency for all tubes over the range 6-15 Mc/s is similar to a combination of resonance and anti-resonance characteristics. For AC/SG, A 442 and 32 tubes C_{af} decreases with frequency to a minimum at 8 Mc/s, then increases till 10 Mc/s and subsequently decreases. For SG 215, it increases till 10 Mc/s, then decreases till 12 Mc/s and subsequently increases again.

MEASUREMENTS OF "$-R_a$," "C_a" AND "C_{af}" OVER RANGE 20-40 Mc/s

Measurements were carried out on dynatrons obtained from the same four tubes mentioned in Sections 3 and 4 over the range 20-40 Mc/s. The working conditions and a.c. resistance (static) were the same as those mentioned in Section 3.

Table IV shows the measured values of $-R_a$, C_a and C_{af} at different frequencies. Measurements on each tube were made at a constant h.f. voltage at all the frequencies.

TABLE IV

Frequency in Mc/s	SG 215 H. F. Voltage=0.3"			AC/SG H. F. Voltage=0.4"			A 442 H. F. Voltage=0.4"			32 H. F. Voltage=0.4"		
	$-R_a$ or R_a	C_a	C_{af}	$-R_a$ or R_a	C_a	C_{af}	$-R_a$ or R_a	C_a	C_{af}	$-R_a$ or R_a	C_a	C_{af}
	ohms	$\mu\mu F$	$\mu\mu F$	ohms	$\mu\mu F$	$\mu\mu F$	ohms	$\mu\mu F$	$\mu\mu F$	ohms	$\mu\mu F$	$\mu\mu F$
20	−286	109	47	−400	147	85	−185	76.7	14.7	−345	84	22.0
22.5	−196	109	42	−137	140	73	−175	76.7	9.7	−339	87.7	20.7
25	−126	184	114	−182	82.8	12.8	−169	119	49	−180	91.0	21.0
27.5	−126	184	114	−116	122	52	−150	109	40	−139	102	32
30	−56	178	99	−43	115	36	−84	115	36	−83	93.4	14.4
32.5	−126	201	115	−54	153	67	−79	147	61	−100	92.4	6.4
35	−101	248	158	+143	108	18	−104	162	72	−107	95.8	5.8
37.5	−98	311	205	+36	87	14 ?	−36	187	81	−103	116	10.0
40	+20	120	8	+714	89.2	14 ?	+44	75	73 ?	−54	123	11.0

On the Positive sign of the Resistance component measured at some of the high frequencies

It will be seen from Table IV that only for 32 the resistance component has been found to be negative up to 40 Mc/s, for SG 215 and A 442 it has been negatiye up to 37.5 Mc/s and for AC/SG it has been negative up to 32.5 Mc/s.

This deviation for some of the tubes at frequencies higher than a certain value may be due to one or both of the causes given below.

(1) The values of I_1, I_2 and I_3 obtained at frequencies above 37.5 and 32.5 Mc/s for SG 215 and A 442 and AC/SG respectively may not have been correct due to loss by radiation from tube systems, portions of circuit, etc., at these high frequencies.

(2) A very large amplitude oscillation (or possibly a very large amplitude oscillation with amplitude increasing with time as in a negative resistance circuit) whose frequency is the same as or near about that of the impressed h.f. voltage may have been set up due to either the "amplification effect" of the type found by the first author elsewhere or the "resonance" effects in the tube system or due to both the causes and caused impairment or break-down of the negative resistance condition.

Variation of $/R_a/$ and C_{af} with frequency

Fig. 4 shows the variation of $/R_a/$ and C_{af} with frequency for all tubes over the range 20-40 Mc/s. It will be observed that the variation of both $/R_a/$ and C_{af} with frequency over this range is more complex than that over 1-6 Mc/s and 6-15 Mc/s ranges.

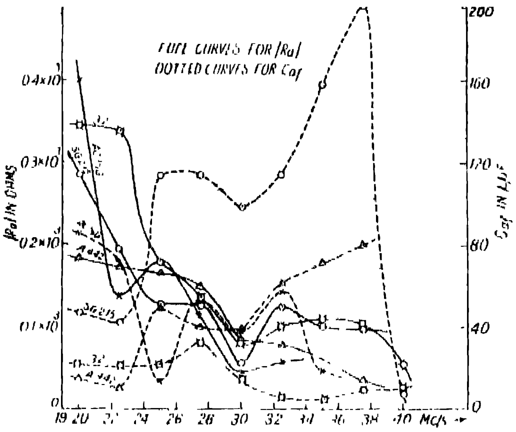

FIG. 4

For SG 215, AC/SG and 32, $/R_a/$ first decreases then increases to decrease again presenting a wavy characteristic; and for A 442 it decreases with frequency though not in a smooth curve.

For SG 215, AC/SG and A 442, C_{af} varies with frequency in a wavy manner whereas for 32 it first increases and then decreases with frequency.

DEPENDENCE OF $/R_a/$, C_a AND C_{af} UPON THE OPERATING H. F. VOLTAGE AMPLITUDE

$/R_a/$, C_a and C_{af} were measured at different values of V, keeping the frequency constant. V was obtained accurately from the product of I_3 and r.

Tables V, VI and VII show the results of measurement at 3, 10 and 30 Mc/s respectively for the four dynatron units operated under conditions mentioned in Section 3.

TABLE V (at 3 Mc/s)

S G. 215				AC/SG				A 442				32			
V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}
volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF
6.1	−3900	66.3	27.3	6.1	−4460	58.3	19.3	3.0	−4500	87.6	48.6	10	−4000	28.6	16.0
12.5	−5210	74.0	35.0	12.5	−5430	68	29.0	6.0	−6250	75.2	36.2	20	−3970	31.2	24.7
16.3	−4310	63.2	24.2	18.5	7040	61.6	22.6	7.3	−5020	75.6	36.6	25	−3330	11.4	7.4
20.0	−4390	61.8	22.8	21.3	−6410	60.9	21.9	8.0	−5100	76.0	37.9	40	−4330	15.7	12.5
23.8	−4170	63.2	24.2	25.0	−5950	61.3	22.3	10.4	−5350	76.8	37.8	50	−4440	16.2	13.0
27.5	−5320	62.2	23.2	28.8	−4310	64.6	25.6	12.1	−4690	76.7	37.7	—		—	—
30.0	−5100	63.5	24.5	—	—	—	—	—	—	—	—	—		—	—

TABLE VI (at 10 Mc/s)

SG 215				AC/SG				A 442				32			
V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}
volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF
1.59	− 357	91.5	53.3	1.59	− 442	78.5	40.3	1.59	− 233	75.5	37.3	1.59	− 443	87.8	49.6
2.30	− 478	58.6	20.4	2.3	− 521	46.0	7.8	2.3	− 478	63.8	25.6	2.3	− 402	54.4	16.2
3.19	− 588	39.2	1.0	3.19	− 1042	56.8	18.0	3.19	− 541	46.6	8.4	2.74	− 361	45.2	7.0
4.07	−1140	46.0	7.8	4.07	− 735	49.4	11.2	4.07	− 1500	47.0	8.8	3.19	− 384	46.1	7.9
4.78	− 555	43.6	5.4	4.78	− 653	45.4	7.2	4.78	− 840	43.3	5.1	4.16	−1770	40.1	1.9
5.31	− 653	43.6	5.4	5.31	− 492	39.3	1.1	5.31	− 735	42.4	4.2	5.2	−1610	39.0	0.8
6.28	− 478	41.2	3.0	6.18	− 442	39.4	1.2	6.28	521	43.0	4.8				

TABLE VII (at 30 Mc/s)

SG 215				AC/SG				A 442				32			
V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}	V	$-R_a$	C_a	C_{af}
volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF	volts	ohms	μμF	μμF
0.12	−158	191	112	0.14	−122	258	179	0.20	−127	188	109	0.27	− 54.6	117	38.0
0.20	−104	210	131	0.21	−108	199	120	0.29	−120	156	77	0.47	− 85	93.0	14.0
0.27	− 56	178	99	0.27	− 58	189	110	0.35	− 84	124	45	0.61	−117	86.9	7.9
0.33	− 55	142	63	0.35	− 38	121	42	0.46	− 84	98	19	0.77	−263	65.0	25.0
0.40	− 46	97	18	0.40	− 43	115	36	0.55	− 80	90	11	0.93	−104	71.3	31.3
0.46	− 59.5	114	35	0.50	− 46	101	22	0.65	− 80	80	1	1.08	− 96	57.2	17.2
0.53	− 66.6	104	25	0.56	− 44	84.4	5.4					1.20	− 86	54.5	14.5
0.65	− 63	93.2	14.2	0.63	− 42	82.0	3.0								

Variation of $/R_a/$ and C_{af} with H.F. Voltage Amplitude

Measurements in Tables V, VI and VII show the variation of $/R_a/$ and C_{af} with h.f. voltage at 3, 10 and 30 Mc/s respectively.

At 3 Mc/s, C_{af} for all tubes decreases in general with increase of voltage—first increasing, then decreasing with slight increase subsequently; and $/R_a/$ for all tubes except 32 at first increases and then decreases, giving peaky curves. For 32, $/R_a/$ remains constant, then decreases and subsequently rises roughly to the initial values.

At 10 Mc/s, for C_{af} for SG 215 and AC/SG at first decreases and then increases slightly to decrease again and for A 442 and 32 it decreases with increase of voltage; and $/R_a/$ for all tubes increases initially to a peak value to decrease subsequently.

At 30 Mc/s, C_{af} for all tubes except 32 decreases in general with increase of voltage and for 32 it first decreases and subsequently increases with increase of voltage; and $/R_a/$ for all tubes except 32 at first decreases in general with increase of voltage (though not in a smooth curve) and then remains roughly constant and for 32 it first decreases, then rises to a peak value to decrease again.

7. DISCUSSION ON THE NATURE OF VARIATION OF $/R_a/$ WITH FREQUENCY

According to Hartshorn, the internal resistance of a triode decreased with increase of frequency.

Mitra and Sil worked out a variation of internal resistance with frequency which differed entirely from Hartshorn's theory. According to their calculation the internal resistance of a triode would be independent of frequency for frequencies lower than a certain value, say 'f' Mc/s, and would increase gradually with increase of frequency for values higher than 'f' Mc/s.

Rao found that the internal resistance of triodes used by him at first decreased with increase of frequency till 1.6 or 2.0 Mc/s (depending upon the tube) and then increased steadily with increase of frequency. Basak found that the resistance of anode—screen-grid space of a screen-grid tube under normal condition decreased with increase of frequency over the range 0.5—1.0 Mc/s.

Hollman and Thoma showed that the resistance of electronic medium inside a thermionic valve would decrease with increase of frequency from very low to very high frequencies.

It will be noted that measurements of internal resistance were carried out by majority of workers over frequency ranges which were not large enough for any definite deduction as to the general nature of variation of $/R_a/$ with frequency to be made, and further the effect of amplitude of h.f. voltage impressed between plate and filament on $/R_a/$ was not considered at all, since this would also modify the nature of variation of $/R_a/$ with frequency unless the h.f. voltage amplitude was adjusted to the same value at all frequencies.

The present work along with the first author's previous work relates to variation of $/R_a/$ of screen-grid tubes *under secondary emission* condition with frequency over the range 0.5 Kc/s—40 Mc/s as well as its variation with h.f. voltage amplitude at various frequencies in the range. Compared to triodes and screen-grid tubes worked under normal condition, the conditions in screen-grid tubes under secondary emission condition affecting the internal resistance and dielectric constant are as follows :—(1) The time of stay of the electrons (T) is somewhat longer (*i.e.*, 0.1×10^{-8} sec., 0.1×10^{-8} sec., 0.11×10^{-8} sec., and 0.2×10^{-8} sec. calculated for SG 215, AC/SG, A 442 and 32 respectively) ; (2) the thermionic current is comparatively smaller and (3) there is more uniform distribution of electrons in anode-filament space.

From measurements performed with time of stay, thermionic and filament currents, control grid voltage, screen-grid and anode voltages and h.f. voltage kept constant at all frequencies, it has been found that the law of variation indicated by the *mean curve* derived from the experimental curve is that the internal resistance decreases with increase of frequency (according to the inverse square law) from very low to very high frequencies in agreement with Hollmann and Thoma as well as Hartshorn. Several "turning points" (more or less of the nature mentioned by Khastgir with reference to Rao's work) are noticeable in the experimental curve if drawn over a sufficiently large frequency range. From these turning points, as frequency increases, the curve can be seen to rise slightly over a frequency band of width varying from less than 1 Mc/s to 8 Mc/s (giving an increase of resistance with increase of frequency over this band) and subsequently to fall at higher frequencies.

If measurement be started from one of these "turning point frequencies" or a frequency higher than this, the internal resistance will be found to increase with increase of frequency over a band width of 7 to 8 Mc/s. If measurement be started from a frequency less than the turning point frequency but is not continued beyond that point, an opposite law of variation will be obtained ; and if measurement be continued beyond the turning point frequency results similar to those of Rao will be found.

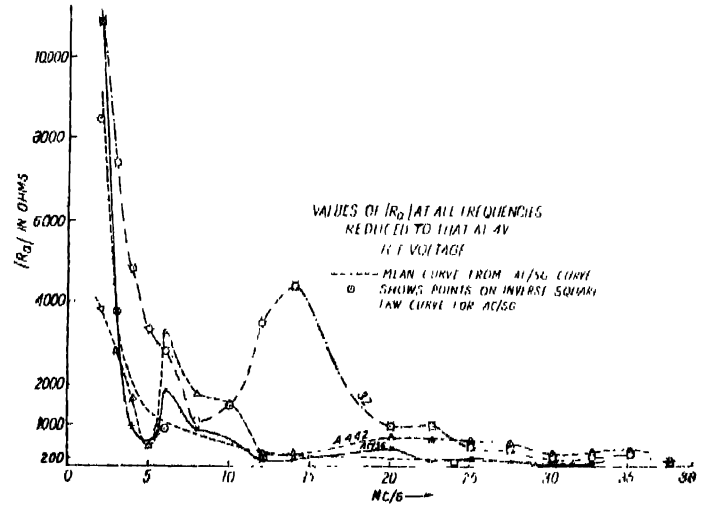

FIG. 5

FIG. 5 shows the variation of $/R_a/$ with frequency (the values of $/R_a/$ at all frequencies having been reduced to those at 4 volts h.f. voltage amplitude) over the range 1-40 Mc/s for AC/SG, A 442 and 32 tubes. Taking the mean curve for AC/SG (drawn plain-dotted) it will be seen to pass almost through all the points lying on the inverse square law curve thereby satisfying the relation $/R_a/ \propto \frac{1}{\omega^2}$ in accordance with the law of conductivity $\sigma \simeq \frac{Ne^2\omega^2T^3}{12m}$ (when ωT is sufficiently small) given by Hollmann and Thoma.

DISCUSSION ON DIELECTRIC CONSTANT OF ELECTRONIC MEDIUM UNDER SECONDARY EMISSION CONDITION AND ITS DEPENDENCE UPON H.F. OPERATING VOLTAGE AND FREQUENCY

The dielectric constant of the electronic medium between anode and filament of screen-grid tubes under secondary emission condition has been estimated over the range 1-40 Mc/s, from values of C_{af} under 'filament on' or 'hot condition' (as given in Tables II, III, IV, V, VI and VII) and values of C'_{af} under 'filament off' or 'cold condition' (as measured by connecting anode-filament capacitance in parallel to the capacitance element of a standard oscillatory circuit and observing frequency-change thereby).

In the past, the dielectric constant of the electronic medium in a screen-grid tube (under normal condition) with increase of frequency has been measured by Prasad and Verma and also by Imam and Khastgir. Prasad and Verma carried out their measurements over the range 0.57-3.7 Mc/s and found their results agreeing with the Eccles-Larmor theory. Imam and Khastgir experimented over the range 60-75 Mc/s and found that dielectric constant of electronic medium between anode and filament decreased as frequency was increased from 60 to 64 Mc/s and then increased with further increase of frequency up to 75 Mc/s. Their measurements between 64-75 Mc/s did not satisfy the Eccles-Larmor theory. Imam and Khastgir further examined the effect of increasing filament current, screen-grid voltage and anode voltage on the dielectric constant.

As in the previous section the measurement of dielectric constant needed to be carried out over a sufficiently large frequency range and the effect of amplitude of h.f. voltage impressed between plate and filament should also have been considered.

The present studies relate to (1) the variation of the dielectric constant of the electronic medium under secondary emission condition with the increase of h.f. voltage applied between anode and filament, keeping filament current, anode voltage, control-grid and screen-grid voltages same at all frequencies; and (2) the variation of the dielectric constant of the electronic medium under secondary emission condition with increase of frequency keeping filament current, anode voltage, control-grid and screen-grid voltages same at all frequencies.

Variation of dielectric constant with h.f. operating voltage. It will be seen from Fig. 6*a* that (*a*) at 3 Mc/s the dielectric constant varies with increase of h.f.

voltage in a wavy manner though the variation is small; (*b*) at 10 Mc/s it decreases with increase of h.f. voltage though not in a smooth curve; and (*c*) at 30 Mc/s it decreases rapidly with increase of h.f. voltage for AC/SG and A 442 but varies in a wavy manner for 32 tube, the variation being larger than that at 3 Mc/s. It may be said that at 10 and 30 Mc/s the dielectric constant is much greater than unity at smaller values of h.f. voltage and becomes in general less than unity at higher values of h.f. voltage.

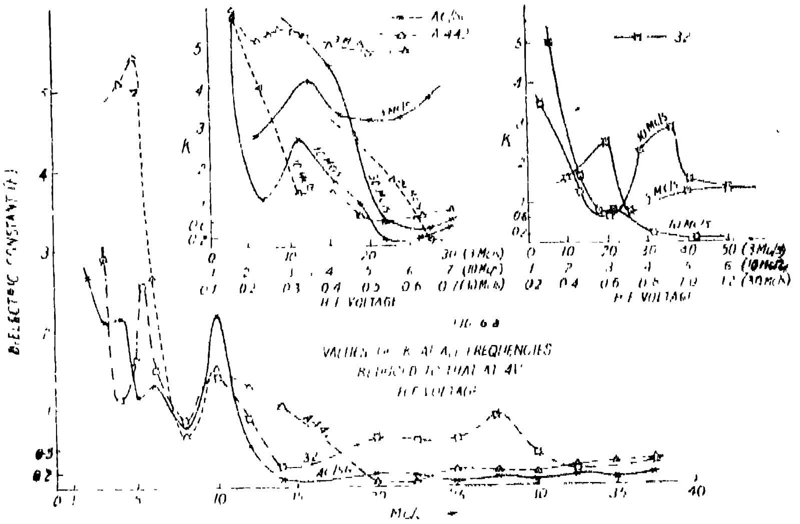

Fig. 6

Variation of dielectric constant with frequency. It will be observed from Fig. 6b (the values of dielectric constant having been reduced to that at 4V h.f. voltage amplitude) that (*a*) the curves of variation between 1-40 Mc/s are wavy showing peaks and depressions and (*b*) the value of 'K' is less than unity between 7-9 Mc/s as well as after 11 Mc/s for AC/SG and 32 and after 14 Mc/s for A 442. The Eccles-Larmor theory does not hold good for the measurements undertaken.

It has already been observed by some of the previous workers for electronic atmosphere in other types of vacuum tube that the dielectric constant could be sometimes less than, sometimes greater than and sometimes equal to unity. The present case appears to confirm this view-point for the anode-filament space of screen-grid tube under secondary emission condition over 1-40 Mc/s range. The effect of much smaller thermionic current and of the time of stay of the electrons shorter compared to the period of h.f. oscillation at lower frequencies has been to give very high values of dielectric constant (greater than unity) at these frequencies. As frequency increases above 10 Mc/s, the time of stay of the electrons (in this case) approaches the period of h.f. oscillation. This fact together with more uniform distribution of electrons in anode-filament space appears to give very low values of dielectric constant (much less than unity) at frequencies higher than 10 Mc/s.

LINEARITY OF NEGATIVE IMPEDANCE ELEMENT OVER RANGE 1-40 Mc/s

The variation of $/R_a/$, C_a and C_{af} with h.f. voltage has been considered in Section 6. When negative impedance has to be used in a circuit or network, the dependence or independence of the magnitude of negative impedance *as a whole* rather than that of its components upon the amplitude of h.f. voltage impressed is of very great importance.

The magnitude of negative impedance (that is $/Z/$) has been computed from the measured values of $/R_a/$ and effective capacitance C_a.

Tables VIII, IX and X show the magnitude of negative impedance as whole as the h.f. voltage is increased at 3, 10 and 30 Mc/s respectively.

TABLE VIII (at 3 Mc/s)

SG 215		AC/SG		A442		32	
V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms
6.1	785	6.1	892	3.0	601	10.0	1684
12.5	711	12.5	773	6.0	702	20.0	1563
16.3	824	18.5	855	7.3	697	25.0	2707
20	812	21.3	864	8.6	684	40.0	2656
23.8	843	25.0	856	10.4	685	50.0	2635
27.5	843	28.8	807	12.1	684		
30.0	825						

TABLE IX (at 10 Mc/s)

SG 215		AC/SG		A442		32	
V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms
1.59	229	1.59	184	1.59	156	1.59	168
2.30	236	2.30	160	2.30	221	2.30	236
3.19	334	3.19	270	3.19	285	2.74	252
4.07	331	4.07	295	4.07	330	3.19	257
4.78	305	4.78	309	4.78	337	4.16	388
5.31	318	5.31	313	5.31	334	5.2	395
6.28	301	6.28	298	6.28	302		

TABLE X (at 30 Mc/s)

S. G. 285		AC/SG		A 442		32	
V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms	V volts	|Z| ohms
0.12	27.4	0.14	20.3	0.20	27.5	0.27	34.9
0.20	25.0	0.21	25.9	0.29	32.7	0.47	47.4
0.27	27.5	0.27	25.3	0.35	38.1	0.61	54.1
0.33	30.9	0.35	28.7	0.46	45.5	0.77	78.0
0.40	35.1	0.40	31.5	0.55	47.5	0.93	60.5
0.46	36.5	0.50	34.6	0.65	48.1	1.08	66.6
0.53	40.5	0.56	35.9			1.20	63.0
0.65	42.2	0.63	35.2				

It will be seen from the tables VIII and IX that at 3 and 10 Mc/s the impedance magnitude for all dynatrons has generally been lower at low voltages and increases to almost constant value at voltages beyond 4 to 6 dbs above the initial voltage. The dynatrons obtained from SG 215, AC/SG and A 442 could be regarded for most purposes as linear impedances at the above frequencies. Table X shows that alteration in impedance-magnitude at 30 Mc/s for voltage variation of 14 dbs is greater than that at 3 and 10 Mc/s for the same variation of voltage.

PHASE-SHIFT CAUSED BY NEGATIVE IMPEDANCE ELEMENT OVER RANGE 1-17 Mc/s

The phase-shift caused by negative impedance element obtained from AC/SG tube has been measured by the " Cathode-Ray Oscillograph Method " employed by the author in a previous paper (Chakravarti, 1943).

A resistance (which is purely non-reactive at frequencies involved) is connected in series with the negative impedance element and fed from the h.f. source by the usual circuit arrangement. The voltage drops across the non-reactive resistance and the negative impedance element are applied to two exactly similar superheterodyne linear amplifiers with the same local oscillator and the corresponding I.F. Voltage outputs are applied to the respective pairs of plates of the oscillograph. The phase-shift caused by negative impedance element has been obtained from the phase difference measured between the two applied voltages. The phase-shift under similar conditions has also been calculated from the measured values of $|R_n|$ and C_n given in section 3 and 4.

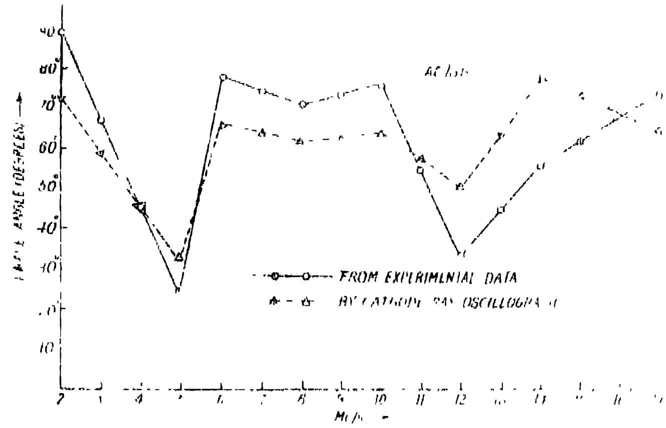

FIG. 7

Fig. 7 shows the phase-shift for AC/SG at different frequencies as obtained by cathode-ray oscillograph method as well as calculated from measured values given in Sections 3 and 4. It will be seen that over the range 1-17 Mc/s the variation of phase-shift is irregular since both R_n and C_n have been found to vary differently over different portions of the frequency range. Between 1 and 5 Mc/s, the phase-shift angle varies inversely as ω and between 5 and 6 Mc/s it varies directly as ω. Between 6 and 17 Mc/s it remains roughly constant except for a decrease at 12 Mc/s.

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