TRAVELLING WAVE TUBES
AND THEIR APPLICATIONS

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Introduction

The problem assigned to be studied in this work was "The conditions of the synchronization of the backward-wave oscillator".

Since the backward-wave oscillator is a travelling-wave device, a thorough study of the travelling-wave tube as an amplifying device was necessary. A survey of the literature concerning the different methods of approach followed in the study of the travelling-wave tube are given in chapter I of this thesis for the two main cases of a small-signal being amplified or a large-signal where the tube is driven into the saturation region. Our contribution to this part of the thesis is minor and is restricted to the consideration of the effect of the space-charge in the treatment given by Pease (8) to obtain different current, voltage and field components in the tube.

The next logical step was to study the conditions of oscillation and the behaviour of the backward-wave oscillator under free running conditions. This is represented in chapter II. In this aspect some trials were explained in the literature to give the output power and [illegible] oscillator, when the beam current is [illegible] to its value necessary for starting of oscillation. In these ori[illegible] the relations governing the behaviour of the oscillator were linearized and sometimes drastic assumptions * were necessary to obtain final expressions of these quantities.

Similarly the analytical work and the experimental findings of Sakuraba (9) considering the frequency pushing of the oscillator, i.e. the variation of the natural frequency of oscillation with the beam current, were studied ; From which large differences between the experimental results and the theoretical expectation were found.

In the study of the behaviour of the backward-wave oscillator, we obtained expressions for the dependence of the output power of the oscillator on the value of the beam current. These expressions unfortunately could not be checked, since there were no published reliable experimental data and no similar expressions available in the literature.

* [illegible] (17) and (18) in the Bibliography

As regards frequency pushing an expression was obtained giving the dependence of the oscillator frequency on the starting current. This expression checks with that suggested by Sakuraba as the most suitable fit for the experimental results except for a multiplier of two which we could not account for.

The final step in this study was the consideration of the synchronization problem of the backward-wave oscillator, and this is represented in chapter III.

The only available publication dealing analytically with this problem is that given by Ash (11). In this publication, assuming linear behaviour of the oscillating system and the beam current is just equal to the starting one, Ash obtained an expression for the value of the necessary input signal to synchronize the oscillator as a function of the frequency deviation. All publications upto 1967 that we passed through and touching the problem referred to the article given by Ash.

Considering the non linear nature of the oscillating system, we attacked the problem and obtained closed forms for the following

1. The critical value of the input signal necessary for synchronization.

[illegible]

[illegible]. The variation of the output power of the synchronized or locked oscillator with the beam current.

It is to be noticed that the results obtained in the above are in line with the general behaviour of a synchronized oscillator concerning the decrease of the amplitude of free oscillation before complete locking is obtained with the input signal.

[illegible]

[illegible] Travelling Wave Tube

1.1 Synopsis

Two different philosophies have been followed in analysing the performance of the travelling-wave tube. In the first, which is known as the small-signal analysis, the signal and its effects are considered small compared to the quiescent conditions of the tube and the Eulerian approach is used in which the beam is considered as a fluid and the conditions for the solution is considered at one point of the beam where the electric field, the electron velocity, the electron concentration and [illegible] the current are determined.

In the second the signal and its effects are considered large and the Lagrangian mechanics is used in which [illegible] electron in the beam is followed to determine [illegible] [illegible] the current and electric field at [illegible] [illegible].

[illegible] first philosophy, different [illegible] [illegible] have been considered. The first [illegible] the parameters of the beam and the [illegible] parameters of the circuit. In this treatment however, Pease did not consider the effects of the space-charges and in the description of this method in what follows, the effect of the space-charges is taken into account, and the differences between the results obtained and those of Pease are pointed out.

The above three methods namely the normal mode method given by Pierce the coupled mode method and that given by Pease are rather approximates and they consider parameters of the equivalent transmission line to be determined experimentally.

A more rigorous method is the field analysis method in which Maxwell equations are applied to the different regions of the helix and the beam separately and then solved to satisfy the boundary conditions between these regions.

This method, although it is more difficult, yet it can be used to determine the parameters of the equivalent transmission line sought in the transmission line approach method. Besides, it can be reduced and simplified to simple equivalent circuit. This equivalent circuit [illegible] suggested by Mathews was [illegible] simpler form. [illegible] our representation by considering the symmetrical properties of the network instead of the solution of three simultaneous equations as suggested by Mathews.

In the following we shall give a description of the main ideas in each of the above mentioned approaches in the small-signal method together with the description of the large-signal method of analysis.

Our comments, if any, will be mentioned in place.

In all the methods of analysis the following assumptions have been considered :

1. We deal with one dimensional problem i.e.
   - (a) The motion of the electrons is confined to the z-direction and there is no transverse electron motion in the y or the x directions.
   - (b) There is aconstant axial electric field over the cross-section of the beam.

2. The electron velocity is a small fraction of the velocity of light, so that non relativistic effects apply. The longitudinal force due to the magnetic field of any travelling field [illegible] the system may be neglected in comparison with the force due to the longitudinal electric field.

[illegible]

. The normal-mode [illegible]

This method consists of simultaneously [illegible] two equations, one relating the r.f. current produced in the electron stream by an impressed r.f. field from the circuit and is known as the electronic equation. The other equation relates the r.f. field produced on the circuit by an impressed r.f. current from the electron stream and is known as the circuit equation.

All signal components are considered to vary as $\exp(j\omega t - \Gamma z)$. Since the signal level is small, then all cross products of alternating quantities may be neglected.

The electronic equation

Following Pierce (27), we shall write the quantities involved in the form of an average plus [illegible] component, as follows :

The electron velocity $= u_0 + v$

The charge density $= -\rho_0 + \rho$

The convection current $= -I_0 + i$

$= S(-\rho_0 + \rho)(u_0 + v)$

[illegible], [illegible] symbols without subscript stand for r.f. quantities.

The equation of motion of an electron in a field E can be written in the form

$$\frac{-e}{m} E = \frac{dV}{dt} = \frac{\partial V}{\partial t} + u_o \frac{\partial V}{\partial z}$$

Hence, $$\frac{\partial V}{\partial z} + JB_e v = \frac{-eE}{mu_o}$$

$$-\gamma v + JB_e v = \frac{-eE}{mu_o} \qquad (1.1)$$

where $B_e = \frac{w}{u_o} =$ The electronic propagation constant.

The continuity equation is given by

$$\frac{\partial i}{\partial z} = -S \frac{\partial \rho}{\partial t}$$

Hence, $$\frac{\partial i}{\partial z} + JB_e i = -JB_e I_o v \qquad (1.2)$$

Combining Eqs.(1.1) and (1.2), we get

$$i = \frac{jweEI_o}{mu_o^3(jB_e - \gamma)^2}$$

which can be written as

$$i = \frac{jEB_e I_o}{2V_o(jB_e - \gamma)^2} \qquad (1.3)$$

where V_o is the beam voltage $= \frac{1}{2}\frac{m}{e}u_o^2$

We note the following on the electronic equation [illegible] with [illegible] valid as [illegible] the i.e. [illegible] properties [illegible] not vary with z.

(b) The electronic admittance Y_e is given by

$$Y_e = \frac{i}{v} = \frac{jB_e I_0}{2V_0(jB_e - \gamma)^2} \qquad \text{mhometer}$$

For a wave which increases in the direction of electron flow (the positive z direction); let

$$\exp(-\gamma z) = \exp((\alpha - jB)z)$$

Hence,
$$Y_e = \frac{B_e I_0}{2V_0} \frac{(2\alpha(B_e - B) - j(B_e - B)^2)}{(\alpha^2 + (B_e - B)^2)^2}$$

The electron stream can transfer energy to the circuit only if the real part of Y_e is negative. That is if $B > B_e$, i.e. if the electron velocity is greater than the phase velocity of the wave.

(c) [illegible] represents [illegible] given position z.

[illegible]

$$[illegible] \qquad (1.4)$$

[illegible]

[illegible] E_{sp}, [illegible] due to excitation by electrons very near to that position.

It is to be noted that the circuit can have more than one mode. The fundamental mode only will be considered. The effect of any other mode if excited can be taken care of by a small modification of the space charge field.

The space charge field can be determined from

$$\frac{\partial E_{sp}}{\partial z} = \frac{\rho}{\epsilon'}$$

and

$$\frac{\partial i}{\partial z} = -S\frac{\partial \rho}{\partial t} = -jW\rho S$$

So

$$E_{sp} = \frac{-i}{jW\epsilon' S} = \frac{-i u_0 [illegible]}{jI_0 W \epsilon'}$$

Where ϵ' is the effective dielectric constant. Defining [illegible] plasma frequency W_1 as

$$W_1^2 = [illegible]$$

[illegible]

$$E_{sp} = [illegible] \qquad (.)$$