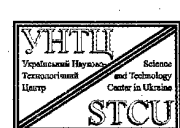
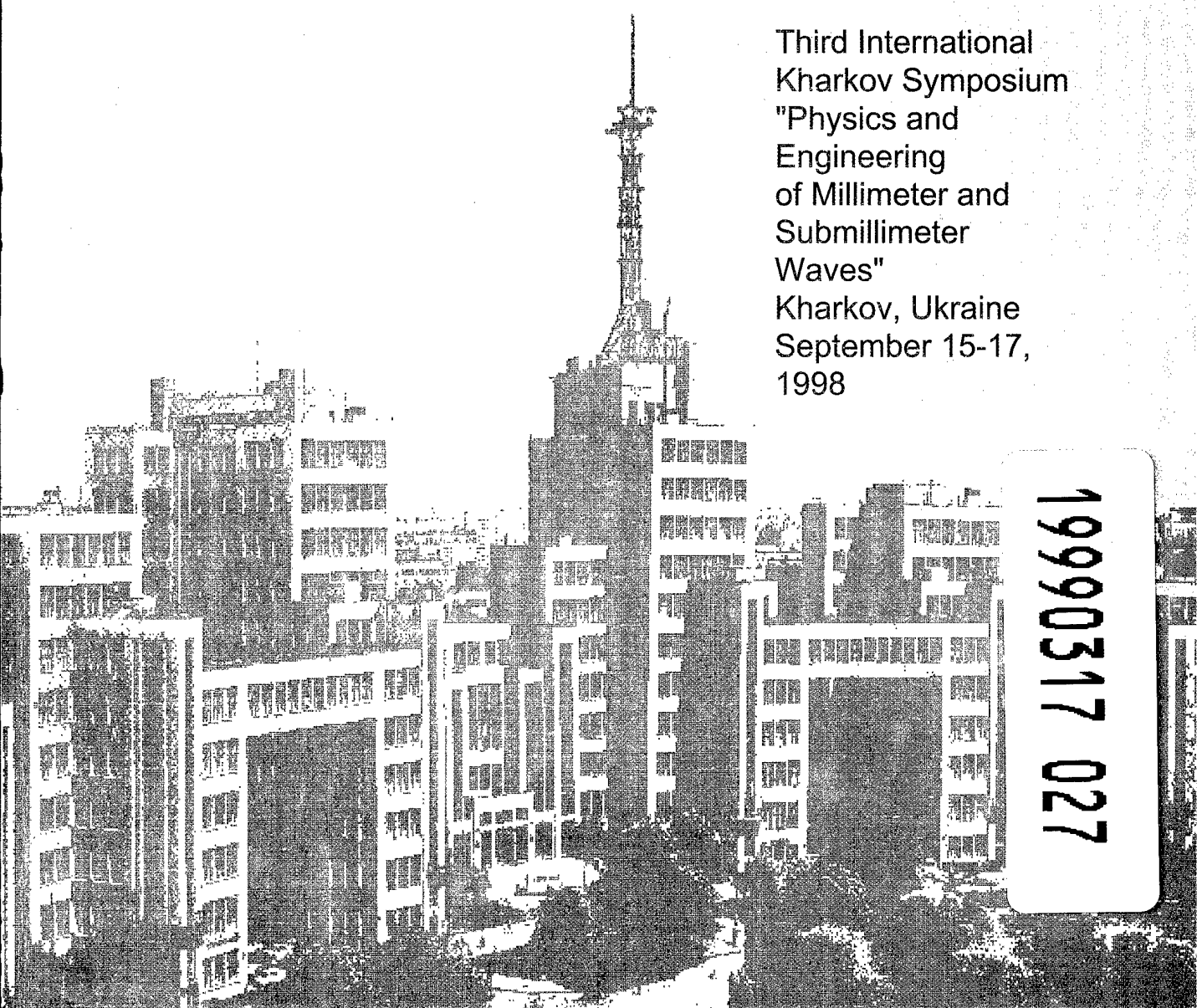


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## ANALYSIS OF ELECTRON-WAVE INTERACTION IN CATHODE DRIVEN CROSSED-FIELD AMPLIFIERS BY COUPLED-MODE METHOD

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Increasing a gain of the crossed-field amplifiers is one of the most important problems [1]. To solve of this problem the various approaches are used. The main attention has been given to the advancement of the existing tubes and improvements in use of new technological processes and new materials. However, the theory of the tubes with improved characteristics is not sufficient advanced to evaluate in full measure their limited opportunities.

In present paper the processes of electron-wave interaction in the cathode driven crossed-field amplifiers are studied. These tubes have a higher gain due to the use of the weakly coupled delay lines placed on the anode and negative electrode (cathode). As a result the r.f. signal of same frequency is applied to the input of a cathode delay line (or to the inputs of the anode and cathode delay lines) and after an amplification the signal is coming to the output of the anode delay line (the mode of cathode excitation).

The interaction space of a classical crossed-field amplifier and cathode driven amplifier is schematically shown in Figure 1. As can be seen the areas of the input of r.f. wave ( $y = d$ ) and the injection of electron beam ( $y = y_0$ ) at the classical tubes are spatially separated (Figure 1, a). The use of the cathode excitation permits maximally to bring together these areas and hence to increase the value of r.f. field at the point in which the electron beam is. As a result we can decrease the power of input signal without deteriorating of the bunching and thus to increase the gain of the tube.

To analyze the physical processes in the cathode driven amplifiers let us use by coupled-mode method [2]. According to given method the system of differential equations will be written in the following form:

$$\frac{d A_i}{d z} = -j C_{ii} A_i - j \sum_{k=1}^N C_{ik} A_k, \quad i = 1, 2, 3, \dots, N, \quad (1)$$

where  $C_{ii} = \beta_i$  is the phased constant of the  $i$ -th wave propagating in a delay line without the electron beam;  $C_{ik}$  is the coupling factors between  $i$ -th and  $k$ -th normal waves ( $i \neq k$ );  $N$  is the number of the coupled waves. As was shown by Sasaki and Van Druzer [3], in the classical crossed-field tubes the electron-wave processes with consideration for the effects of space-charge are described by six normal waves ( $N = 6$ ): two cyclotron-waves (fast and slow), two space-charge waves (growing and decaying) and two waves propagating

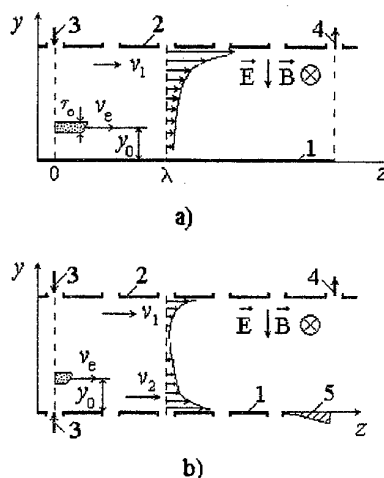


Figure 1. Schematic diagram of cathode driven crossed-field amplifier:

1,2-cathode and anode delay lines; 3 - r.f. input; 4 - r.f. output, 5 - matched load

to the positive and negative direction of the circuit, respectively. To simplify the problem let us suppose that the coupling factor between the cyclotron-waves in a beam and the waves in the circuit is weak (their coupling factors are less than to unit [2]). In this case we can take into account only four waves ( $N = 4$ ): two waves in the circuit (the main waves on cathode  $A_1$  and anode  $A_2$  delay lines) and two waves in the electron beam (growing  $A_3$  and decaying  $A_4$  waves). As a result the complete solution of the equations system (1) is given by the expression:

$$A(z) = \sum_{i=1}^4 A^i(0) \exp(-j\gamma_i z), \quad (2)$$

where  $A^i(0)$  and  $\gamma_i = \beta_i + j\alpha_i$  are the initial amplitude and complex propagation factor of the  $i$ -th normal wave. For a determination of the phase constants of the normalized waves and coupling factors  $C_{ik}$  the results of the reference [3] were used. The expressions for these constants are indicated in Appendix.

To find the propagation factor of the normal waves  $\gamma_i$  ( $i = 1, 2, 3, 4$ ) we can use the non-trivial solution of the system of equations (1) (compatibility condition). As a result the dispersion equation for the propagation factor can be written in the following form:

$$(\beta_e - \gamma)^2 (\beta_1 - \gamma)(\beta_2 - \gamma) + \beta_e^2 (\beta_1 - \gamma)(\beta_2 - \gamma) S^2 + (\beta_e - \gamma)(\beta_1 - \gamma) \beta_1^2 D_1^2 + (\beta_e - \gamma)(\beta_2 - \gamma) \beta_2^2 D_2^2 = 0. \quad (3)$$

To define the initial amplitudes of a normal waves  $A^i(0)$  it is necessary to use the initial conditions on the input (or output) of the forward (backward) wave amplifier as the following system of the equations:

$$\sum_{i=1}^4 A_1^i(0) = E^2(0); \quad \sum_{i=1}^4 A_2^i(0) = E^1(0); \quad \sum_{i=1}^4 A_3^i(0) = 0; \quad \sum_{i=1}^4 A_4^i(0) = 0, \quad (4)$$

where  $E^{1,2}(0)$  are the r.f. amplitudes of the waves on the input of the cathode and anode delay lines of the forward-wave amplifier (or on the output of the backward-wave amplifier).

Figure 2 shows the gain as the function of the mismatch parameter  $b_1$  for the case, when  $D_1^2 = 0.03$ ,  $D_2^2 = 0.01$ ,  $S = 0.1$ ,  $b_2 = 0$  (curves 1 - 4). For comparison in this figure the similar dependence is submitted for the classical crossed-field amplifier, when  $D^2 = 0.03$ ,  $S = 0.1$  (curve 5). As can be seen the gain of the tube with the cathode excitation exceeds its value, received for the classical amplifier in cases, when the interaction of the electron beam takes place with forward waves of the cathode and anode delay lines (the case positive dispersion) (Figure 2, curves 1 and 2). The use of the delay lines with negative dispersion in these tubes deteriorates the process of interaction between the electron beam and r.f. waves. As result the gain reduces and does not exceed the gain of the classical crossed-field amplifier (Figure 2, curves 3, 4 and 5).

On the other hand it should be noted that non-monotonous nature of a variation is specific for the dependence  $K = K(b_1)$ . The gaps on this dependence the most strongly present themselves in the cases when the cathode and anode delay lines have the negative dispersion (backward wave interaction). It is connected with the amplifying influence of the interference phenomena when the normal waves propagating in the

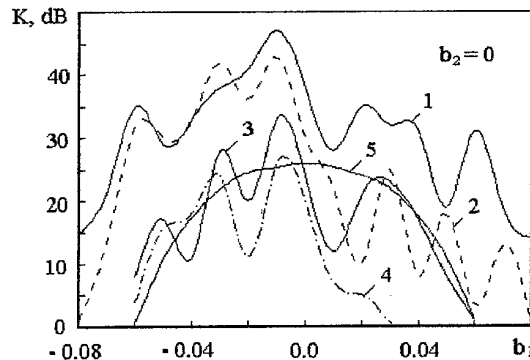


Figure 2. Gain versus the parameter of mismatch

electron-wave system with the different phase velocities are either in the phase or in the antiphase. This effect manifests stronger itself in the area of the positive values of the parameter  $b_1$ , i.e. when the electron beam is ahead of the waves, propagating on the anode and cathode structures on condition that  $b_2 = 0$ . Variation of the parameter  $b_2$  offers a shift of the dependence  $K = K(b_1)$  according to the behavior of roots of the dispersion equation (3). The analysis shows that the gain depends on the mismatch parameter  $b_2$  and decreases with its growth ( $|b_2| > 0$ ). As a result the maximum gain of the tubes with the cathode excitation takes place in the case of a synchronous movement of the waves on the anode and cathode delay lines, when  $v_1 = v_2$ . Thus the use of the cathode delay lines with the positive dispersion permits to increase the influence of r.f. field on the bunching. As a result the gain of the tubes with the cathode excitation increases and the anode voltage zone, corresponding the stable gain, expands. The negative influence of r.f. wave, propagating in the cathode delay line, to the electron-wave interaction process exists and connects with a grow of wave interference phenomenon.

## Appendix

Expressions for the coupling factors:

$$\begin{aligned} C_{13} &= jK_1\sqrt{\alpha_1}(1+j); & C_{14} &= jK_1\sqrt{\alpha_1}(1-j); \\ C_{23} &= jK_2\sqrt{\alpha_2}(1+j); & C_{24} &= jK_2\sqrt{\alpha_2}(1-j); \\ C_{31} &= -jK_1\sqrt{\alpha_1}(1-j); & C_{32} &= -jK_2\sqrt{\alpha_2}(1-j); \\ C_{41} &= -jK_1\sqrt{\alpha_1}(1+j); & C_{42} &= jK_2\sqrt{\alpha_2}(1+j), \end{aligned}$$

$$\text{where } K_1 = \frac{\beta_1}{2} \sqrt{\frac{\omega I_0 Z_1}{\omega_c 2U_a}}, \quad K_2 = \frac{\beta_2}{2} \sqrt{\frac{\omega I_0 Z_2}{\omega_c 2U_a}}, \quad D_1 = \frac{2K_1\sqrt{\alpha_1}}{\beta_e}, \quad D_2 = \frac{2K_2\sqrt{\alpha_2}}{\beta_e},$$

$$\beta_e = \frac{\omega}{v_e}; \quad \beta_1 = \frac{\omega}{v_1}; \quad \beta_2 = \frac{\omega}{v_2}; \quad \beta_3 = j\beta_e - \beta_s; \quad \beta_4 = j\beta_e + \beta_s.$$

$S = \frac{\beta_s}{\beta_e}$  is the space-charge parameter;  $\beta_s = \frac{\beta_e}{\omega_c \varepsilon_0 \tau_0} \left[ \frac{I_0}{2U_0} \right]$  is the growth (or decay) factor for the space-charge waves.  $\alpha_1 = \text{cth}(\beta_e y_0)$  and  $\alpha_2 = \text{cth}[\beta_e (d - y_0)]$  are the circuit parameters;  $b_1 = \frac{\beta_e - \beta_1}{\beta_1}$  and  $b_2 = \frac{\beta_2 - \beta_1}{\beta_1}$  are the parameters of mismatch of the electron beam and waves in the cathode and anode delay lines;  $\omega_c = \eta B$  is a angular cyclotron frequency;  $U_a$  is a dc anode voltage;  $I_0$  is a dc beam current;  $Z_{1,2}$  is a coupling impedance of the anode and cathode delay lines;  $d$  is a distance between anode and cathode.

## References

1. Skowron J.F.: "The continuous-cathode (emitting-sole) crossed-field amplifier" *Proc. IEEE*, 1973, v. 61, 3, p. p. 330-356.
2. Louisell W.H.: "Coupled mode and parametric electronics", New York: Wiley, 1960.
3. Sasaki A. and Van Druzer T.: "Coupled-mode analysis of interactions in crossed fields", *IEEE Trans.*, 1966, ED - 13, 5, p. 494-501.