EUROTeV-Report-2008-014

16.3 Studies of the Transient Response of a Klystron

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Keywords: Klystrons; Transient response; Computer modeling; Experimental measurements.

1. Introduction

Klystrons are commonly employed as RF power sources in particle accelerators for a variety of scientific and medical purposes. As such they are components in control systems which may have to meet very tight specifications for the amplitude and phase of the RF power supplied to the accelerating structure [1]. A further application is for powering the 'crab cavities' used to rotate bunches of charged particles [2]. In order to achieve the requirements of these systems it is important to be able to model the transient response of a klystron and to understand how this depends on its design. This paper reports progress in research aimed at achieving these objectives.

2. Experimental measurements

In order to understand the transient behaviour of a klystron, and to validate the theoretical models, measurements have been made on a TH2450 klystron. This is a five-cavity tube with a saturated output power of 3 kW at 6 GHz and a bandwidth of up to 60 MHz. Fig. 1 shows the experimental arrangement. The signal from an RF oscillator was modulated and fed to the input of the klystron which was operated under small-signal conditions. A PIN diode switch was used to achieve 100% amplitude shift keyed (ASK) operation and an electronic phase shifter for phase shift keyed (PSK) operation. A sample of the output from the klystron was combined with a sample from the RF source in a double-balanced mixer and the d.c. output was displayed on an oscilloscope. For the PSK measurements the mixer was operated in its saturated mode so that the results were independent of the signal amplitudes.

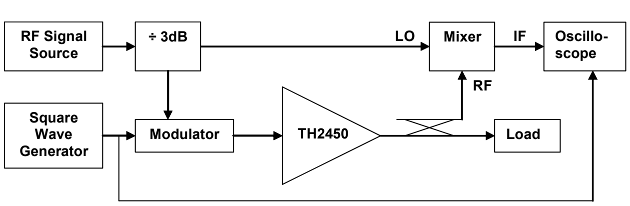


Figure 1. Experimental arrangement

3. Modelling

In order to model the transients of a klystron it is necessary to have accurate knowledge of its parameters. We have been able to obtain this information for the TH2450 tube apart from the frequencies of the second, third and fourth cavities whose tuning is uncalibrated. To establish this information and to confirm the other data the tube was modeled using a small-signal frequency domain model. Figure 2 shows a comparison between the results of these calculations and those of measurements.

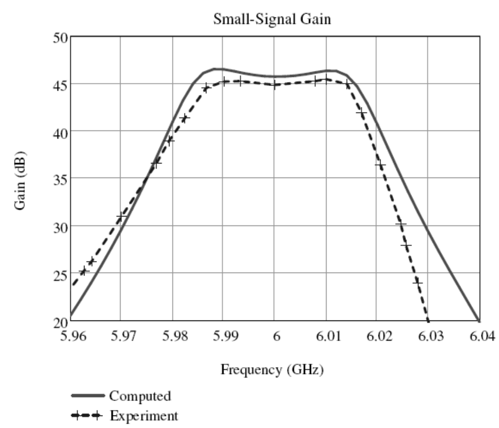


Figure 2. Comparison of measured and simulated small-signal gain of a TH2450 klystron

The modeling of klystrons under transient electron beam conditions has been described by Lavine et al. [3]. The same method was used to study the response of a klystron, operated with a constant electron beam, to changes in the input signal. Each cavity in the klystron is modeled by the equivalent circuit shown in fig.3. The driving current is assumed to have constant frequency and time-dependant complex amplitude. The driving current is the input signal for the first cavity and the electron beam for the remaining cavities.

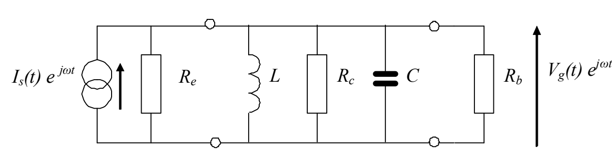


Figure 3. Cavity equivalent circuit

It can be shown that the gap voltage (V_g) obeys the equation

$$\frac{d^2V_g}{dt^2}+\left(2j\omega+\frac{\omega_1}{Q_1}\right)\frac{dV_g}{dt}+\left(\omega_1^2-\omega^2+j\frac{\omega\omega_1}{Q_1}\right)V_g=\omega_1\left(\frac{R}{Q}\right)_1\left(\frac{dI_s}{dt}+j\omega I_s\right) \quad (1)$$

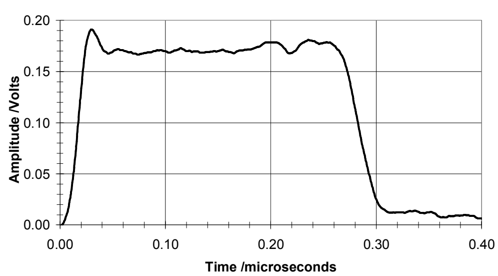
where ω_1 is the resonant frequency of the cavity, Q_1 is the loaded Q and $(R/Q)_1$ is the ratio of the shunt impedance R_c to the unloaded Q of the cavity. The gap voltage in each cavity was assumed to be zero at $t = 0$ and the complex amplitude of the source current was defined as a continuous function of time. The modulation of the beam is described by space-charge wave theory so that the driving current of the n^{th} cavity is given by

$$I_n=-jM_nY_e\sum_{i=1}^{n-1}M_iV_{gi}\sin\left(\beta_q\left(z_n-z_i\right)\right)\exp-j\beta_e\left(z_n-z_i\right) \quad (2)$$

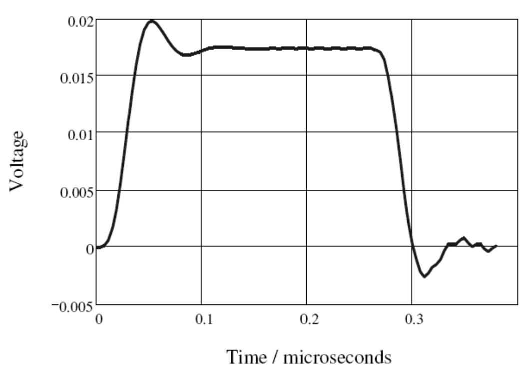
where M_i is the coupling coefficient of the ith cavity and z_i its position, Y_e is the electronic admittance of the beam, β_e is the electronic propagation constant and β_q the reduced plasma propagation constant. The complex amplitudes of gap voltages of the cavities were computed in turn as functions of time using the adaptive Runge-Kutta routine in Mathcad. The accuracy of the calculations was established by comparing the steady-state results with those from a small-signal frequency-domain calculation.

4. Results

Figures 4(a) and (b) show preliminary results of experiment and simulation obtained with 100% ASK modulation of a 6 GHz carrier. The simulated curve shows the output of an ideal mixer.



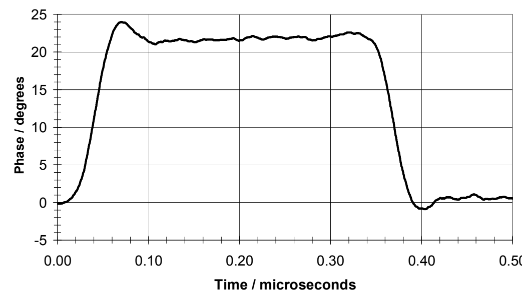
(a)



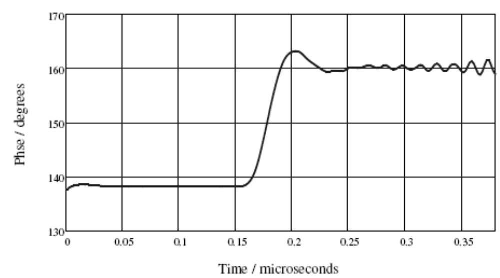
(b)

Figure 4. (a) Experimental and (b) simulated responses to 100% ASK modulation

Figures 5(a) and (b) show preliminary results for 22º PSK modulation. In both cases there is good agreement between measurement and simulation with very similar risetime and overshoot. Although the experimental measurement in fig. 4(a) does not show an overshoot on the trailing edge of the pulse we have observed that behaviour at other frequencies. The ripples observed towards the right hand side of each simulation are thought to be the result of numerical instability. Further work is needed to improve both the experimental and numerical methods but the results obtained so far show that this numerical model is able to achieve the goals of the research.



(a)



(b)

Figure 5. (a) Experimental and (b) simulated responses to 22º PSK modulation

Acknowledgement

This work is supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899. The help of Thales Electron Devices and CPI Inc. is gratefully acknowledged..

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