THE STABILITY OF MAGNETRONS UNDER SHORT PULSE CONDITIONS

by

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ABSTRACT

The relationship between missing pulses, front edge jitter and video spectrum inter-line noise is discussed for magnetrons operating under short pulse conditions. The measurement of missing pulse count can determine the rate of rf power growth at the start of oscillation.

INTRODUCTION

This paper is concerned with the pulse performance of a range of small, rugged magnetrons that operate in the X and Ku band, and range in peak power output from 200 W to 40 kW. These devices have a number of special characteristics including very small size and weight, rapid switch-on and extreme ruggedness. They have also been designed to have very good pulse stabilities, and it is this feature that is discussed below.

Traditionally magnetron stability has been measured by the missing pulse count: a pulse is said to be missed when the energy in that pulse is less than 70 % of the mean pulse energy. A number of mechanisms resulting in a missed pulse have been identified eg. electrical breakdown in the device, failure to start and moding, which is oscillation in a frequency other than the dominant one. A marine radar magnetron may have a missing pulse specification of about 1 %, the devices in question here are better than 0.01 %. Clearly a missing pulse as defined above is a fairly rare event associated with an appreciable departure from the average behaviour of the magnetron.

The trend in modern systems is towards higher pulse repetition rates and shorter pulse lengths, and the measure of stability has become the signal to noise ratio of the video spectrum. Since any departure from an infinite train of perfectly uniform pulses produces spectral components between the discrete prf lines, a measure of the video pulse modulation can be made by looking at interline noise. In the system considered here, the detected X-band pulse train from a magnetron is amplified in a frequency selective A.C. amplifier whose bandwidth is limited to half the pulse repetition frequency placed between two prf lines. (For example, if the magnetron is operating at 100 kHz prf and 50 ns pulse length, the selective amplifier would have a bandwidth from about 1 kHz to 50 kHz). The output of the selective amplifier is further processed by rectification, to obtain a mean level, and then smoothed in a R.C. circuit to limit response time. Fig. 1 shows a typical trace of the processed interline noise versus time.

Fig. 2 shows the interline noise from another valve operating under the same conditions as the valve used in Fig. 1. Both noise traces show similar D.C. and A.C. components, except that in Fig. 2 there is the occasional transient increase in the noise level (spike). Valve specifications usually place limits on both the mean and transient noise levels.

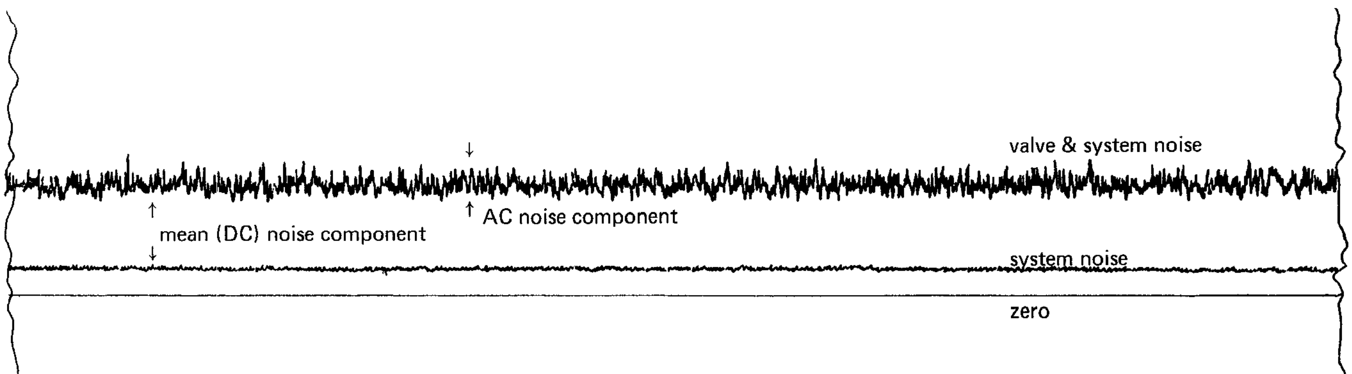

Fig. 1 Typical processed interline noise voltage (linear scale) versus time

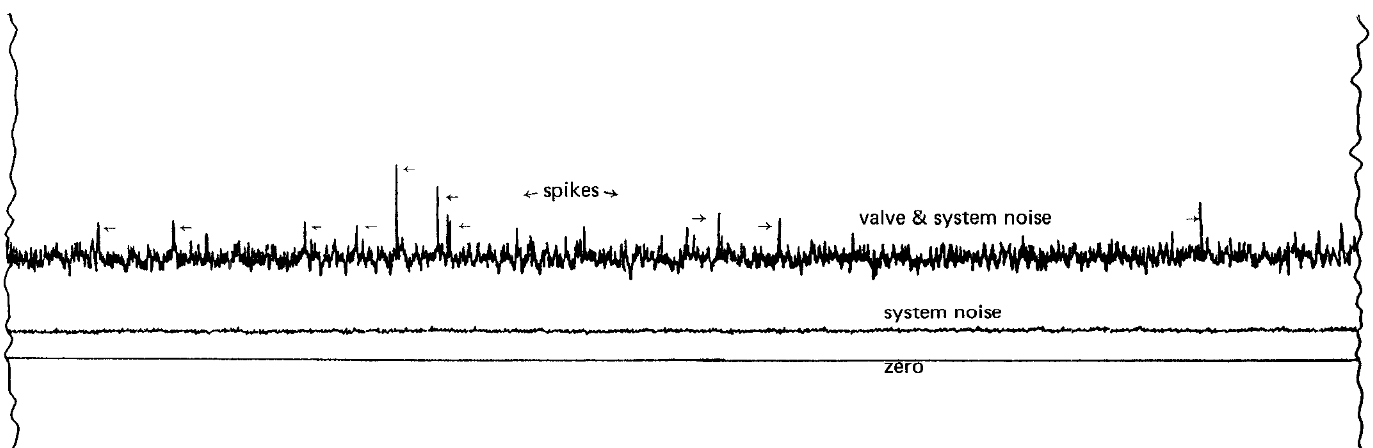

Fig. 2 Processed interline noise voltage (linear scale) versus time with spikes

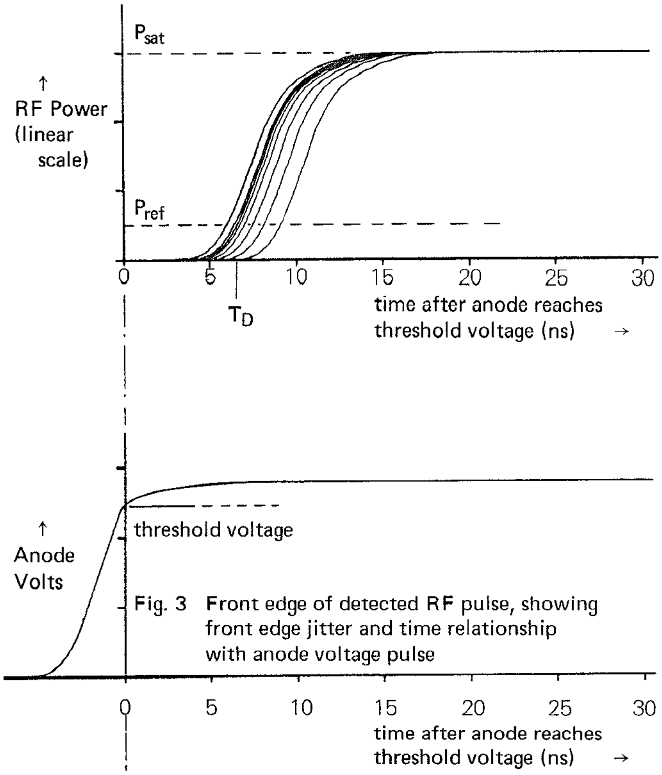

Fig. 3 Front edge of detected RF pulse, showing front edge jitter and time relationship with anode voltage pulse

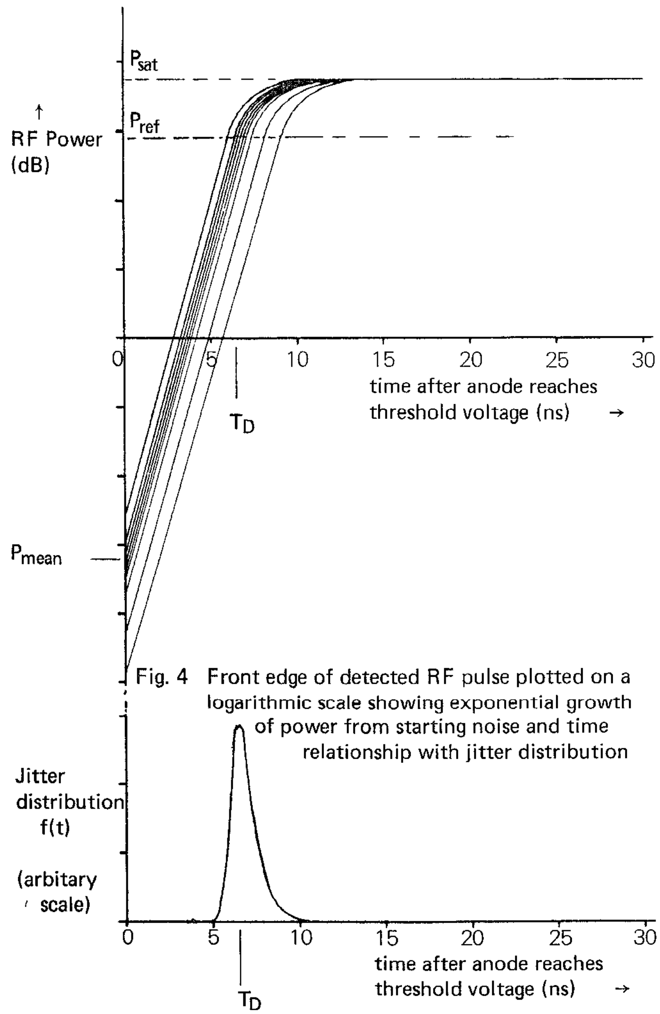

Fig. 4 Front edge of detected RF pulse plotted on a logarithmic scale showing exponential growth of power from starting noise and time relationship with jitter distribution

That some valves show spikes and some do not when operating under similar conditions has led us to start looking more closely at the sources of interline noise and missing pulses, and to see if any relationship exists between them. Two possible sources are front edge time jitter and frequency moding. These are discussed below.

FRONT EDGE JITTER

Magnetron pulses show detectable front edge jitter as shown in Fig. 3. Front edge jitter is defined as the pulse to pulse time variation of the position of the front edge of the rf pulse with respect to the time the voltage pulse reaches the threshold voltage. This random fluctuation leads to interline noise which has been shown experimentally[1] to have an approximately uniform spectral energy density between the prf lines.

The origin of the front edge jitter[1/2/3] is the noise signal induced onto the anode rf circuit, at the start of the voltage pulse, by the noisy crossed-field electron beam which circulates the cathode. Since the dominant resonance (π-mode) of the anode circuit has a high Q, the response of the anode circuit to the noise from the electron beam is a quasi-sinewave from which oscillations grow exponentially up to saturation, provided that the applied voltage conditions are correct. The frequency of the quasi-sinewave is close to the π-mode frequency and the amplitude has a Rayleigh probability distribution. The higher the amplitude of this starting signal, the sooner a reference power level P_{ref} is reached, Fig. 4. The probability that this reference level is reached in the time interval t to t+dt from starting, ie. from when the threshold voltage is reached, is given by

$$f(t)\,dt = \frac{P_{ref}}{\tau P_{mean}} \cdot \exp -\frac{t}{\tau} \cdot \exp\left(-\frac{P_{ref}}{P_{mean}} \cdot \exp -\frac{t}{\tau}\right) \cdot dt \qquad \text{(eqn. 1)}$$

Where τ is the rf power growth constant defined by

$$P(t_2) = P(t_1)\exp\left(\frac{t_2 - t_1}{\tau}\right)$$

and P_{mean} is the average noise power on the rf circuit when t = 0.

Some probability distributions for τ = 0.35, 0.50 and 0.63 ns are shown in Fig. 5. It can be shown that the width of the distribution is 2.45 τ between the half probability and 4.86 τ between the 10 % probability points and might be typically 1 – 2 ns.

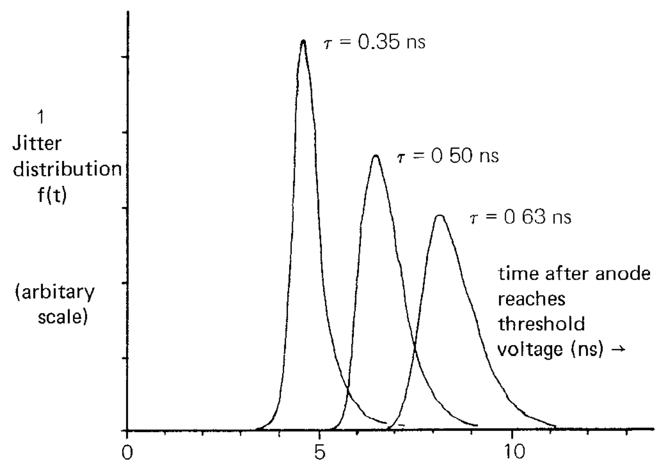

Fig. 5
Theoretical jitter distributions for three values of τ but same $\frac{P_{ref}}{P_{mean}}$

Following the theoretical analysis of MacFarlane[4] the energy density spectrum and hence interline noise level of a train of pulses with front edge jitter, as described above, can be found. However, the exact calculation is difficult and only approximate solutions have been obtained by us so far. Nevertheless, the approximate interline noise levels and energy density spectrum predicted are similar to those found experimentally[1].

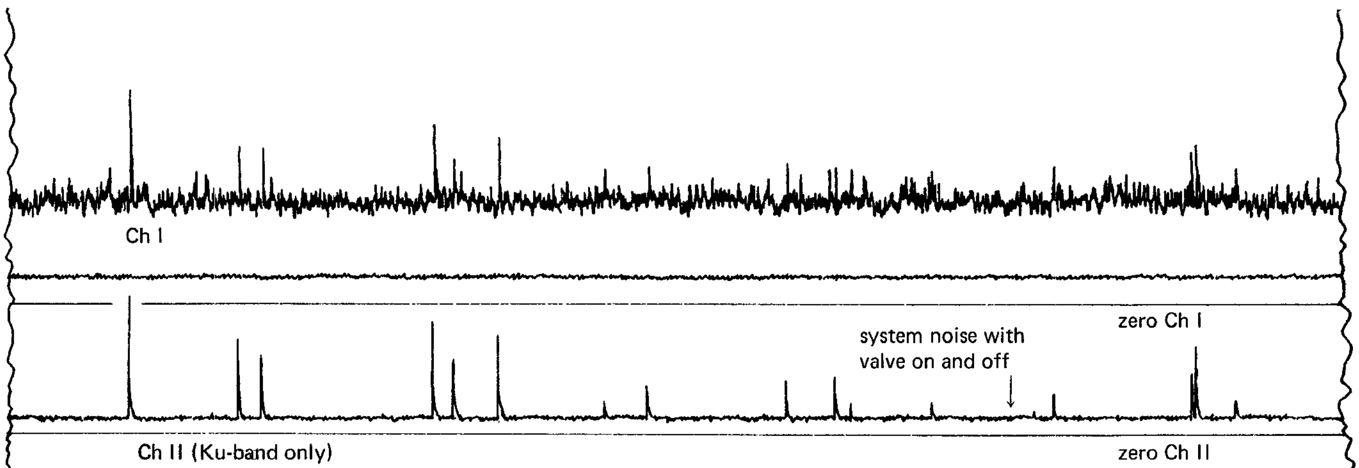

Fig. 6 Ch I processed interline noise voltage (linear scale) versus time. Ch II as Ch I, but with Ku-bandpass filter.

MODING

To investigate the effect of moding on the interline noise, the noise was measured on two channels simultaneously. Typical outputs are shown in Fig. 6. The first channel was identical to that used in Figs. 1 and 2, whereas the microwave detector in the second channel was preceded by a 12 GHz high-pass filter giving $\geqslant$ 50 dB isolation at the valve operating frequency ($\sim$ 10 GHz).

The only significant output from the J-band noise channel, Ch II, was the occasional spike – most of which corresponded with spikes in the normal measurement channel, Ch. I. A check with a microwave bandpass filter showed the Ku-band signal to be between 14 and 16 GHz, which includes the most probable moding frequency. The lack of any significant mean level from the Ku-band noise channel implies that, in this case, moding was not making a significant contribution to the mean interline noise level.

FRONT EDGE JITTER AND MISSED PULSES

From the jitter distributions shown in Fig. 5, it can be seen that the probability of a late pulse decreases rapidly with time. However, occasionally a pulse will be late by 30 % or more of the mean pulse duration and this would register as a missing pulse as defined in the introduction. Integration of eqn. 1 above shows that the probability F(t) that a pulse will reach the reference level after time t asymptotically becomes

$$\log_{10} F(t) = -\frac{(t - T_D)}{10} \cdot Rg$$

where Rg, the rf growth rate, is given by $Rg = \frac{4.34}{\tau}$ dB/ns

and T_D, the delay time, is given by $\exp \frac{T_D}{\tau} = \frac{P_{ref}}{P_{mean}}$

Physically T_D is the time required for the most probable power growth curve to reach the reference level.

Now, assuming the mean starting time is equal to T_D, a missed pulse will occur when

$$t - T_D \geqslant 0.3\ T_p,$$

where T_p is the pulse length, so the probability of a missed pulse – caused by front edge jitter only – is given by

$$\log_{10} F_m \doteq -0.03 \cdot Rg \cdot T_p \qquad \text{(eqn. 2)}$$

Plots of F_m versus T_p, for different Rg, are shown in Fig. 7, and it can be seen that the probability of jitter causing a missed pulse decreases very rapidly with increasing pulse length and rf growth rate. Note the missed pulse rate is given by F_m multiplied by the pulse repetition frequency.

CONCLUSIONS

Front edge jitter is a major source of mean interline noise. It is fundamental to the starting of a magnetron and depends on the rate of rf growth only.

In the increasingly more common case of very short pulses, or when the rf growth rate is very low, front edge jitter can result in "traditional" missing pulses ($\leqslant$ 70 % mean energy).

Transient increases in the interline noise (spikes) can be caused by the magnetron operating in the wrong mode.

Specifications calling up low levels of mean interline noise imply small front edge jitter and therefore virtually no missing pulses.

In a system in which front edge jitter is the only source of instability, a measurement of the missing pulse count could, together with eqn. 2, be used to calculate the rate of rf growth.

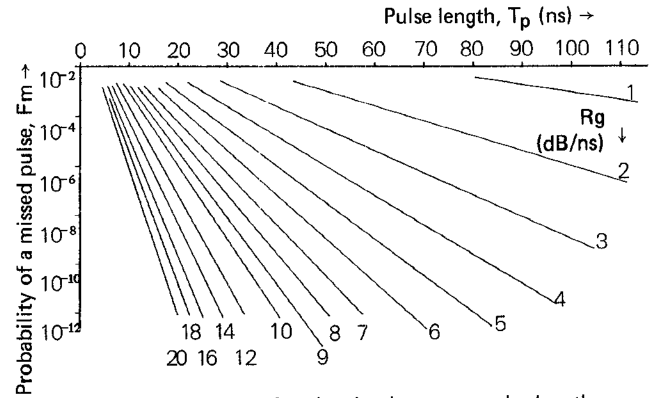

Fig. 7 Probability of a missed pulse versus pulse length

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