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WHITE NOISE METHOD TO MEASURE THE CAVITY RESONANT FREQUENCIES OF THE MULTI-CAVITY KLYSTRONS

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ABSTRACT

White noise method has been used to measure the tuning frequencies of the input and the intermediate cavities of one type of TRISTAN high power CW klystrons. Comparison has been made with the cold test results and has shown a good agreement. This method is quite useful to check the tuning of the klystron *in situ* and to measure the resonant frequencies of the cavities without coupling probes.

INTRODUCTION

In order to get the optimum gain and the highest efficiency of a multicavity klystron, tuning of each cavity is most essential. Even if the resonant frequency is adjusted at the stage of a cavity subassembly, it can be shifted from a desired value in assembling and heat treating process. It can be changed after long term operation or by transportation, too. Cases not unfrequently occur in which it becomes required to recheck the cavity resonant frequencies once during operation. In such a situation it may be quite convenient if an accurate measurement of tuning frequencies can be made without socketting out the klystron tube. Furthermore, in case of cavity with no coupling ports, it is absolutely impossible to measure its tuning frequency even if the tube is drawn out. In this report a method is described of observing *in situ* the resonant frequencies of the drive and intermediate cavities of a klystron, in which a white or a semi-white noise is used in combination with a signal averaging technique.

WHITE NOISE METHOD

If the spectrum of the rf output of a multicavity klystron is examined with a spectrum analyzer, it will often appear, as shown in Fig. 1, to consist of a very sharp carrier and a relatively broader signal component, at frequencies close to the carrier, whose power is much less than the power contained in the carrier.

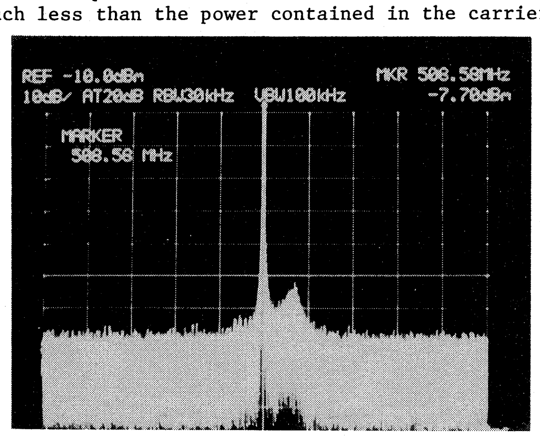

Fig. 1 Spectrum of the rf output as seen on a MS611A spectrum analyzer. Small peak corresponds to the 2nd cavity resonance.

The latter does not disappear even if the drive power is switched off, the drive line is disconnected or the drive input is terminated with a short termination. Careful study shows that such a component originates, for example, from the high Q 2nd cavity whose resonance is a little bit detuned from the operating frequency. The signal source may be a shot noise and/or a thermal noise which can be considered to be randomly excited and injected into the input cavity and may be practically treated as a white noise. Although its frequency component corresponding to the respective cavity is very small at the input, it is amplified by a klystron amplification to a detectable power level at the output. This phenomenon can be positively used as a tool to check the tuning frequency of each cavity of a multicavity klystron.

Fortunately, of late, we had a chance to try this method and study its feasibility, using a real klystron tube in operation. Measurement has been made of one type of TRISTAN high power CW klystron which has 6 interacting cavities in all. Resonant frequency of each cavity obtained by this method has been compared with the original factory value and the value obtained by a conventional reaction dip signal measurement. The latter is available in cold state, as this model of klystron is installed with a monitoring probe in each cavity. This helps to cross-check the resonant frequencies and to evaluate the new frequency-determing procedure.

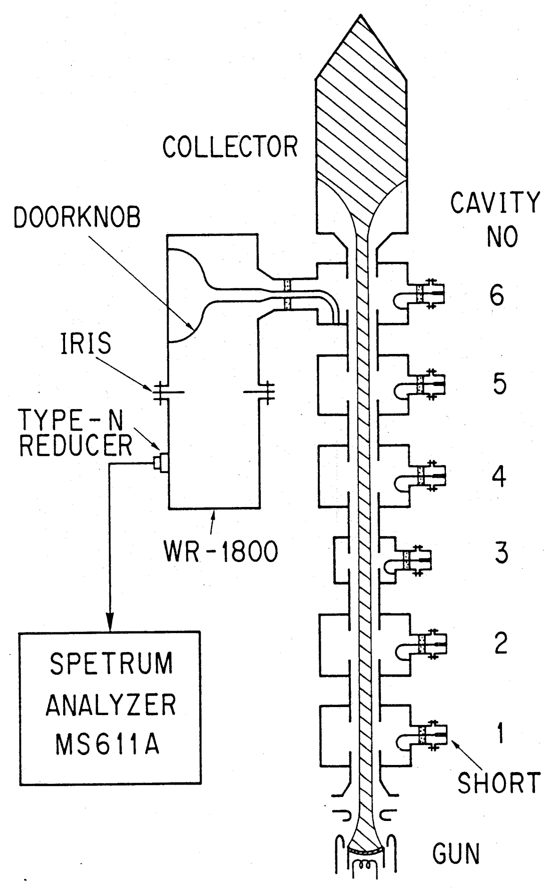

Fig. 2 Setup of the white noise method. Input coupler is short circuited.

Figure 2 shows the measuring setup of the white noise method. Special attention should be paid to the input coupler of the 1st cavity, which is short circuited with a Type N terminator. No drive signal is fed to the klystron via the drive line. The heater current and the focus coil current are kept at the usual values, while the cathode voltage is reduced and the beam current is limited by setting the modulation anode voltage as low as possible. In our case, however, the lowest available values of the cathode voltage and the beam current are limited by rating of our power supply to be about 47 kV and 0.2 A, respectively. The signal is collected from the output cavity, transmitted through a doorknob transducer and picked up by a type-N reducer attached to a WR-1800 waveguide. The signal then goes to a spectrum analyzer (Anritsu, model

MS611A) via a flexible coaxial cable. As this analyzer model installs a signal averaging function, the signal-to-noise ratio can be improved by a process known as an averaging technique. In such a process the successive sweeps of data are stored and added point for point. The output signal-to-noise ratio is proportional to the square root of the number of pulses that are added. Usually, 100 to 256 sweeps give a signal with sufficiently large signal-to-noise ratio.

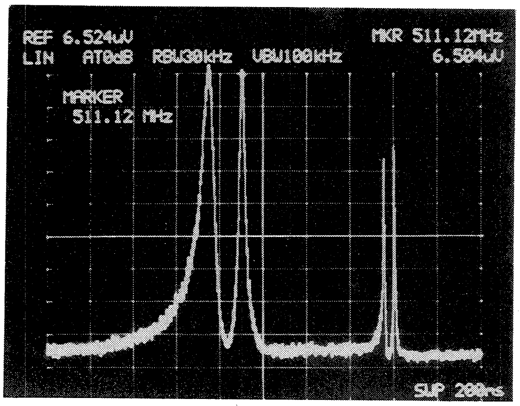

Fig. 3 Spectrum showing resonances of the cavities, from left to right, No. 1, 2, 5 and 4. Frequency span is 40 MHz. I_b 0.3 A.

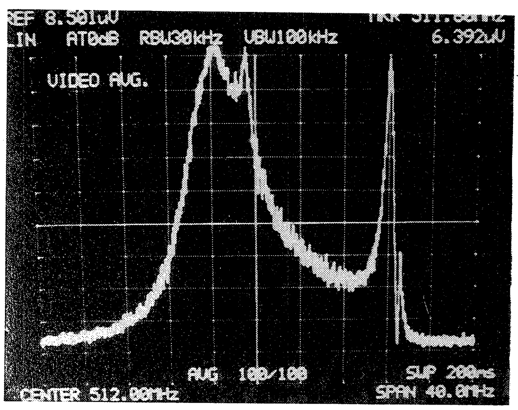

Fig. 4 Spectrum deforms with current increase. I_b 1.2 A.

Figure 3 shows one of the examples of the frequency spectrum of the klystron rf output which was obtained by signal averaging 100 times with the rf input shorted. The ordinate corresponds to the power level measured, in this case, in linear scale. The klystron beam current I_b is 0.3 A and the cathode and the anode voltage are set at 47 kV and 5.3 kV, respectively. The frequency span is 40 MHz. Four peaks, from left to right, correspond to the signals from the cavities No. 1, 2, 5 and 4, respectively. The shape of the spectrum, however, depends on the extent of the beam loading. With the increase of I_b, the base line grows up and some of the peaks coalesce into one broader peak as shown in Fig. 4 which was taken for the beam current of 1.2 A. For our purpose, the smaller beam current with the smaller accelerating voltage seems to be better. In order to get the precise frequency structure, each peak can be separately averaged as shown in Fig. 5. It shows, as an example, the peak of the 2nd cavity with a frequency span of 3.0 MHz. The 256 sweeps gave a good signal-to-noise ratio. The signal level is 8.194 μV at the peak (f_0 = 511.120 MHz) and only 680.0 nV at the bottom. If one measures the half-power width Δf_0 of the resulting spectrum, $f_0/\Delta f_0$ gives the value 1262. Although this value does not directly reduce to the Q value, it gives a good measure of Q of the 2nd cavity, as the sharpness of the peak well corresponds to the resonance width of each cavity. Summarized in Table 1 are results of the tuning measurements. Cold tests of

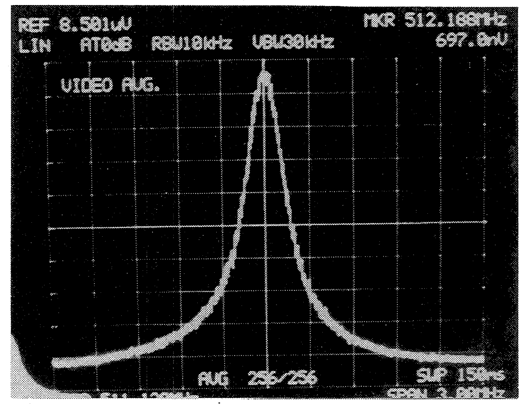

Fig. 5 Spectrum of the 2nd cavity resonance. Center frequency is 511.120 MHz with a span of 300 MHz. Averaging of 256 sweeps.

Table 1

Cavity No	Tuning Frequency f_0 (MHz)			$f_0/\Delta f_0$
	Factory Value	Cold test	This method	
1	508.4	508.8	508.12	423.4
2	512	511.07	511.12	1262
3	1015	1015.15	1015.14	219
4	520	525.2	525.17	3202
5	523	525.1	524.19	6552
6	512	511.0	—	34

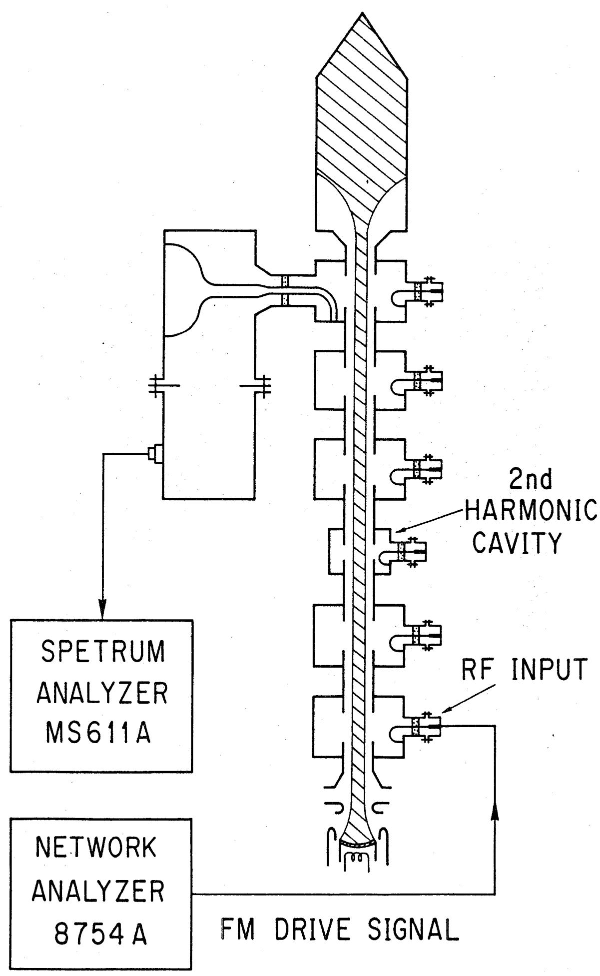

Fig. 6 Modified setup to detect the 2nd harmonic cavity resonance.

No. 1 to No.5 cavities have been done, with the klystron being drawn out the socket. Reaction dip has been measured by connecting a network analyzer directly to each coupling port. As for the last cavity, the loaded Q is so small, the dip signal is not so clear. Then for this cavity, the resonant frequency and the Q have been determined from the transmission measurement in which both the search port and the main rf output are used.

MEASUREMENTS ON THE 2nd HARMONIC CAVITY

The 3rd cavity of this klystron is the 2nd harmonic cavity. As the microwave components including doorknob coaxial to waveguide transducer, iris and the type N reducer are frequency-selective ones and adjusted to match at the carrier frequency (508.58 MHz), the signal from this cavity is depressed to a very small level. Even averaging of 1000 sweeps is insufficient. If I_b and V_k could be decreased to a level of 0.1 A and 20 kV, determining of the 3rd cavity peak might be realized.† Our power supply system, however, determines the lowest value of I_b and V_k to much higher levels as mentioned before. In order to get the faint signal of the 3rd cavity, white noise method was a little bit modified by using the excitation with a semi-white noise near the 2nd harmonic frequency. Figure 6 shows this modification. The klystron is driven by a small FM signal whose power level is 10 dBm and sweep width is 5 MHz with a center frequency of 1015 MHz. As a signal generator HP8754A network analyzer is used in a fast sweep mode. The 2nd harmonic signal, however, is still not large enough even with the averaging system and the reinforced white noise.

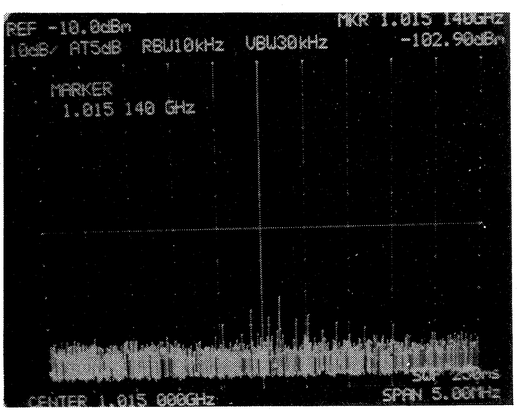

Fig. 7 One shot spectrum taken in maximum hold mode. Sweep width and a span are both 5.00 MHz.

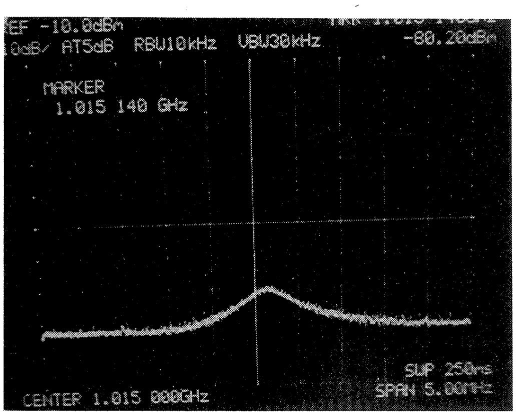

Fig. 8 Spectrum near the 3rd cavity taken in the maximum hold mode. Center frequency is 1015.14 MHz. I_b 1.2 A.

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† H. Bohlen, private communication.

The spectrum analyzer MS611A, in this case, is operated in maximum hold mode instead of averaging mode. The resonance gives the incidental projection of the power as shown in a single sweep spectrum of Fig. 7. The ordinate is given by a log scale in this case. If such a signal is accumulated for 5 minutes, the maximum holded projections give the envelope of the resonance line as shown in Fig. 8. The peak corresponds to 1015.14 MHz and the frequency span is 5.00 MHz. The beam conditions are as follows: I_b 1.2 A, V_a 8.3 kV, V_k 47.3 kV. For this measurement the beam current of 0.2 ∿ 0.3 A seems to be too small, while the beam current of 2 A is too large. By increasing the beam current, some confusing ghost signals appear in the spectrum as shown in Fig. 9(a), 9(b) and 9(c).

(a)

(b)

(c)

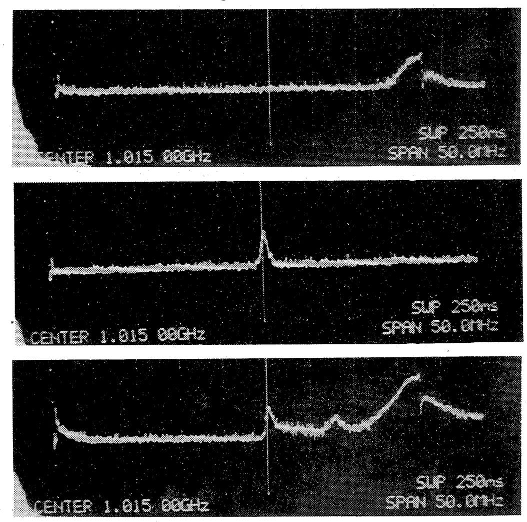

Fig. 9 Change of the spectrum near the 3rd cavity with the beam current. (a) I_b 0.3 A (b) I_b 1.2 A (c) I_b 2 A. No signal of the 2nd harmonic cavity is found in (a), while ghost signals appear in (c).

Although further studies and analyses are needed, these ghost signals probably relate to the excitation of the 2nd harmonic components of the fundamental frequency cavities. Anyway the tuning frequency of the 3rd cavity measured by this semi-white noise method agrees very well with the value measured by the cold test as shown in Table 1. As the beam current is so small, the frequency shifts by the susceptance component of the beam loading is very small. As the rf power is also very small, the values in Table 1 do not show the tuning frequencies in hot state.

CONCLUDING REMARKS

Tuning frequencies of the input and the intermediate cavities have been successfully measured *in situ* by the white noise method. Signal averaging techniques improved the signal-to-noise ratio in these measurements. The tuning frequency of the 2nd harmonic cavity has been obtained by the modified white noise method in which the klystron has been driven by a frequency modulated small rf signal (semi-white-noise) and the signal has been accumulated in the maximum hold mode. Tuning frequencies measured by this method are in good agreement with the values in cold test. Although further studies are needed, application of this method, however, to the measurement of the output cavity may be probably difficult because of its low Q value.

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