OVERSIZED INTERFERENCE SWITCHES IN MICROWAVE PULSE COMPRESSORS*

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Abstract

Oversized interference switches in resonant microwave compressors have high electrical strength. The switches of two types with a gaseous discharge gap were studied experimentally. The first type was developed on basis of the oversized rectangular waveguide H-tee with the H_{01} operation mode. The output pulse power of 2.8MW and pulse width of 3.5ns were obtained. The second type was a compact packet of common single mode switches incorporating the five identical waveguide tees. Synchronous operation of the switches was provided by the gas discharge plasma formed in the mutual side arm of the packet.

INTRODUCTION

Microwave resonant compressors (MRC) produce pulses by accumulating energy in a resonant cavity during a relatively long time and subsequent rapid extraction of the energy into a load. The ultimate output power of a MRC is equal to a power of the travelling wave component in a resonant volume. The coupling between a cavity and a load is controlled by the phase shift between the waves radiating from the cavity and from the side arm of the tee. The phase is inverted by the gaseous microwave switch having the trigatron type triggering. The limited cross section of a single waveguide limits the electrical strength of the elements and the output power value. An increase of gas pressure leads to big energy losses in the discharge plasma and a decrease of efficiency. For example the output pulse power for switches located in S-band waveguides of the cross section 72×34 mm^2 does not usually exceed 200 MW [1] and the efficiency is within the range of 0.2-0.3 at the losses value in the switch of 2-3dB. The switching in oversized cavities involving mode transformation increases the limiting output power [2,3]. This report presents the study of switch designs based on oversized waveguides but intended for fast energy extraction and keeping high values of amplification.

OVERSIZED INTERFERENCE SWITCH

It was assumed the strong coupling between the output line and the switching resonator and the necessary frequency change are enough for developing an effective interference switch no matter what operational wave mode is used.

Switching resonators made of single mode waveguides were connected to storage volumes by T-junctions or bridge junctions and demonstrated high switching efficiency. Although the cross section limited by the cut-off frequency value limits the electric strength and the output power.

One possible solution of increasing a waveguide cross section is the use of rectangular waveguides with H_{01} operational wave mode [4]. Corresponding elements in a tee or bridge manner keep the switching parameters of single mode analogs, does not require the special mode transformation into the primary mode of an output waveguide and make the maximum output peak power greater by several-fold. These oversized switches, besides usual requirements to the level of multimode transformation, raise some specific conditions to be provided for effective operation of the switch and the compressor. In order to provide switching over to extraction the phase of wave reflected from the tee should be changed by about 180^0 along with the change of the frequency beyond the resonance curve by value of $\delta f \approx nf / Q_a$, where $n \geq 3$ and Q_a - quality factor of the tee arm. Although it was found the dimensions of switching arm should be less some value determined by the ratio of the volume parameter transient time to the time of two ways wave travelling along the storage cavity.

The expression for the limit of the oversized waveguide wall size at the given arm length of $L_{arm} \approx \lambda_w / 2$ was derived:

$$b_{\max} < \frac{z_0 Q_{arm} l^3}{90 na L_{arm} \lg\left(\dfrac{2l}{r}\right)} = \frac{z_0 Q_{arm} \left(0.2 L v_{pl} / v_g\right)^3}{90 na L_{arm} \lg\left(\dfrac{0.4 L v_{pl}/v_g}{r}\right)} \qquad (1)$$

where v_g – wave group velocity, v_{pl} – plasma propagation velocity, $L_{arm} \approx T v_g / 2$, l – length of the plasma spark channel, r – cross section radius of the plasma channel. As is clear from (1) the size is proportional to $f^{1.5}$. This means the switches are more efficient for higher frequencies of the microwave band when the relative increase of the wall size is higher at given T.

Experimental study was made in X-band and the tee waveguides had the cross section of 58×25 mm^2. External view of the tee is shown in Fig.1. The longitudinal section of the tee is identical to the single mode one. So when dimensions are precise and operational mode H_{01} is not converted the switch of this type operates similarly to the common switch as there are no physical causes impeding that. It was proved by measuring the transition attenuation in the switch close state. The attenuation was 41±2 dB in

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the frequency range 8800-9500 MHz and that corresponded to the attenuation of a common tee.

Figure 1: Interference switch on the basis of oversized rectangular waveguide.

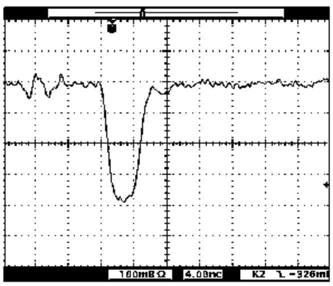

Figure 2: Envelope of the formed microwave pulse.

The tee with H_{01}-mode came to the open state by a slight change of the short-circuited arm parameters. It was verified as well when the switch was installed in the compressor. The calculated double time interval of wave travelling along the storage cavity was 4 ns at the quality factor of 1.6×10^4. That gave the calculated power gain of about 20dB. The measured gain value was 17.5dB at the pulse width of 3.5ns. The primary exciting microwave source was the pulse magnetron generator with the power of 50 kW and so the output pulse power reached 2.8 MW. The switch was triggered by illumination of the discharge gap by the electric discharge spark or by the light beam of the nitrogen laser. The switch discharge was formed in argon at atmospheric pressure in a waveguide volume or in a quartz tube located in the area of maximum electric field and aligned along the electric flux. The typical output pulse envelope is shown in Fig. 2. As the figure shows the energy extraction time is equal to the double time of wave travelling along the cavity that is similarly to operation parameters of a singlemode switch.

PACK OF SYNCHRONIZED SWITCHES

Several synchronized switches connected to a single cavity can enable the energy extraction time close to the double time of wave travelling along the cavity volume. The extraction time decreased with increase in the number of switches but the spread of switch triggering was compared to the output pulsewidth recorded at a single switch output [5]. High-level synchronization was reached when the switches were arranged closely to each other i.e. they formed a packet of parallel switches [6]. External view of the switch packet in a rectangular waveguide of the tee, the short-circuit plate is disconnected, is shown in Fig. 3.

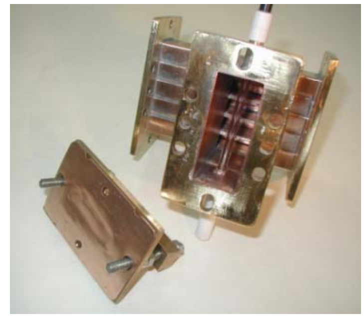

Figure 3: Packet of switches with mutual side arm.

The key problem of synchronous power extraction is maintaining identical switching conditions in each gap. First, the electric field strength values in the gaps should be equal and this condition depends on the cavity geometrical arrangement, the type of the wave working mode, the waveguide interior surface quality, the coupling between switches and the cavity. For the proposed design the H_{01} mode of a prismatic cavity is most acceptable. The E-field strength along the larger wall is constant and this contributes to equality of field strength values in the switches. The wave modes H_{01} and H_{10} are easily transformed into each other and so combining the energy extracted through all switches is not difficult.

The second issue is the quantity of switches in the packet which affects the compressor limiting power. The effective switching corresponds to the switching time less than T and if t_f is a characteristic time of the discharge development then the maximum number of switches is given by $n < T/t_f$. For example, in X-band the acceptable number is in the range 2…5 at T = 5ns and $t_f \approx 2ns$ that is the number is not so great. For higher frequencies the usage of the packet may be efficient as $t_f < 1ns$ and, keeping the same T value, the allowable switch number is larger.

The larger number of switches requires hard locking of discharge triggering. The mutual switching area as a joint oscillation system was supposed to be realized as a mutual switching tee arm. The switching process should be controlled by a single discharge and should not be a need for special synchronization of switches. But the resonant frequency of the arm should be withdrawn beyond the resonant curve during the time interval about T. It may be executed by the discharge having the spark channel length much less than the total length of channels when switching proceeds in uncoupled arms. The wave traveling time along the mutual arm is less than the discharge formation time so the phase inversion of waves reflected by the arm is synchronous and so the switches of the packet come to open state also synchronously. The maximum number of switches is estimated by $n < L/b$, where b- size of the narrow wall of the tee waveguide.

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Experimental tests in X-band proved that the strong coupling between the switching arms is the requirement for synchronous operation. The coupling in the packet was introduced by different ways e.g. by holes in adjoining switch walls, by slots between the short-circuit and flat ends of side arms and by integrating the side arms into a mutual side arm in the form of an oversized regular waveguide section. The level of synchronism rose with increase of the coupling between the arms. The packet with coupled not in full arms is responsible for unsteady process of energy extraction characterized by the spread of output pulses as shown in Fig. 4.

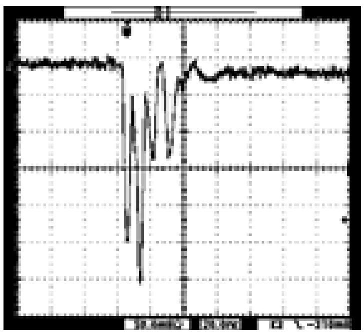

Figure 4: Output pulse envelope when separate side arms are coupled not in full.

The simultaneous energy extraction during the double transmission time along the cavity is reached with the strong coupling. The strong coupling is reached by integrating the side arms of tees of the packet into a section of a regular rectangular oversized waveguide. The power gain of the compressor with the oversized storage cavity and the mutual oversized side arm of 58x25 mm^2 cross section was 16.5dB at the pulsewidth of 3.5 ns and the corresponding peak power of 2.2MW. The envelope of the output pulse is shown in Fig. 5. According to estimate the energy extraction through a packet with 5…7 switches can form pulses with the peak power of 0.1GW in X-band and the peak power 1GW to 2GW in S-band.

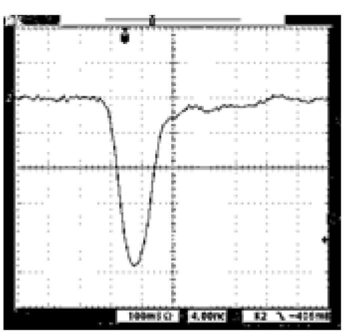

Figure 5: Output pulse envelope with switching in the mutual oversized side arm.

The packet of interference switches may combine parallel resonant cavities fed by different sources into a single high power compression system.

CONCLUSION

Thus, we demonstrated that microwave power can rapidly be extracted from a set of cavities through a packet of synchronized switches based on *H* tees. It was established that the commuting arms of the tee junctions should be strongly coupled to obtain complete synchronization. The limiting number of switches in the packet is proportional to the ratio of the cavity length to the small wall dimension of H- tee waveguide. Therefore, the use of a packet is most efficient for short microwaves at a specified cavity length. For example, according to estimates, in the case of X- band, power extraction through a packet containing five to seven switches can provide formation of pulses with a power up to 0.1 GW. In the 10_cm range, a system similar to the investigated one can generate 1 to 2GW pulses. A packet with single mode cavities and uncoupled commuting arms can be used to form nanosecond microwave pulses with a high repetition frequency. This packet can also be used to increase the pulse energy of resonant microwave compressors with large accumulating volumes, fed from different sources and coupled via a packet.

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