

High-Power Microwave Pulse Compressors with a Variable Geometry of Accumulative Resonant Cavity

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Abstract — We propose a new approach to designing the geometry of large accumulative systems of compact Microwave Pulse Compressors (MPC's) used to generate ~10-ns rectangular pulses in the S- and X-bands. A resonant system having a variable geometry replaces the traditional cylindrical, spherical, or prism-shaped storage cavity. Our design uses standard structural elements made from single-mode or moderately multimode waveguide sections with ends terminated by waveguide *tees* or their analogs. One arm of each T-junction connects to a section of the resonant cavity, the second arm is close-circuited, and the third arm connects to an adjacent linear section. The plasma switch, used to Q-spoil the cavity, mounts in the side arm of another *tee*. Thus, the accumulative system is formed using compact planar and three-dimensional structures (or combinations thereof) by alignment of standard elements through the arms of *tees* or their analogs. The proposed approach leads to development of very compact systems. Integration of an MPC into an existing RF generator is also straightforward without significantly expanding its footprint.

We present schemes for several types of MPC's with variable geometry of the accumulative system. Our work shows that a specific architecture of the accumulative system, accounting for the relevant distribution of energy and method for pulse extraction, is useful in building MPC's with discretely controlled output pulse parameters. We also show that the variable geometry of the accumulative system makes it possible to design compact, cascade compression systems with power multiplication of the traveling wave in the resonant cavity. This paper also demonstrates the first results from an experimental study of MPC's with a planar accumulative system.

Keywords — microwave pulse compressor; microwave compression; resonant cavity; plasma switch; H-tee; waveguide

I. INTRODUCTION

The 1960's witnessed a new trend in electronics associated with the development of sources of powerful, nanosecond-duration RF pulses. Interest in these microwave sources arises from both fundamental and specific features of nanosecond pulses. Nanosecond-duration pulses are comparable to the characteristic time scales for various physical processes of current scientific interest.

Examples of such processes include RF breakdown in microwave devices, failure of electronic equipment under the influence of pulsed RF radiation, and reflection of short RF pulses from probed objects during radio positioning. Going from microsecond to nanosecond pulses, the delay in discharge formation provides an increase in the dielectric strength of microwave devices. Because the time scale for these transient processes is longer than the pulse lengths discussed here, higher-power RF pulses do not risk breakdown, i.e., these pulses may contain the equivalent energy of longer-duration pulses without incurring any undesirable effects. Shorter pulses increase accuracy and information content during exploration by radio positioning. Thus, powerful RF pulses find applications in plasma-chemical technology [1], where square RF pulses are preferable in most cases. When used in acceleration devices [2,3], short pulses increase the acceleration rate and reduce the dispersion of particle energy. When used in electronic warfare devices, they increase the range and accuracy of failure rate determination. When used for radio positioning, they increase positional accuracy and simplify processing of the received signal. In addition, compact and inexpensive sources are preferable for obvious reasons [4]. The range of applications is not limited to those mentioned here. All these reasons explain the importance of developing compact sources of powerful nanosecond RF pulses having a rectangular waveform.

II. ACTIVE MICROWAVE PULSE COMPRESSION SYSTEM. PROBLEMS

Simultaneously with the development of the most powerful albeit rather complicated and expensive relativistic RF generators and amplifiers, passive methods were also studied in an effort to increase the RF pulse amplitude. One of these methods is the relatively simple and effective method of resonant pulse compression.

The microwave pulse compressors used in this method are passive RF amplifiers providing accumulation of energy from a relatively long and weak RF pulse in a resonant cavity, followed by fast output of this energy into a load (see Fig. 1). Typically, microsecond pulses are fed into the input port of such amplifiers, while shorter and more powerful nanosecond pulses are generated at the output port.

The output pulse parameters of a resonant MPC depend on the Q-factor and dielectric strength of the resonant cavity as well as on the energy extraction method. The Q-factor and dielectric strength determine the amount of accumulated energy. The energy extraction method and system topology determine the nature and instant of energy output; in any case, the larger the amount of the stored energy, the faster and greater the energy output. Consequently, the efficiency is also improved. Given the relative simplicity of such amplifiers, our prototype devices produced gain coefficients up to ~ 25 dB, pulse powers up to $\sim 0.1\text{-}1$ GW, and efficiencies over 60%.

At the same time, several issues important for development of compressors remain unsolved. One of them is the problem of generating long and powerful nanosecond pulses with a rectangular shape in compact MPC's. For X-band and S-band pulses of $\sim 10\text{-}100$ ns and $\sim 0.1\text{-}1$ GW, the length of the radiated wave train is a few to tens of meters, which grossly exceeds the length of typical compressors ($\sim 1\text{-}2$ m).

In addition to the difficulty of generating a rectangular shaped pulse, unsolved problems exist concerning the geometry used to form the resonant cavity. As a rule, the storage cavity of the resonator is a cylinder, sphere, or prism. Compressors, being passive amplifiers, depend upon the design of the active source. Integration of fixed-form MPC's with standard sources is problematic, especially if size is a concern.

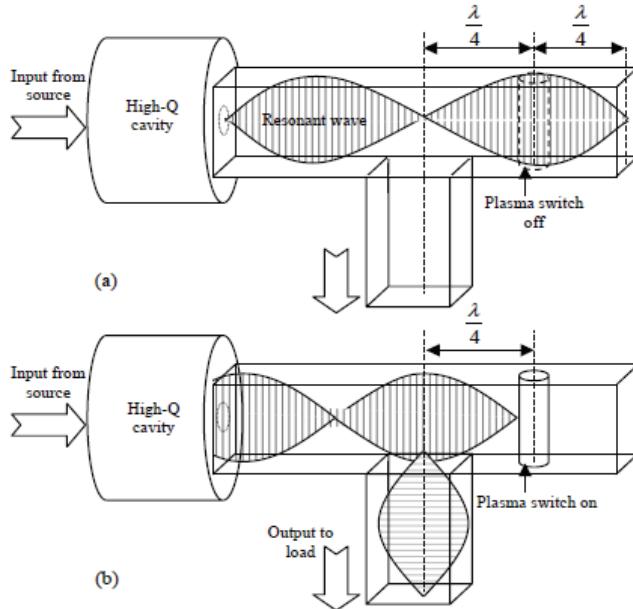


Fig. 1. Scheme of an active high-power MPC with output energy via an interference plasma switch: (a) plasma switch is off; (b) plasma switch is on (picture taken from [5]).

III. SOLUTION OF THE PROBLEMS

To solve the aforementioned problems, we propose a new approach to the design of a resonant storage cavity. A resonant system with variable geometry replaces the traditional fixed-form resonant cavity. As shown in Fig. 2, we construct our system using standard structural elements made from single-mode or moderately multimode waveguide sections with ends

terminated by two waveguide tees or their analogs. One arm of the tee connects to a section of the resonant cavity, the second arm is close-circuited, and the third arm connects to a tee from an adjacent linear section.

An accumulative system made in this way may be formed utilizing extended linear or three-dimensional structures, or combinations thereof, by alignment of standard elements through open arms of node devices. In addition to solving the problem of generating sharp pulses in a compact compressor, this approach increases the functionality of the compressor. The proposed approach simplifies development of systems that must fit within a small space. Integration of an MPC into an existing RF system is also easier with a concomitant savings in space.

A simple analysis of the resonant system using the dispersion matrix method shows that it is possible to implement our system with a wave-transmission coefficient that approximates the value obtained with the orthodox configuration shown in Fig. 1.

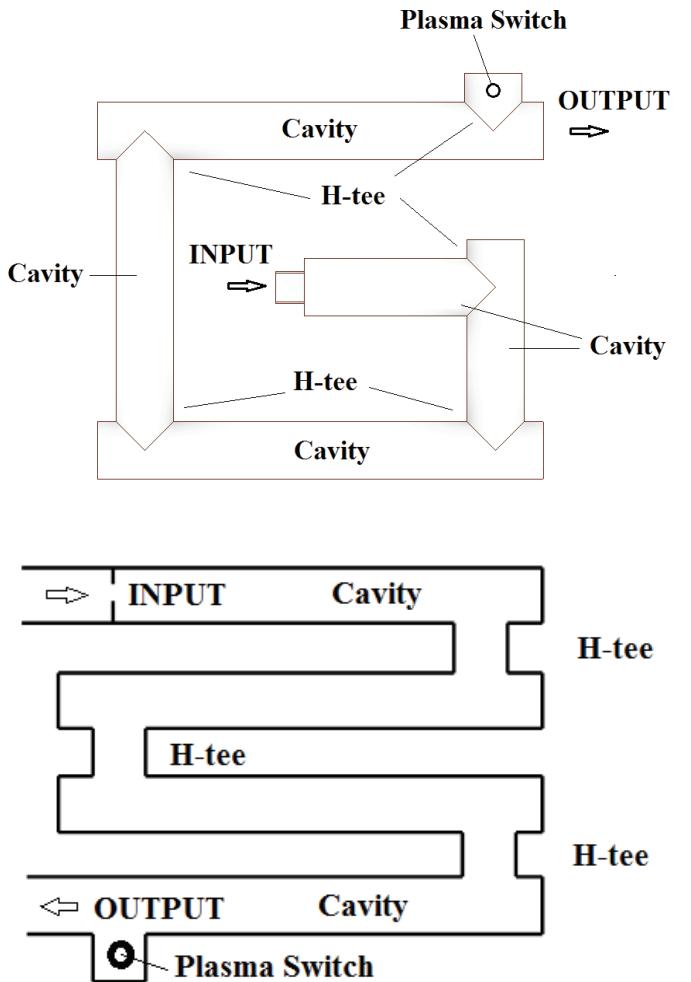


Fig. 2. Examples of the proposed geometry for compact resonant cavities.

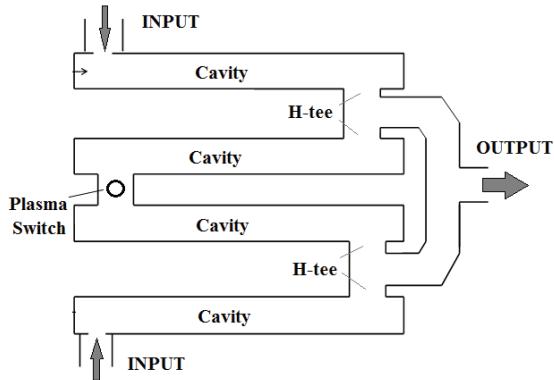


Fig. 2. (Continued) Examples of the proposed geometry.

IV. RESULTS

As shown in Fig. 3, we built several simple types of S-band MPC's with a compact storage cavity having a variable geometry. Specific architectures of the accumulative system along with placement of the output coupler are advantageous in building microwave compressors with discretely controlled output parameters. We also show that the proposed approach to the design of storage cavities makes it possible to develop compact, cascade MPC's with power multiplication of the travelling wave from each resonant cavity to the next.

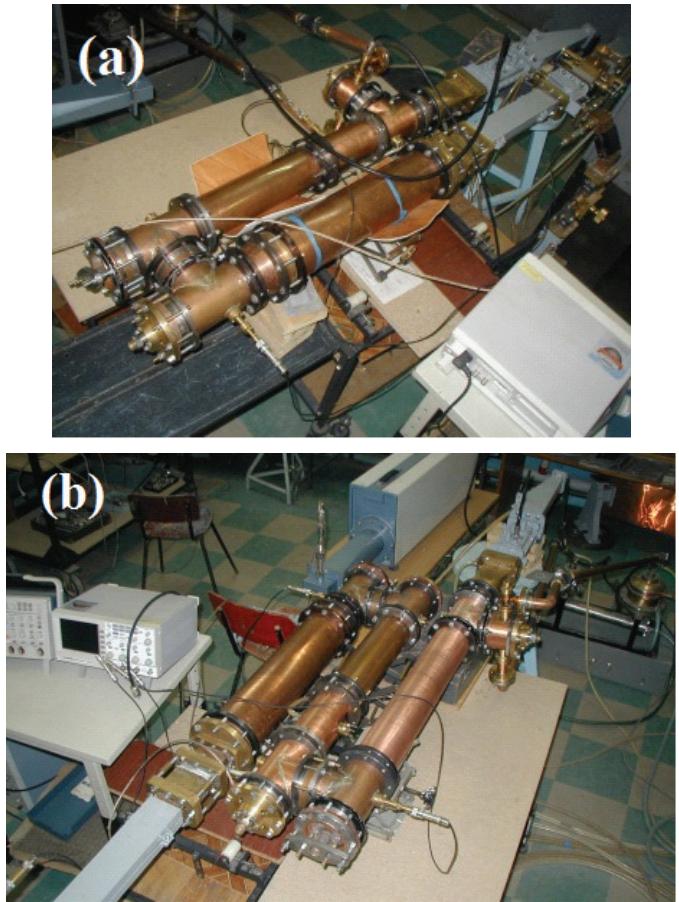


Fig. 3. Photographs of compact, active, high-power MPC's with (a) two- and (b) three-section storage cavities.

The emphasis of the present experiments is the study of MPC's with planar resonant cavities. Representative output from a three-section cavity is shown in Fig. 4; the input pulse parameters are frequency 2.8 GHz, power 2 MW, and pulse width 3.2 μ s. These compressors are based on resonant cavities following a *meander* shape. The components are located in one plane and consist of sections of single-mode round waveguide (90 mm internal diameter) and TE-tees. T-junctions are used to connect linear sections as well as to mount the plasma switch [6]. The operating mode is TE11. The intrinsic Q-factor of the resonant cavity is 24,000, while during pulse storage this parameter is approximately 12,500. The output port is connected to a matched load.

Different layouts produce identical pulses if the resonant cavity lengths are identical. We confirmed experimentally that such compressors generate nearly rectangular shaped pulses with duration equal to the double transit time of a traveling wave within the resonant cavity and with power compatible to that generated in a much longer, linear cavity. We defined the necessary conditions under which such pulses are generated.

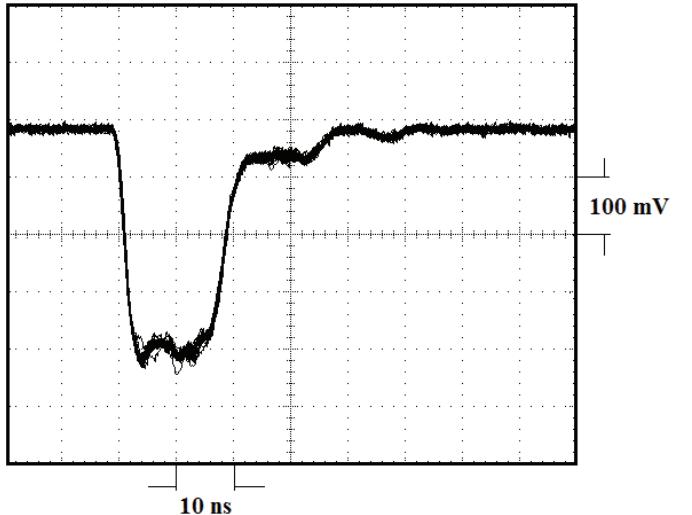


Fig. 4. Typical oscillosogram of multiple output pulses from a compressor with a three-section resonant cavity (gain 13 dB, duration 25 ns, output power 40 MW).

V. PROSPECTS

The proposed approach appears also to be effective when assembling the resonant cavity from sections of moderately multimode round waveguide. Based on the known equivalence of the field structure in a standard switch and in round waveguide with a TE01 wave, we can assume that the upper cutoff diameter of the section will be less than the critical diameter for a TE02 wave. As shown in Fig. 5, rectangular TE01 waveguides or axially symmetric radial feeders form the connecting sections. The resulting mode structure will be TE01(p).

The output device for such a compressor is (a) an H-tee interference switch using an oversized rectangular waveguide [7] or (b) an alternative topology based on a packet of standard

H-tees with a shared commuting arm that synchronizes the work of the packet [8]. Cascade interference switches will increase the working power [9].

Computational simulations show that such connections allow the resonant cavity to be formed using various planar or three-dimension geometries, including cubes and parallelepipeds. The wave propagates with very little reflection, which allows generation of long, nanosecond-duration MW pulses of nearly rectangular shape and high power.

As shown in Fig. 6, we also developed a prototype device for a compact MPC system operating in the X-band using our folded topology and we are conducting experimental studies at low power. The first results confirm our hypotheses. Excitation of oscillations and simulation of the switch in the output mode demonstrate essential functionality of the system.

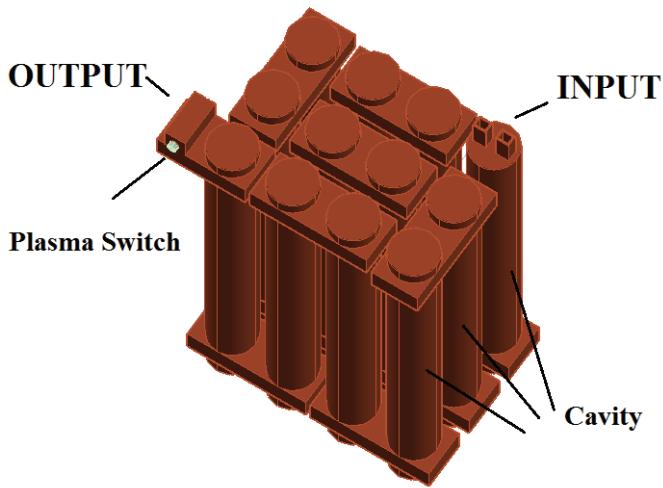


Fig. 5. Scheme of a compact compressor made from sections of moderately multimode round waveguide with a TE01 mode structure.

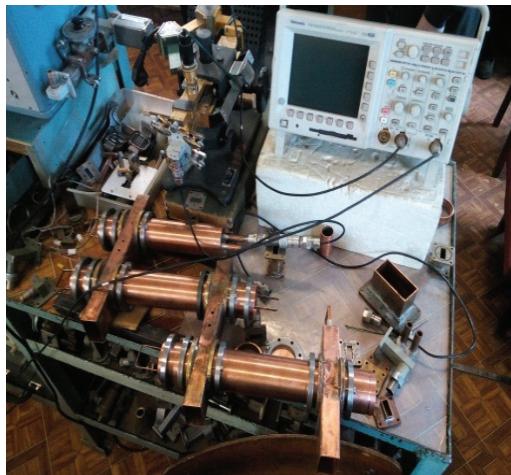


Fig. 6. Photograph of an active MPC with an oversize, three-section cavity.

VI. CONCLUSIONS

This work confirms the possibility of compact, active, microwave pulse-compression systems capable of generating long and powerful nanosecond-duration RF pulses with a rectangular shape and sufficiently high gain.

In addition to making the integration of components easier, the use of a variable-geometry resonant volume improves the functionality of the compressor by affording proper connection of various output devices to the tees. Effective generation of pulses with various waveforms, powers, and durations is therefore feasible.

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