# Microwave Pulse Compression Experiments at Low Power[1]

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**Abstract – We demonstrate here low-power microwave pulse compression at 1.3 GHz in WR-650 waveguide, using a gas switch. The cavity was constrained at the input with an inductive iris, and at the output with an H-plane tee and sliding short. The switch was a tube of dry low-pressure air, operating at a pressure of 10–13 mTorr. The switch was positioned a quarter wavelength from the sliding short. A trigatron ensured that the switch consistently fired when the stored energy approached a maximum value. The trigatron was driven by a 4 kV solid state pulser with 3 ns pulse width. The input signal was 1 kW power with 1.5 microsecond pulse width, and the output signal was 36 kW. The output pulse widths were 9 and 15 ns wide, for cavities 3 and 5 guide wavelengths in length, respectively. These pulse lengths are equal to the round-trip transit-times of the cavity, in terms of the group velocity, as predicted by theory. We observed a gain of 22 dB within the cavity, and 15.6 dB at the output. The gain within the cavity, 22 dB, approaches the theoretical maximum of 24 dB for TE10 mode WR-650 waveguide. Our energy conversion efficiency was 16%.**

## 1. Introduction

We report here a series of low-power experiments conducted to test various concepts in microwave pulse compression (MPC). The advantage of MPC is that it allows one to use a source with only modest power to realize a source with significantly higher power. Such considerations become important in operational HPM sources, because as their power increases, they become increasingly more massive, and therefore less practical for field use.

Pulse compression has been used commonly at X-band and higher frequencies [1, 2], but there are relatively few instances near 1 GHz [3–5]. The frequency spectrum near 1 GHz is of particular interest because it is most capable of upsetting and/or damaging electronics.

In this paper, we demonstrate pulse compression at 1.3 GHz, in WR-650 rectangular waveguide. We drove the cavity with a 1 kW amplifier, and realized a gain of 22 dB within the cavity, and 15.6 dB at the output.

We experimented with a variety of switches, including triggered and untriggered gas discharge tubes (GDTs) filled with low-pressure air. We found that if we controlled the pressure carefully, the switch would self-break, however its reliability was poor. To address this, we added a trigatron to ensure that the switch fired consistently when the cavity approached a maximum stored energy. Typical operating pressures were around 10–13 mTorr, which were on the left side of the Paschen curve for breakdown of air.

## 2. Experimental Configuration

We provide here the experimental configuration, as shown in Fig. 1. The resonant cavity was a length of WR-650 rectangular waveguide, either $3\lambda_g$ or $5\lambda_g$ in length, where $\lambda_g$ is the guide wavelength. The cavity was constrained on the input end by an inductive iris centered in the waveguide, with a slot width of one-quarter the waveguide width. On the output end, the cavity was constrained by an H-plane tee, with a sliding short tuned to provide an optimal resonance. The gas discharge tube (GDT) containing the switch was positioned $\lambda_g/4$ from the sliding short.

The input signal was 1 kW, the pulse repetition frequency was 10 Hz, and the input pulse width was 1.5 μs.

The switch consisted of a Gas Discharge Tube (GDT) of low-pressure dried air, which was placed $\lambda_g/4$ from the sliding short. The GDT was fabricated from a polyethylene tube, with 3/8 in. outer diameter, 1/4 in. inner diameter, and smooth copper electrodes at either end, with 1/4-in. outer diameter. The end cap of one of the electrodes had two small holes that allowed one to apply a vacuum. The pressure in the GDT was 10–13 mTorr.

Pulsed CW was emitted from the amplifier with pulse repetition frequency of 10–50 Hz, and pulse width of 1.5 μs, at a frequency of 1.3 GHz. The delay pulser, the SRS model DG535, controlled the frequency and pulse width of the pulsed CW driving the cavity. It also controlled the timing of the trigatron pulser.

To stabilize the switch timing, we added a trigatron to our switch. Thus, at one end of our Gas Discharge Tube (GDT), we placed a spark gap that was

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triggered by a Grant Applied Physics model HYPS source, with 4 kV peak voltage and 3 ns pulse width. Photos of the trigatron are shown in Fig. 2.

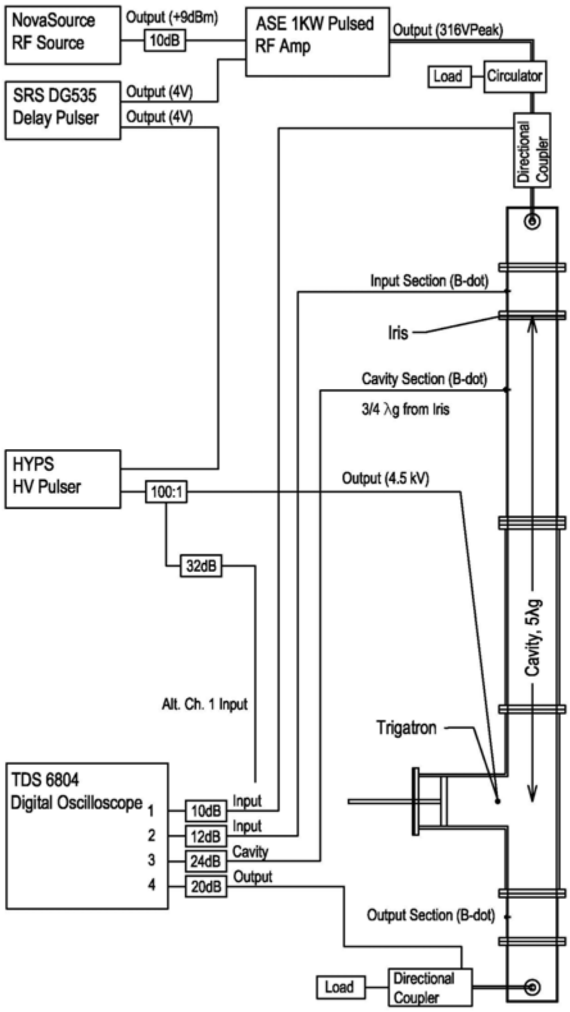


Fig 1. Experimental setup of microwave pulse compression, using a trigatron

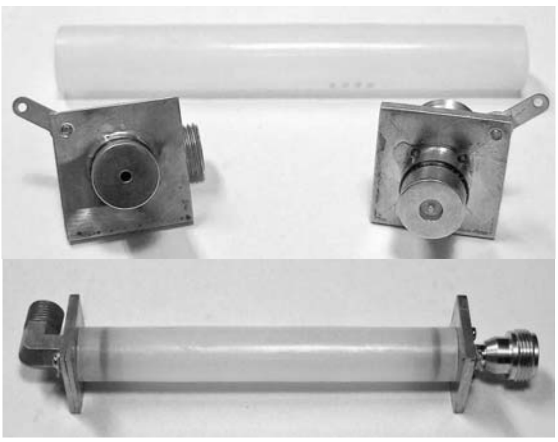

Fig. 2. Details of the trigatron and Gas Discharge Tube Switch

Data were recorded from directional couplers positioned at the input and output to the cavity. Data were also recorded from a small loop (B-dot) sensor positioned in the side wall of the cavity, positioned to record the maximum value. All data channels were calibrated to show voltages on consistent vertical scales. Data were recorded on a Tektronix model TDS6804 oscilloscope, at a resolution of 0.1 ns/point, or 10 gigasamples/s.

We recorded three channels of output, as shown in Fig. 3; the directional coupler at the input section (top), the small loop (B-dot) sensor in the cavity (middle), and the directional coupler in the output section (bottom). From this, we see clearly that the switch fires at the proper time, when cavity is nearly full. Note that the vertical scales correspond to voltage within the waveguide, and they are all consistent. In this case, we observe a gain of around 11.6 dB from the input to the output.

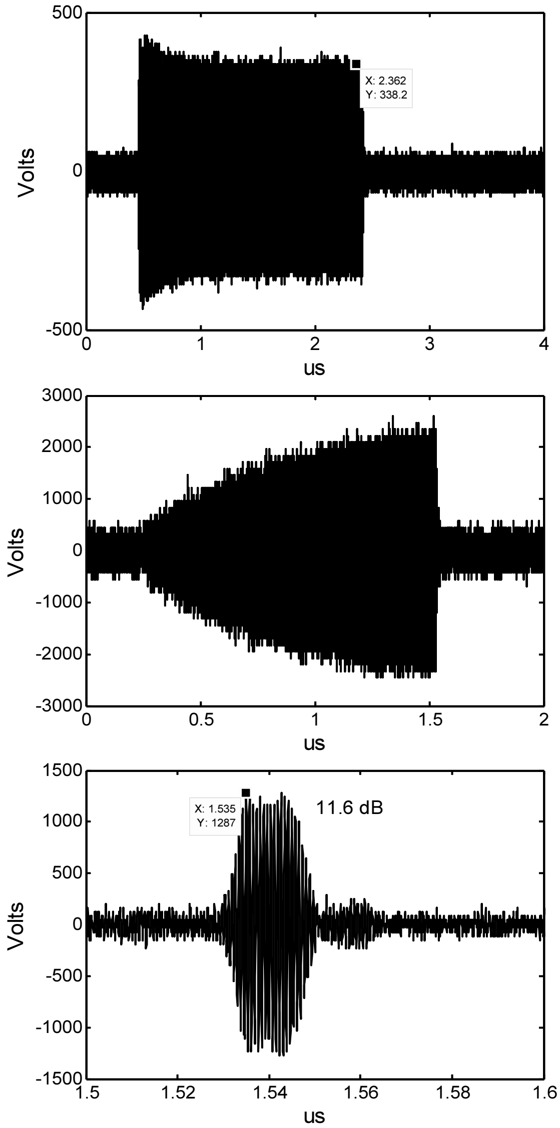


Fig. 3. The signals from the input waveguide (top), cavity (middle), and output (bottom). Note that all three vertical scales are consistent

### 3. Pulse width and risetime/falltime

We compared the length of an output pulse in a cavity that is 3 $\lambda_g$ and 5 $\lambda_g$ in length. The results are shown in Fig. 4, where we observe that the 3 $\lambda_g$ cavity produces an output 9 ns in length, and the 5 $\lambda_g$ cavity produces an output 15 ns in length, measured at Full-Width Half Maximum (FWHM). Thus, the pulse widths are proportional to the cavity lengths.

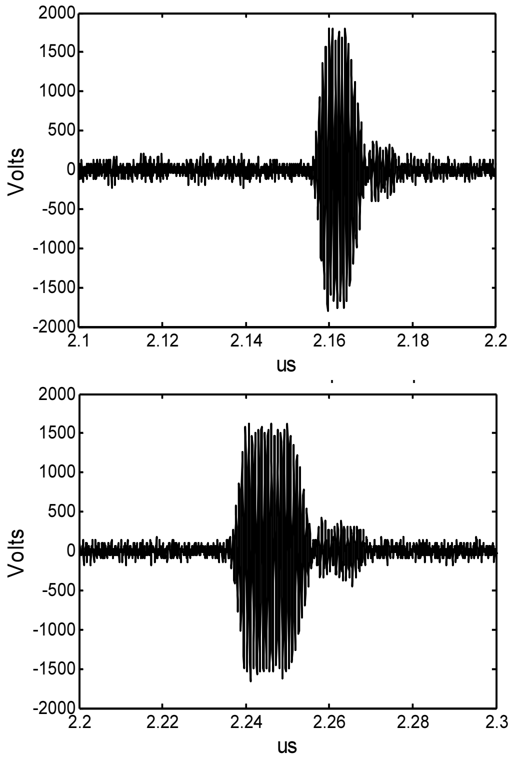


Fig.4. Pulse width study for a 3 $\lambda_g$ cavity (top) and 5 $\lambda_g$ cavity (bottom)

We next compared the two pulse widths to the round-trip transit time of the cavity at group velocity. The group velocity is

$$v_g = c\sqrt{1-(f_c/f)^2}, \tag{1}$$

where $f_c$ and $f$ are the cutoff and operating frequencies, and $c$ is the speed of light in free space. The guide wavelength, $\lambda_g$, is

$$\lambda_g = \frac{c}{f\sqrt{1-(f_c/f)^2}} \tag{2}$$

and the length of the cavity is an integral number of guide wavelengths. From this, we can calculate that the round-trip transit time of our 3$\lambda_g$ and 5 $\lambda_g$ cavity are 9 and 15 ns, respectively, which is consistent with our measurements.

Note that the data taken in Fig. 4 were taken without a trigatron, and in this series of measurements we obtained slightly better gain. The data here can be compared to the input signal in Fig. 3, so we see that we have 15.2 dB of gain with the 3 $\lambda_g$ cavity.

Next, we estimated the risetime and falltime of the data in Fig. 4 (top), by simply expanding the scales, as shown in Fig. 5. We estimate a risetime of 2.5 ns and fall time of 4 ns.

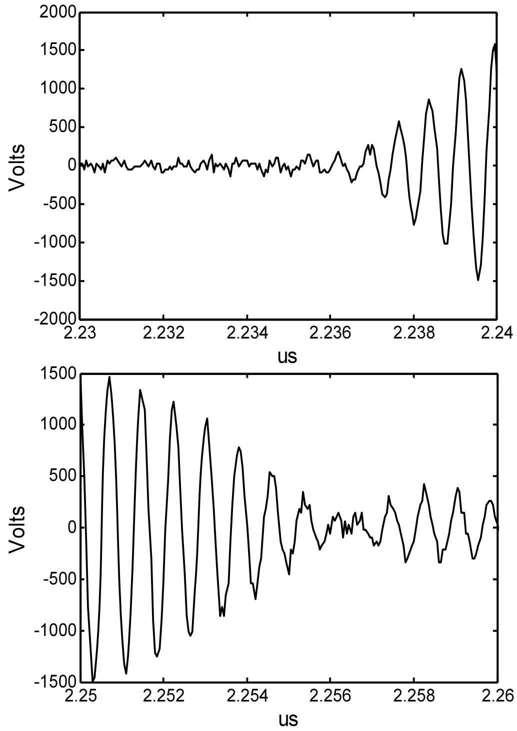


Fig. 5. Risetime and fall time of the data in Fig. 4 (top)

### 4. Gain Study

We explore here the best possible theoretical cavity gain that can be realized with our pulse compression configuration. In [6], Andreev et al. consider the simplest possible type of cavity – a shorted cavity of length ($n\,\lambda_g$)/2, with an inductive iris aperture, as shown in Fig. 6. Note that our configuration does not have a short circuit, but an H-plane tee with a sliding short. So this theory provides a best case calculation.

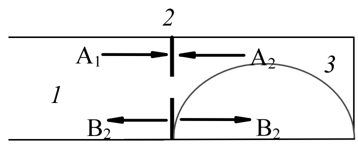


Fig. 6. The configuration analyzed in Andreev et al.

With an optimal iris opening, the optimal gain within the cavity is

$$G_{opt} = \frac{1}{4\alpha L}, \tag{3}$$

where $L$ is the length of the cavity waveguide in meters, and $\alpha$ is the attenuation of the waveguide in Np/meter. We find the midband attenuation constant of WR-650 waveguide is 0.25 dB/100 ft, or 0.008 dB/m. Noting that 1 Np = 8.68 dB, we find $\alpha \approx 0.001$ Np/m. Thus, for a 3 $\lambda_g$ cavity, we find

$G_{opt}$ = 24 dB. We observed 22 dB in our cavity, so we are close to the theoretical maximum.

## 5. Network Analysis

We also measured the steady-state CW return loss of the cavity, and the cavity gain, relative to a calibrated measurement in a waveguide without the cavity. This data was taken with an Agilent model 8753ES Vector Network Analyzer. The results are shown in Fig. 7, where we see that the return loss at resonance is better than –12 dB, and the cavity gain at resonance is 19 dB.

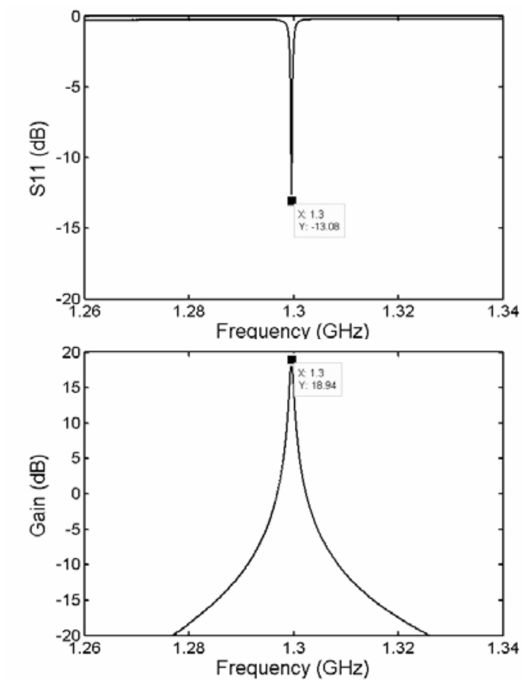


Fig. 7. Steady-state CW S11 of the input to the cavity (top) and cavity gain (bottom)

## 6. Conclusions

We have built and tested a low-power microwave pulse compressor operating at 1.3 GHz, using a self-breaking switch consisting of a gas discharge tube filled with low-pressure air. We realized a gain of 15.2 dB and a pulse width of 15 ns. The observed pulse width is consistent with theory, as is the maximum realized gain within the cavity. Having demonstrated pulse compression at low power, we now work toward high-power pulse compression.

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