RESULTS FROM A TEST FIXTURE FOR BUTTON BPM TRAPPED MODE MEASUREMENTS*

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Abstract

A variety of measures [1-7] have been suggested to mitigate the problem of button BPM trapped mode heating. A test fixture, using a combination of commercial-off-the-shelf and custom machined components, was assembled to validate the simulations. We present details of the fixture design, measurement results, and a comparison of the results with the simulations.

INTRODUCTION

A brief history of the trapped mode button heating problem and a set of design rules for BPM button optimization are presented elsewhere in these proceedings [8]. Here we present measurements on a test fixture that was assembled to confirm, if possible, a subset of those rules:

1. Minimize the trapped mode impedance and the resulting power deposited in this mode by the beam.
2. Maximize the power re-radiated back into the beampipe.
3. Maximize electrical conductivity of the outer circumference of the button and minimize conductivity of the inner circumference of the shell, to shift power deposition from the button to the shell.

The problem is then how to extract useful and relevant information from S-parameter measurements of the test fixture.

THE TEST FIXTURE

In this age of extremely powerful 3D electromagnetic analysis software, it is arguably quaint to build and measure test fixtures. In all but the most complex of circumstances, our fiducials are found in simulation software in the hands of experts, and what we can measure is the relative imperfection of our fixtures, instruments, and methods. However when time and resources permit, and when the problem under investigation is not yet fully understood and documented in the literature, it may be that there is some significant benefit beyond nostalgia in actually making measurements, if only as a learning exercise.

The trapped mode resonance in the NSLS-II 7mm buttons is at ~13.65GHz, a frequency at which we have little experience, expertise, or hardware. We scaled the test fixture by a factor of ~10, permitting us to build almost all of it from off-the-shelf 3.125" transmission line components [9], as shown in figure 1.

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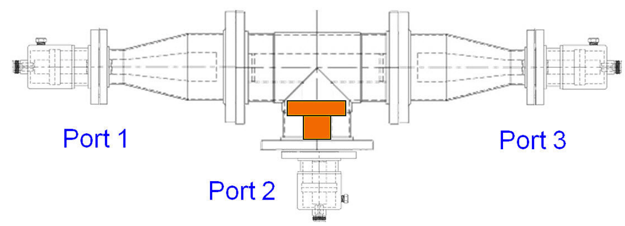

Figure 1: The test fixture.

The 'tee' center conductor portion of the tee assembly was replaced with standard conductor, creating a DC open circuit between port 2 and ports 1 and 3. The custom machined button assembly (shaded gold in the figure) accommodated the selection of buttons shown in table 1. Button "0" is the NSLS-II 7mm button. No measurements were made on this button.

Table 1: Button Parameters

button	diameter [mm]	gap [mm]	thickness [mm]	material button/housing
0	7	0.25	2	Moly/SStl
1	71.6	2.6	6.4	Cu/Cu
2	71.6	2.6	19.1	Cu/Cu
3	66.3	5.3	19.1	Cu/Cu
4	66.3	5.3	19.1	SStl/Cu

THE MEASUREMENTS

Using an Agilent E5071C network analyzer, S-parameter measurements were made on the four button configurations shown in table 1. To establish a baseline, measurements were also made with no button, with the tee in the as-manufactured configuration, without the DC open circuit between port 2 and ports 1 and 3. These results are shown in figure 2.

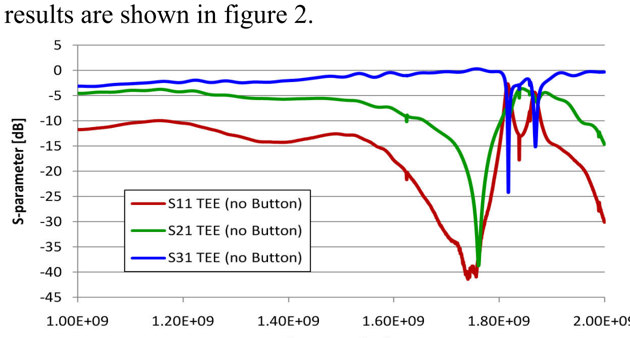

Figure 2: Measurements with no button.

The calculated cutoff frequency for 3.125" commercial hardline is ~1.73GHz. The manufacturer quotes a 'useful' cutoff of ~1.6GHz. The measurement is in good agreement with this, and shows that the test fixture in the as-manufactured configuration seems well-behaved at the anticipated ~1.4GHz trapped mode frequency of the x10 scaled buttons.

Button measurement data can be conveniently presented in either of two chart formats; all three S-parameters for a given button, or a given S-parameter (say for instance S21) for all buttons. Figure 3 shows all three S-parameters for button 2, the button that scales most faithfully to the 7mm NSLS-II button.

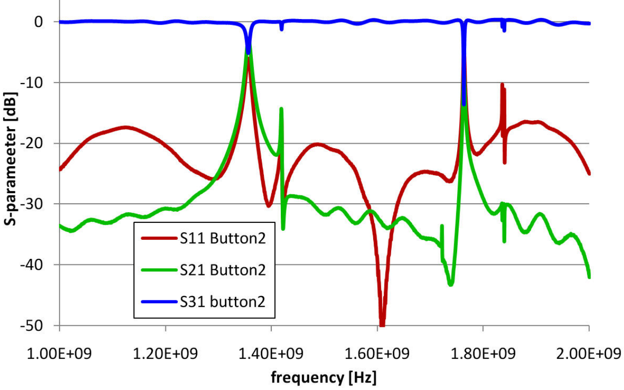

Figure 3: Measurements with button 2.

The figure shows that the trapped mode resonance is reasonably well separated from the spectral structure in the vicinity of cutoff. Figure 4 is a zoom on the resonance of figure 3.

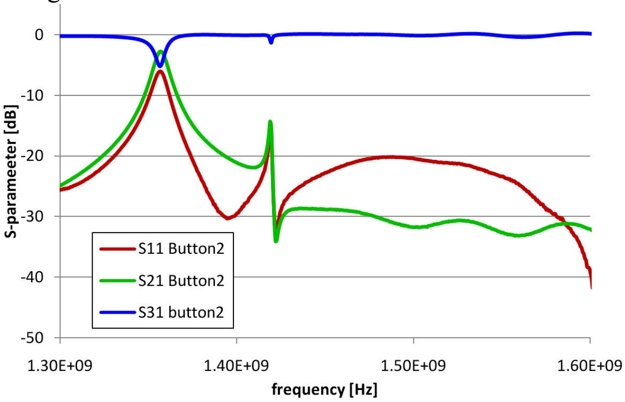

Figure 4: Zoom on the resonance.

In the measurements presented here, port 1 represents the entrance of the beam into the BPM pickup, and port 3 the exit. In understanding the measurements it is helpful to keep two things in mind.

First, in these measurements port 1 is being driven with a 50 ohm source impedance, whereas the beam is rigid. The beam source impedance is essentially infinite.

Second, it is useful to consider how the behavior of S-parameters differ in the presence of series and parallel resonances. This is briefly summarized in table 2.

With table 2 in mind, figure 4 shows immediately that the S11 and S21 measurements see the 1.36GHz trapped mode resonator as having its inductance and capacitance in parallel, whereas the S31 measurement sees them in series. The effect of the 50 ohm source impedance is not yet obvious, and will hopefully become clearer shortly.

Table 2: S-parameter Resonance Behavior

parameter	resonance type	
	series	parallel
S11	min	max
S21	max	min
S31	max	min
impedance	min	max

A less prominent feature of figure 4 is the second weaker resonance that appears at ~1.42GHz. The origin of this mode splitting can be understood by looking at the results of a GdfidL simulation.

Table 3: Simulation Results

button material	housing material	f1 [GHz]	Q1	f2 [GHz]	Q2
Cu	Cu	1.47	2750	1.53	2800
Cu	SStl	1.47	820	1.53	817

Table 3 shows the frequencies and quality factors of the resonances illustrated in figure 5, where f1 corresponds to the upper image in the figure and f2 to the lower. Why these frequencies are higher than the measured values is not understood.

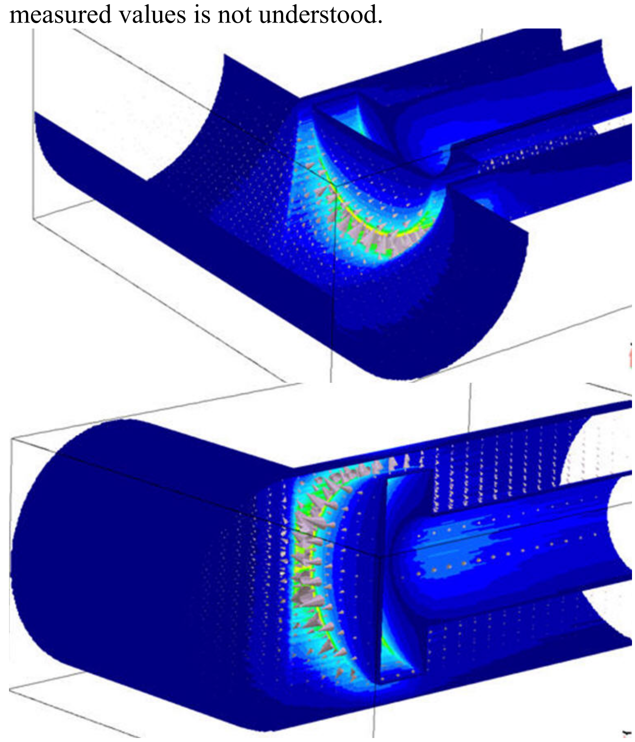

Figure 5: The two modes.

The two modes likely result from the difference in the outer conductor geometry in the horizontal and vertical planes. The additional capacitive coupling of the button to the wall in the upper image causes f1 to be lower than f2.

The relative strengths of the resonances is also not understood. When the button is driven from port 1, the field gradients generated by the excitation should couple strongly to the mode at the higher frequency f2, the lower of the two images in figure 5. In principle it should couple not at all to the mode at the lower frequency f1. Yet what we see in figure 4 is the opposite. This is not understood.

Figure 6 presents data in the previously mentioned second chart format, showing a given S-parameter (in this case S31) for all buttons. As in figure 4, for button 2 the mode frequencies appear reversed. They appear well behaved for the other three buttons.

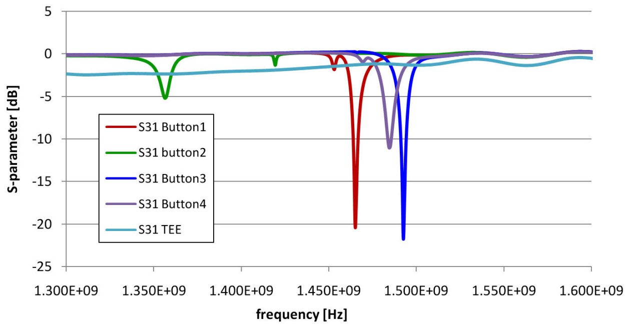

Figure 6: S31 for all buttons.

Ignoring for the moment the puzzle of the coupling to the mode frequencies, it is interesting to look at the S31 data in more detail, keeping in mind that the source impedance is that of the 50 ohm network analyzer rather than that of the beam.

Table 4: Measurement Summary

button	button material	style	S11 max	S11 Q	S21 max	S21 Q	S31 min	S31 Q
1	Cu	large thin	-1	163	-19	147	-21	1628
2	Cu	large thick	-6	151	-3	136	-5	136
3	Cu	small thick	-2	149	-13	142	-21	1866
4	SStl	small thick	-4	122	-10	114	-11	401

As can be seen in table 4, the style of button 2 is 'large thick'. With the resulting large capacitance and small inductance, the impedance of the trapped mode will be small, in agreement with the fact that the hole in the spectrum at the ~1.36GHz resonance frequency of figure 6 is comparatively shallow. The other three buttons have significantly larger impedance, suggesting that of the options considered here, button 2 (the 7mm analog) is the best choice. The only concern is the effect of the large capacitance on the signal strength.

What is surprising is the comparatively small Q for this all copper resonator, perhaps due to the comparatively low source impedance of the network analyzer.

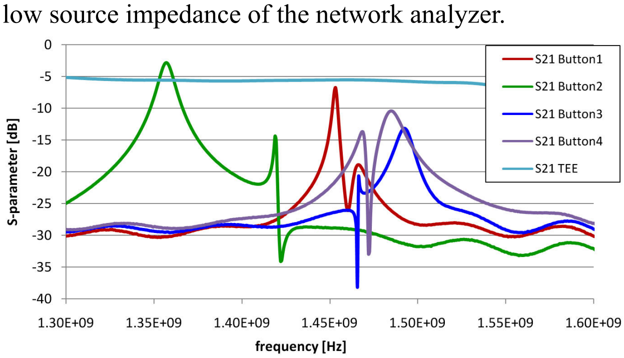

Figure 7: S21 for all buttons.

Figure 7 is, like figure 6, for all buttons, here showing S21 rather than S31. What is quite surprising is that at the resonance frequency of button 2, the attenuation of this 'trapped' mode is only 3dB. The mode is escaping, or so these measurements would seem to indicate. Such a circumstance would surely be both serendipitous and unlikely. Serendipitous in that it would again greatly favour the button 2 design. In contrast to the other buttons, half the energy captured by its comparatively low impedance would leak out port 2. The only explanation for this unexpected result again appears to be the 50 ohm network analyzer source impedance. This will be investigated in more detail.

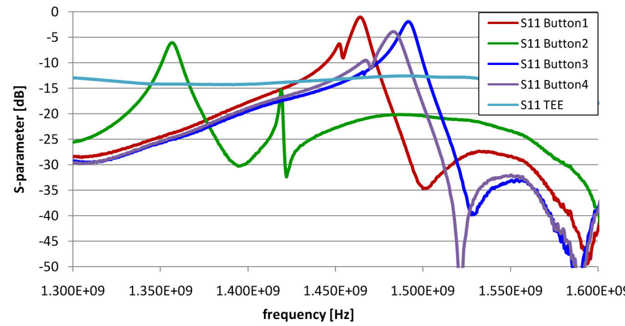

Figure 8: S11 for all buttons.

Finally, figure 8 shows S11 for all buttons. The reflected power is least for button 2, in agreement with its low impedance and high transmission out port 2.

CONCLUSION

While the measurements seem to confirm the NSLS-II 7mm button design with regard to minimizing trapped mode heating, the measurement results seem at least a bit surprising, particularly the S21 value of button 2. They ask for further attention.

ACKNOWLEDGEMENTS

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