HOM Damping Specification to C75 Cryomodule at CEBAF

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The HOM damping specification for C75 cavity is mostly related to the C75 Higher Order Dipole Modes' (HOMs) frequencies, Qexts and R/Qs' calculation. The cavity was designed and their HOM parameters are calculated by Frank Marhauser with CST. The spreadsheet of HOM frequency range was only from 1.75287 to 2.4756GHz. The R/Qs and Qexts' range was only up to 2.296GHz. The CST simulation data can be only found in a spreadsheet dated on August 28, 2017. It has been used for the calculation of measured HOM impedance for a VTA HOM survey on the first C75 cavity pairs on August 29, 2017.

The HOM survey conducted on September 29, 2021 at NL13 for 8 C75 cavities and at NL13 for #1 and #2 C75 cavities (first C75 cavity pairs in hybrid C75/C50 cavity module) have used Franks' spreadsheet as the guidance of maximum allowable Qs.

Since the HOM loads on the C75 cryomodules are rebuilt from the C50/C20 cryomodules, only SRF cavities and the HOM loads are redeveloped for the C75 upgrade program [1].

I have successfully recovered C75 CAD model from the Modeling, History List in the CST menus. I kept the original Frank's dummy JLab Reduced Height (RH) waveguide load as shown in the V-wedge shape on left insert of Figure 1 in order to properly simulate the Fundamental Mode Coupler' s(FPC) damping to the HOMs . I used original C50 HOM loads in the CST simulations since they are reused in the C50 to C75 cavity's refurbishing program [2] if they were not damaged. I repaired the the original C50 CAD mode where new tetrahedral meshing problem occurred on the HOM waveguides. So CST's lossy eigen solver can be used and total loaded Qs can be calculated from the lossy material.

The lossy material properties have been defined for the C50 HOM loads by second order Debey function fitted by given dielectric constants at 5.8, 5.9 and 6GHz with measured values of ε' and ε". The dummy FPC load is defined as the absorber in constant fit of Debey function with parameters of ε_r=1.592, μ_r=1.592 and loss tangents of both electric and magnetic values of tanδ=0.5071 at 1.497GHz.

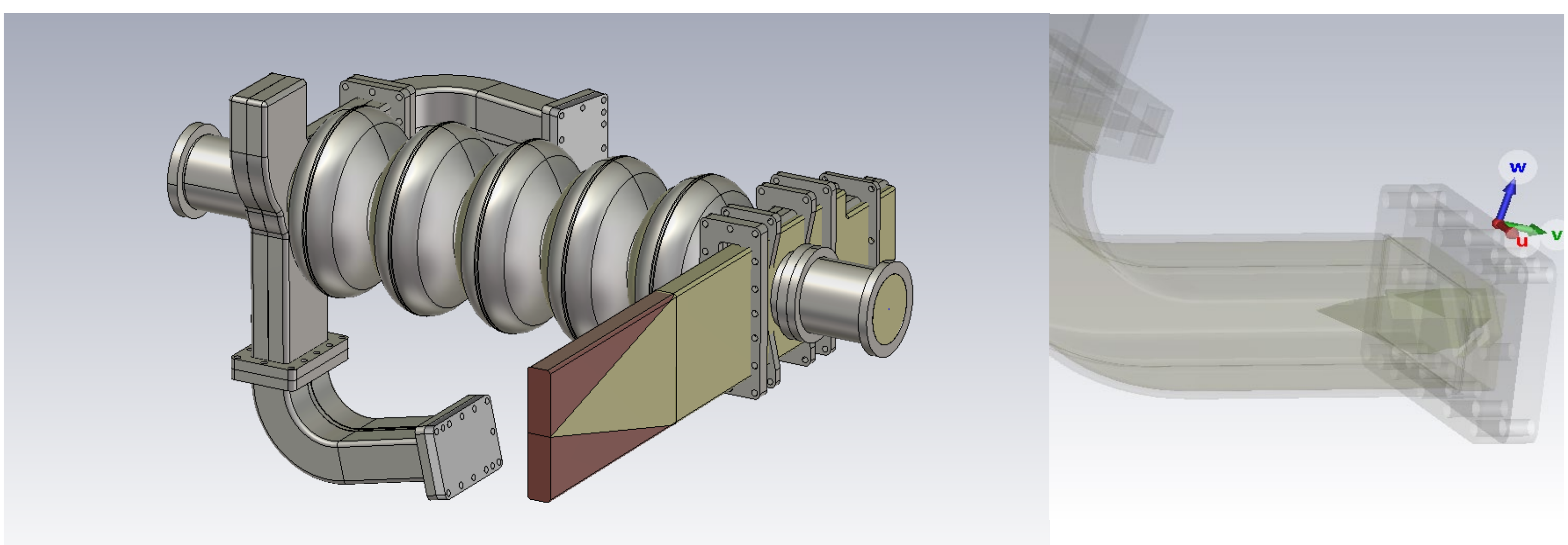

Figure 1: C75 CAD model rebuilt from existing C50 cavity model with new "High Current" 5-cell cavity shape design (left: rebuilt C75 cavity with dummy "V-wedge" shape load on the FPC couler; right: one of C50 cold HOM loads original developed for CEBAF).

Two eigen-solver runs in CST 2024 have been conducted with 60-modes solution each. The first run covers up to HOMs' frequencies up to 2560MHz, which has reconfirmed Frank's previous result recorded in his spreadsheet dated on August 28, 2017. I have also it used for the guidance of HOM surveys in 2017-2021. The second run covers HOMs' frequencies from 2560MHz up to 3GHz. Their mode identities have been marked up based on their integrated longitudinal beam voltages of β=1 particle on beam axis and off-axis as well as the 3D EM field distribution patterns in their 3D field maps.

Table 1 has summarized the specification of HOM damping requirement and the guidance on the HOM frequencies and external Qs for the QA control of HOM survey. Only regenerative type of Beam Break Up (BBU) threshold from the dangerous dipole mode impedances of < 1e10 Ω/m is listed up here.

Other HOMs with their identities including monopoles, quadruple, TE types and location-wise at HOM and FPC couplers with very low Qs are listed in Table 2 as reference. The maximum allowable Qs are all calculated for the dipole mode impedances.

From the simulation result, Only TE111, TM110 and TE112 dipole passband modes between 1.5 to 3 GHz are found. Like the C100 type 7-cell SRF cavity, the TM111 modes are highly degenerated. They are possibly damped by the HOM loads and the filter on the FPC and not seen as the high Q resonance modes. The dipole mode impedances, no matter their mode types, are calculated by Panofsky-Wenzel theory [3] from their longitudinal beam voltages at off-axis distances.

Table 1: C75 SRF cavity HOM dipole modes damping specification parameters simulated by CST and their maximum allowable external Qs for the 400uA beam current at CEBFA

Mode ID	CST Frequency	Calculated Loaded Q	Calculated R/Q$_{\perp}$ max	Qext requirement for Dipole Modes Damping
cavity passband-tilt to_polarization #	(MHz)	with C50 HOM loads	(Ω/m)	with 5-pass 400uA of CEBAF beam current BBU threahold (Ω/m) of
		and Waveguide HOM Filter		1.00E+10
TE111-1pi5_1	1752.847341	3.91E+05	42.84	2.33E+08
TE111-1pi5_2	1753.014271	3.06E+05	4.95	2.02E+09
TE111-2pi5_1	1793.615815	1.60E+05	3722.96	2.69E+06
TE111-2pi5_2	1797.8799	9.90E+04	0.36	2.78E+10
TE111-2pi5-WG	1805.206542	2.01E+05	7475.32	1.34E+06
TE111-2pi5-FPC	1858.977474	3.51E+00	196.59	5.09E+07
TE111-3pi5_1	1861.662992	1.05E+05	333.11	3.00E+07
TE111-3pi5_2	1862.335379	4.06E+04	47.07	2.12E+08
TE111-4pi5_1	1929.888705	3.28E+05	1564.72	6.39E+06
TE111-4pi5_2	1930.661563	4.90E+04	1204.05	8.31E+06
TE111-pi_1	1995.61019	1.14E+06	1525.58	6.55E+06
TE111-pi_2	1997.518005	2.70E+05	709.14	1.41E+07
TM110-pi_1	2041.171136	2.18E+04	59.53	1.68E+08
TM110-pi_2	2042.137551	2.24E+03	180.96	5.53E+07
TM110-pi-HOM	2057.237237	1.41E+04	15.33	6.52E+08
TM110-pi-FPC	2064.909089	2.94E+01	992.15	1.01E+07
TM110-4pi5-HOM	2090.84234	1.89E+04	2427.56	4.12E+06
TM110-4pi5_1	2107.623841	8.35E+03	675.85	1.48E+07
TM110-4pi5_2	2110.03099	6.98E+03	533.46	1.87E+07
TM110-3pi5_1	2150.188788	1.99E+05	874.08	1.14E+07
TM110-3pi5_2	2150.734999	1.86E+04	795.94	1.26E+07
TM110-2pi5_1	2173.630248	5.21E+04	301.83	3.31E+07
TM110-2pi5_2	2174.163003	6.40E+04	174.10	5.74E+07
TM110-1pi5_1	2181.292204	1.73E+04	52.25	1.91E+08
TM110-1pi5_2	2181.765032	2.11E+05	5.62	1.78E+09
TM110-1pi5-FPC	2185.089487	2.08E+03	292.67	3.42E+07
TE112-pi_1	2745.676275	2.56E+04	5635.88	1.77E+06
TE112-pi_2	2748.19243	5.36E+03	22.79	4.39E+08
TE112-4pi5_1	2749.758434	8.61E+03	2485.16	4.02E+06
TE112-4pi5_2	2778.473288	1.79E+03	106.11	9.42E+07
TE112-3pi5_1	2779.47997	8.56E+02	74.66	1.34E+08
TE112-3pi5_2	2796.934672	6.38E+02	194.14	5.15E+07
TE112-2pi5_1	2800.915717	1.27E+03	595.66	1.68E+07
TE112-2pi5_2	2801.592287	1.00E+02	144.34	6.93E+07
TE112-1pi5_1	2803.386506	2.18E+03	293.45	3.41E+07
TE112-1pi5_2	2826.109108	8.95E+01	283.69	3.52E+07
TE112-WG	2834.274871	1.24E+05	332.22	3.01E+07
TE112-FPC	2834.786731	6.28E+02	301.06	3.32E+07

In Figure 2, I have plotted the HOM survey data against to the maximum allowable Qs. Only TE112 passband modes are important for the regenerative multi-turn BBU threshold since the BBU thresholds for quadrupole and TM011 passband modes are normally one order of magnitude higher than 1e10 Ω/m.

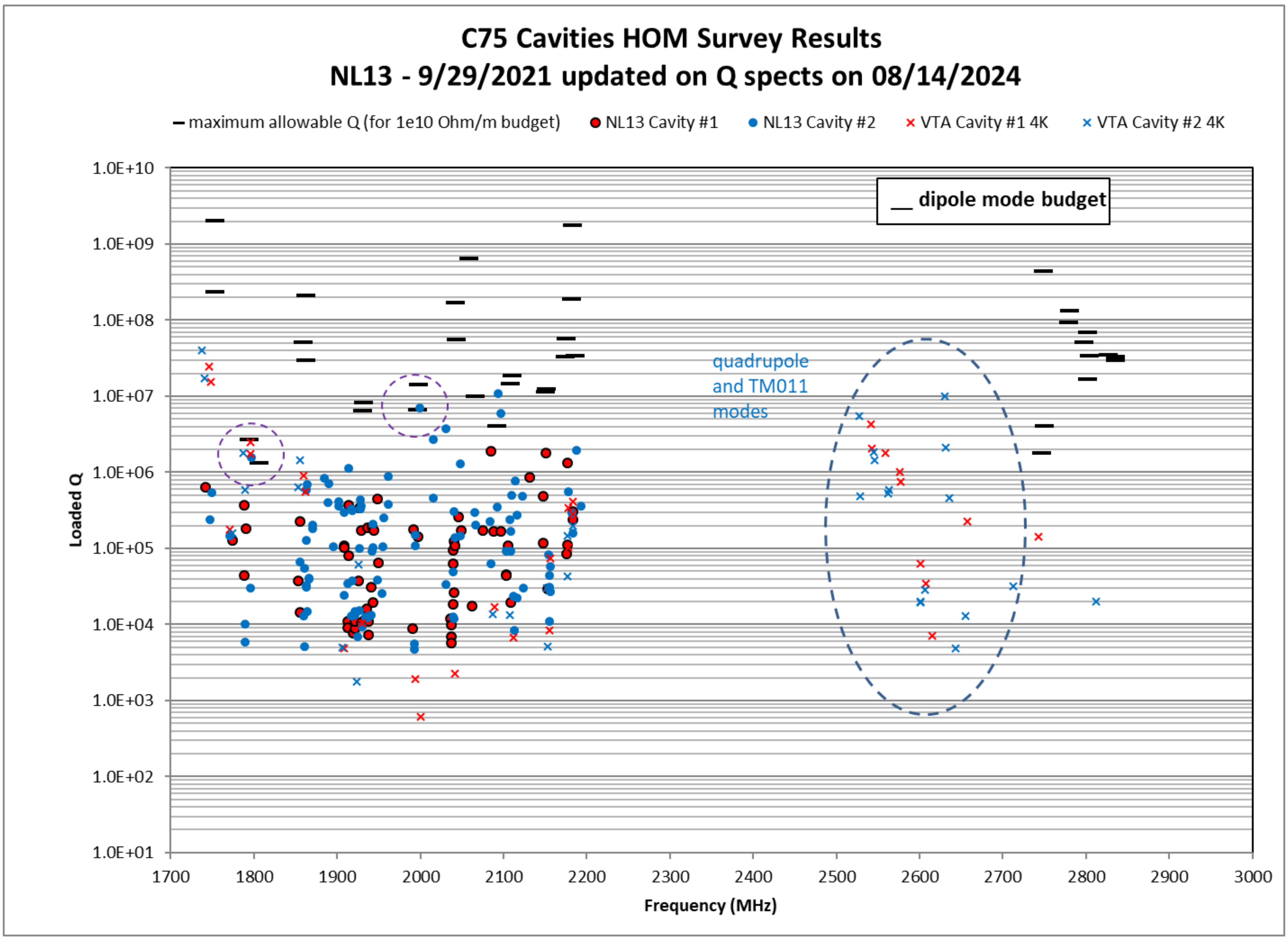

Figure 2: HOM survey data on NL13 C75 cavities against to their maximum allowable external Q specification. Extra data from the VTA measurement are the extra modes identified by the reference parameters in Table 2.

Table 2: All 119 Higher Order Modes (HOM) parameters simulated by CST eigen solver with their color codes and Mode IDs

Mode ID	CST Frequency	CST Q_{load}	R /Q, β=1 on-axis	R /Q, β=1 x-offset=10mm	R /Q, β=1 y-offset=10mm	R /Q, β=1 a-offset=14.14mm	R /$Q_{\perp}$, β=1 max	$R_{\perp}$ dipoe max	Qext Requirement for Dipole Modes Damping
cavity passband-tilt to_polarization #	(MHz)	with C50 HOM loads	(Ω)	(Ω)	(Ω)	(Ω)	(Ω/m)	(Ω)	for 5.5-pass 400uA of CEBAF beam current BBU threahold (Ω/m) of
x is in FPC waveguide port dir.		and Waveguide HOM Filter		x is in FPC waveguide port dir.		a=sqrt(x^2+y^2)			1.00E+10
TM010-pi	1496.722185	1.646E+07	5.27E+02	5.27E+02	5.27E+02				
FPC-WG-TE10_1	1610.490786	1.968E+00	4.83E-02	4.67E-02	8.66E-02	1.33E-01	1.974E+01	3.886E+01	5.06E+08
HOM-WG_x1	1676.005407	1.173E+01	3.69E-15	4.74E-15	5.69E-15	1.04E-14	1.485E-12	1.742E-11	6.73E+21
HOM-WG_y2	1676.038184	1.173E+01	3.01E-15	6.87E-15	5.86E-15	1.27E-14	1.813E-12	2.126E-11	5.52E+21
TE111-1pi5_1	1752.847341	3.906E+05	1.56E-01	1.58E-01	1.57E-01	3.15E-01	4.284E+01	1.673E+07	2.33E+08
TE111-1pi5_2	1753.014271	3.065E+05	1.90E-03	1.37E-02	2.27E-02	3.64E-02	4.951E+00	1.517E+06	2.02E+09
TE111-2pi5_1	1793.615815	1.597E+05	1.72E+01	1.42E+01	1.38E+01	2.80E+01	3.723E+03	5.944E+08	2.69E+06
TE111-2pi5_2	1797.8799	9.896E+04	2.06E-03	2.71E-03	5.98E-06	2.71E-03	3.602E-01	3.564E+04	2.78E+10
TE111-2pi5-WG	1805.206542	2.014E+05	3.32E+01	2.84E+01	2.82E+01	5.66E+01	7.475E+03	1.506E+09	1.34E+06
TE111-2pi5-FPC	1858.977474	3.515E+00	5.68E-01	5.64E-01	9.68E-01	1.53E+00	1.966E+02	6.910E+02	5.09E+07
TE111-3pi5_1	1861.662992	1.055E+05	7.05E-02	1.34E+00	1.26E+00	2.60E+00	3.331E+02	3.514E+07	3.00E+07
TE111-3pi5_2	1862.335379	4.061E+04	1.25E+00	1.57E-01	2.11E-01	3.67E-01	4.707E+01	1.911E+06	2.12E+08
HOM-WG_x3	1922.52685	7.297E+00	1.44E-14	7.77E-15	9.04E-15	1.68E-14	2.086E-12	1.522E-11	4.79E+21
HOM-WG_y4	1922.593206	7.295E+00	1.06E-14	8.50E-15	2.73E-14	3.58E-14	4.443E-12	3.242E-11	2.25E+21
TE111-4pi5_1	1929.888705	3.277E+05	6.21E-01	1.03E+01	2.37E+00	1.27E+01	1.565E+03	5.128E+08	6.39E+06
TE111-4pi5_2	1930.661563	4.899E+04	1.36E-01	1.52E+00	8.23E+00	9.74E+00	1.204E+03	5.899E+07	8.31E+06
TE111-pi_1	1995.61019	1.139E+06	8.05E-01	8.50E+00	4.26E+00	1.28E+01	1.526E+03	1.737E+09	6.55E+06
TE111-pi_2	1997.518005	2.698E+05	9.53E-02	1.37E+00	4.57E+00	5.94E+00	7.091E+02	1.914E+08	1.41E+07
HOM-WG_y5	2015.411689	2.533E+01	1.96E-13	1.83E-13	2.20E-13	4.03E-13	4.768E-11	1.208E-09	2.10E+20
HOM-WG_y6	2015.453045	2.534E+01	3.43E-13	2.65E-13	3.04E-13	5.68E-13	6.727E-11	1.705E-09	1.49E+20
HOM-WG_x7	2021.572955	1.067E+01	1.71E-13	1.32E-13	8.92E-14	2.21E-13	2.611E-11	2.786E-10	3.83E+20
HOM-WG_x8	2021.7489	1.068E+01	2.93E-13	2.17E-13	3.02E-13	5.19E-13	6.123E-11	6.537E-10	1.63E+20
TM110-pi_1	2041.171136	2.183E+04	6.02E-02	4.52E-01	5.69E-02	5.09E-01	5.953E+01	1.300E+06	1.68E+08
TM110-pi_2	2042.137551	2.242E+03	5.55E-01	6.55E-01	8.94E-01	1.55E+00	1.810E+02	4.058E+05	5.53E+07
TM110-pi-HOM	2057.237237	1.409E+04	2.44E-02	1.15E-01	1.69E-02	1.32E-01	1.533E+01	2.160E+05	6.52E+08
TM110-pi-FPC	2064.909089	2.945E+01	5.23E+00	5.38E+00	3.21E+00	8.59E+00	9.922E+02	2.922E+04	1.01E+07
TM110-4pi5-HOM	2090.84234	1.889E+04	4.76E+00	1.08E+01	1.05E+01	2.13E+01	2.428E+03	4.585E+07	4.12E+06
TM110-4pi5_1	2107.623841	8.349E+03	4.18E-03	3.03E+00	2.94E+00	5.97E+00	6.758E+02	5.642E+06	1.48E+07
TM110-4pi5_2	2110.03099	6.980E+03	9.25E-01	1.75E+00	2.97E+00	4.72E+00	5.335E+02	3.724E+06	1.87E+07
TM110-3pi5_1	2150.188788	1.987E+05	1.35E-02	7.44E+00	4.37E-01	7.88E+00	8.741E+02	1.737E+08	1.14E+07
TM110-3pi5_2	2150.734999	1.860E+04	5.90E-03	2.02E-01	6.97E+00	7.18E+00	7.959E+02	1.480E+07	1.26E+07
TM110-2pi5_1	2173.630248	5.214E+04	3.22E-03	2.75E+00	3.36E-03	2.75E+00	3.018E+02	1.574E+07	3.31E+07
TM110-2pi5_2	2174.163003	6.403E+04	5.50E-03	1.88E-02	1.57E+00	1.59E+00	1.741E+02	1.115E+07	5.74E+07
TM110-1pi5_1	2181.292204	1.729E+04	5.71E-04	4.77E-01	9.59E-04	4.78E-01	5.225E+01	9.035E+05	1.91E+08
TM110-1pi5_2	2181.765032	2.113E+05	7.80E-05	3.17E-04	5.11E-02	5.14E-02	5.621E+00	1.188E+06	1.78E+09
HOM-WG_x9	2182.751265	1.045E+01	3.25E-14	1.53E-13	1.11E-14	1.64E-13	1.795E-11	1.875E-10	5.57E+20
HOM-WG_x10	2182.768824	1.045E+01	1.10E-14	3.68E-14	6.02E-15	4.28E-14	4.681E-12	4.891E-11	2.14E+21
TM110-1pi5_FPC	2185.089487	2.080E+03	1.85E-04	2.68E+00	3.95E-04	2.68E+00	2.927E+02	6.086E+05	3.42E+07
FPC-WG-TE10_3	2250.51684	3.102E+00	9.02E-02	9.35E-02	1.70E-01	2.64E-01	2.796E+01	8.673E+01	3.58E+08
TM011-HOM	2256.784855	1.660E+09	3.58E+00	1.22E+00	1.40E+00	2.63E+00	2.778E+02	4.610E+11	3.60E+07
FPC-WG-TE11_1	2314.887518	4.613E+01	9.38E-06	6.36E-01	6.33E-05	6.36E-01	6.556E+01	3.025E+03	1.53E+08
HOM-WG_y11	2390.249436	1.126E+01	8.38E-14	7.51E-14	6.63E-14	1.41E-13	1.411E-11	1.589E-10	7.09E+20
HOM-WG_x12	2390.308818	1.127E+01	4.70E-14	4.30E-14	3.52E-14	7.82E-14	7.807E-12	8.797E-11	1.28E+21
HOM-WG_x13	2403.860185	7.379E+00	1.64E-15	2.57E-15	2.43E-15	5.00E-15	4.960E-13	3.660E-12	2.02E+22
HOM-WG_y14	2403.949394	7.382E+00	1.31E-13	1.00E-13	1.22E-13	2.22E-13	2.203E-11	1.627E-10	4.54E+20
HOM-WG_xy15	2434.976852	6.819E+08	1.37E-03	4.44E-01	6.33E-01	1.08E+00	1.056E+02	7.201E+10	9.47E+07
FPC-WG--TE10_4	2450.174762	2.554E+01	2.47E+00	2.74E+00	1.78E+00	4.51E+00	4.395E+02	1.123E+04	2.28E+07
HOM-WG-BP_1	2475.244623	6.629E+09	4.73E-02	1.78E-01	1.50E-01	3.28E-01	3.164E+01	2.097E+11	3.16E+08
FPC-WG-TE11_2	2475.380997	2.527E+01	4.01E-05	7.22E-02	1.64E-04	7.24E-02	6.975E+00	1.763E+02	1.43E+09
HOM-WG_xy16	2475.900563	4.858E+08	9.62E-04	2.00E-02	5.84E-02	7.84E-02	7.555E+00	3.670E+09	1.32E+09
HOM-WG_y17	2516.516661	7.944E+00	1.30E-14	5.81E-15	3.24E-14	3.83E-14	3.627E-12	2.881E-11	2.76E+21
HOM-WG_x18	2516.69648	7.945E+00	5.44E-15	2.26E-15	5.16E-15	7.42E-15	7.038E-13	5.592E-12	1.42E+22
FPC-WG-BP_1	2525.831012	1.281E+03	1.94E-02	2.79E-02	4.22E-02	7.01E-02	6.619E+00	8.479E+03	1.51E+09
FPC-WG-BP_2	2526.637409	3.751E+04	1.05E-05	1.40E-01	4.07E-05	1.41E-01	1.327E+01	4.976E+05	7.54E+08
TE211-1pi5_1	2540.404507	5.629E+07	1.80E-05	2.68E-03	2.90E-03	5.58E-03	5.241E-01	2.950E+07	1.91E+10
TE211-1pi5_2	2540.418075	9.897E+07	7.34E-06	5.17E-02	5.10E-02	1.03E-01	9.641E+00	9.542E+08	1.04E+09

color code	
	acceleration mode
	HOMs in WG or FPC
	monople modes
	dipole modes
	quadruple modes
	TE monople modes

The nomenclature of Mode ID is made based on the group name identity. First group: cylindrical cavity EM type in transverse (r, φ) direction with the node number of Bessel function in (r, φ, z) direction in sequence; Second group: passband mode distribution pattern in the cavity cells (or the cavity EM field in the phase-advance per cell in radian) or at the cavity end group structure; Third group: polarization number in φ direction.

Table 2: Continued, all 119 Higher Order Modes (HOM) parameters simulated by CST eigen solver with their color codes and Mode IDs

TE211-FPC-1pi5_1	2548.925416	3.613E+00	5.88E-02	6.39E-02	1.28E-01	1.92E-01	1.795E+01	6.486E+01	5.57E+08
TE211-1pi5_3	2554.228608	2.264E+07	7.32E-05	2.74E-02	2.34E-02	5.08E-02	4.743E+00	1.074E+08	2.11E+09
TE211-1pi5_4	2554.247352	3.505E+07	1.40E-07	4.07E-02	4.07E-02	8.13E-02	7.598E+00	2.663E+08	1.32E+09
HOM-WG_y19	2557.447901	5.771E+00	1.17E-14	1.51E-14	5.35E-14	6.86E-14	6.401E-12	3.694E-11	1.56E+21
TE211-2pi5_1	2571.043464	5.126E+07	1.75E-04	9.76E-04	1.43E-03	2.40E-03	2.228E-01	1.142E+07	4.49E+10
TE211-2pi5_2	2571.053325	2.014E+07	1.50E-04	2.39E-04	9.01E-04	1.14E-03	1.058E-01	2.131E+06	9.45E+10
TM011-1pi5	2578.934169	1.084E+07	2.63E-02	1.93E-02	2.41E-02	4.34E-02	4.013E+00	4.352E+07	2.49E+09
TM011-2pi5	2610.765976	1.139E+06	1.36E+01	1.40E+01	1.40E+01	2.80E+01	2.556E+03	2.912E+09	3.91E+06
HOM-WG_x19	2628.784251	6.047E+00	1.10E-15	9.95E-16	6.12E-16	1.61E-15	1.459E-13	8.821E-13	6.86E+22
HOM-WG_y20	2628.948495	6.048E+00	2.88E-16	1.13E-15	8.00E-16	1.93E-15	1.754E-13	1.061E-12	5.70E+22
TE211-2pi5_3	2632.560227	6.691E+07	1.79E-04	1.62E-05	1.15E-04	1.32E-04	1.193E-02	7.981E+05	8.38E+11
TE211-2pi5_4	2632.793387	4.450E+08	1.21E-04	4.72E-02	4.64E-02	9.37E-02	8.488E+00	3.777E+09	1.18E+09
TE211-3pi5_1	2635.035901	7.339E+05	3.96E-07	3.26E-02	2.71E-02	5.97E-02	5.402E+00	3.964E+06	1.85E+09
TE211-3pi5_2	2635.073432	1.229E+05	8.41E-05	1.89E-03	1.87E-03	3.76E-03	3.407E-01	4.186E+04	2.94E+10
TM011-3pi5	2651.069639	4.082E+05	5.77E+01	5.70E+01	5.74E+01	1.14E+02	1.029E+04	4.201E+09	9.72E+05
FPC-WG-TE11_3	2658.257144	1.510E+01	2.63E-05	3.45E-01	2.59E-05	3.45E-01	3.097E+01	4.675E+02	3.23E+08
TM011-4pi5	2685.451758	4.434E+06	1.38E+01	1.29E+01	1.26E+01	2.55E+01	2.270E+03	1.006E+10	4.41E+06
FPC-WG-absorber_1	2711.314969	1.019E+00	1.94E-08	2.02E-08	5.65E-08	7.67E-08	6.750E-06	6.876E-06	1.48E+15
TM011-pi	2720.911667	8.547E+03	4.77E+01	4.79E+01	4.76E+01	9.55E+01	8.374E+03	7.158E+07	1.19E+06
HOM-WG_x21	2733.59045	7.848E+00	1.54E-16	1.20E-15	1.98E-16	1.39E-15	1.216E-13	9.546E-13	8.22E+22
HOM-WG_y22	2733.727193	7.846E+00	1.35E-16	8.32E-16	9.36E-17	9.26E-16	8.079E-14	6.339E-13	1.24E+23
TE112-pi_1	2745.676275	2.562E+04	2.87E+01	3.16E+01	3.32E+01	6.49E+01	5.636E+03	1.444E+08	1.77E+06
TE112-pi_2	2748.19243	5.363E+03	8.31E-02	1.90E-01	7.29E-02	2.63E-01	2.279E+01	1.222E+05	4.39E+08
TE112-4pi5_1	2749.758434	8.605E+03	1.39E+01	1.41E+01	1.46E+01	2.86E+01	2.485E+03	2.139E+07	4.02E+06
TE112-4pi5_2	2778.473288	1.788E+03	5.46E-01	5.89E-01	6.46E-01	1.24E+00	1.061E+02	1.897E+05	9.42E+07
TE112-3pi5_1	2779.47997	8.564E+02	2.50E-01	5.87E-01	2.82E-01	8.70E-01	7.466E+01	6.394E+04	1.34E+08
TE112-3pi5_2	2796.934672	6.383E+02	2.05E-01	2.90E-01	1.99E+00	2.28E+00	1.941E+02	1.239E+05	5.15E+07
TE112-2pi5_1	2800.915717	1.270E+03	7.27E-01	3.21E+00	3.78E+00	6.99E+00	5.957E+02	7.564E+05	1.68E+07
TE112-2pi5_2	2801.592287	1.001E+02	3.11E-03	1.69E+00	2.23E-03	1.70E+00	1.443E+02	1.445E+04	6.93E+07
TE112-1pi5_1	2803.386506	2.183E+03	6.38E-02	9.60E-01	2.49E+00	3.45E+00	2.935E+02	6.407E+05	3.41E+07
TE011-1pi5	2803.880755	1.473E+07	1.29E-06	4.00E-04	1.74E-04	5.74E-04	4.883E-02	7.193E+05	2.05E+11
TE011-2pi5	2808.724048	5.268E+08	1.78E-05	2.20E-05	4.19E-06	2.62E-05	2.227E-03	1.173E+06	4.49E+12
TE011-3pi5	2813.674018	1.765E+09	8.60E-06	9.81E-07	2.45E-06	3.43E-06	2.911E-04	5.139E+05	3.44E+13
TE112-1pi5_2	2826.109108	8.951E+01	9.72E-06	3.36E+00	2.17E-05	3.36E+00	2.837E+02	2.539E+04	3.52E+07
TE112-WG	2834.274871	1.241E+05	1.31E-01	1.18E+00	2.77E+00	3.95E+00	3.322E+02	4.124E+07	3.01E+07
TE112-FPC	2834.786731	6.278E+02	1.33E-01	1.86E-01	3.39E+00	3.58E+00	3.011E+02	1.890E+05	3.32E+07
TE211-4pi5_1	2847.031642	1.450E+06	4.86E-04	1.15E-01	5.88E-02	1.74E-01	1.459E+01	2.117E+07	6.85E+08
TE211-4pi5_2	2847.045675	2.908E+06	2.74E-03	3.21E-01	1.32E-01	4.54E-01	3.800E+01	1.105E+08	2.63E+08
TE211-4pi5_3	2847.317272	2.029E+07	9.25E-03	2.68E+00	1.34E+00	4.02E+00	3.372E+02	6.841E+09	2.97E+07
TM210-4pi5_1	2860.823948	1.077E+06	6.74E-04	1.71E-03	5.69E-04	2.28E-03	1.905E-01	2.051E+05	5.25E+10
TM210-4pi5_2	2860.841758	5.577E+05	8.31E-04	2.20E-03	5.77E-03	7.98E-03	6.652E-01	3.710E+05	1.50E+10
TM210-3pi5_1	2877.242619	1.806E+06	3.43E-04	1.51E-03	3.70E-04	1.88E-03	1.559E-01	2.816E+05	6.41E+10
TM210-3pi5_2	2877.289933	2.850E+05	1.16E-03	6.12E-04	2.09E-03	2.70E-03	2.242E-01	6.389E+04	4.46E+10
TE011-4pi5	2878.169313	1.120E+10	1.00E-05	2.15E-06	4.32E-05	4.54E-05	3.760E-03	4.213E+07	2.66E+12
TE011-pi	2878.429	1.807E+10	4.07E-06	4.01E-05	4.43E-07	4.05E-05	3.358E-03	6.068E+07	2.98E+12
TM210-4pi5_3	2890.801957	1.352E+07	1.59E-03	1.46E-03	1.11E-03	2.57E-03	2.122E-01	2.869E+06	4.71E+10
TM210-4pi5_4	2890.833539	2.117E+05	4.64E-04	3.01E-02	3.71E-02	6.72E-02	5.548E+00	1.175E+06	1.80E+09
HOM-WG_x23	2891.19701	1.174E+01	6.35E-17	2.03E-16	5.95E-17	2.63E-16	2.168E-14	2.545E-13	4.61E+23
HOM-WG_x24	2891.220042	1.175E+01	2.60E-17	3.02E-16	1.19E-16	4.21E-16	3.474E-14	4.081E-13	2.88E+23
TM210-pi_1	2896.362462	1.912E+06	2.99E-04	2.15E-02	2.48E-02	4.63E-02	3.812E+00	7.288E+06	2.62E+09
TM210-pi_2	2896.387317	2.886E+05	1.06E-03	1.46E-01	1.28E-01	2.74E-01	2.259E+01	6.520E+06	4.43E+08
HOM-WG_y25	2918.767286	5.277E+00	1.22E-16	1.40E-16	4.64E-16	6.04E-16	4.934E-14	2.604E-13	2.03E+23
HOM-WG_y26	2918.931572	5.277E+00	9.50E-16	5.80E-16	2.11E-15	2.69E-15	2.200E-13	1.161E-12	4.55E+22
FPC-WG-TE10_5	2919.398847	4.774E+00	4.35E-02	5.42E-02	1.17E-01	1.71E-01	1.396E+01	6.667E+01	7.16E+08
HOM-WG_x26	2919.917226	7.338E+00	2.94E-17	4.06E-17	2.47E-17	6.53E-17	5.337E-15	3.916E-14	1.87E+24
HOM-WG_y27	2920.057436	7.338E+00	1.97E-16	1.62E-16	1.55E-16	3.17E-16	2.588E-14	1.899E-13	3.86E+23
FPC-WG-TE11_4	2935.931517	1.348E+01	8.73E-04	3.30E-01	6.68E-04	3.30E-01	2.683E+01	3.617E+02	3.73E+08
HOM-WG_x28	2949.21401	5.371E+00	9.38E-17	3.00E-16	3.18E-16	6.18E-16	4.998E-14	2.685E-13	2.00E+23
HOM-WG_y29	2949.441482	5.370E+00	2.08E-16	2.36E-16	1.79E-16	4.15E-16	3.358E-14	1.803E-13	2.98E+23
FPC-WG-TE10_6	2975.787201	7.788E+00	1.40E-01	1.99E-01	3.63E-01	5.62E-01	4.504E+01	3.508E+02	2.22E+08
HOM-WG_y30	2982.00606	5.640E+00	4.00E-16	6.49E-16	1.25E-15	1.90E-15	1.516E-13	8.552E-13	6.59E+22
HOM-WG_x31	2982.007767	5.641E+00	2.12E-16	5.78E-16	5.95E-16	1.17E-15	9.391E-14	5.297E-13	1.06E+23

Conclusion

The HOM damping requirement of total 5-pass beam current of 400uA in 12GeV at CEBAF for the dipole modes of TE111, TM110, TE112 passbands with impedance budget of 1e10 Ohm/m have been given in the specification tables. Making up the missing the R/Qs calculation for the TE112 passband modes and updated beyond the Frank Marhauser's work, by extra CST simulations and mode identification, maximum allowable external Qs for the specification have been given in the spreadsheet format. An example of surveyed HOM data up to 3GHz to compare the measured external Qs with the specification has been given.

We should use this tech note as the project document for the QA control of HOM damping performance of newly rebuilt C75 cryomodules in the future. All HOM surveys to be conducted should use this published data for the reference and QA guideline.

Reference:

[1] Frank Marhauser, etc. "Absorber Materials at Room and Cryogenic Temperatures", TUPS106, Proceedings of IPAC2011, San Sebastián, Spain.

[2] Private conversation to Jiquan Guo and Liang Zhao in August 2024, both at SRF S&T and Production Department.

[3] M. Broman, "Uisng the Panofsky-Wenzel Theorem in the Analysis of Radio-Frequency Deflectors", PAC 1993 publication in JACoW. https://accelconf.web.cern.ch/p93/PDF/PAC1993_0800.PDF