Study and Design of a New Over-damped Cavity Kicker for the PEP II Longitudinal Feedback System

F. Marcellini*, M. Tobiyama°, P.A. McIntosh, J. Fox, H. Schwarz, D.Teytelman, A. Young[1]

*Laboratori Nazionali di Frascati-INFN, Via E. Fermi 40, Frascati (Rome) Italy
° KEK, High Energy Accelerator Research Org., Oho 1-1, Tsukuba-shi, Ibaraki 305-0801, Japan
Stanford Linear Accelerator Center, 2575 Sand Hill Road - Menlo Park Ca 94025 USA

Abstract. PEP-II has been running for several years using drift-tube style longitudinal kickers. They have functioned well at the design current in the HER and LER. Machine upgrade plans for PEP-II have encouraged the analysis and design of cavity kickers for the longitudinal feedback systems in PEP-II. The cavity kicker design is based on the use of an extremely low Q°cavity, where the Q of the system is determined primarily by ridged waveguides coupling to external loads. This kicker design has originally developed at LNF-INFN, and is attractive for use at PEP- II to reduce the kicker impedance at frequencies outside the working bandwidth and consequently reduce the strong beam-heating of the structure and the feedthroughs. The cavity-style kicker is also better suited to external cooling, as it is without internal elements which must be cooled through either radiation or conduction out through some path. The design options, including the choice of operating frequency (9/4*RF vs. 13/4*RF), the kicker shunt impedance, the number of external coupling ports (4 vs. 8) and the selection of the kicker bandwidth, are briefly described and three different solutions are proposed. Results are presented estimating the shunt impedance, bandwidth and HOM impedances via the use of the Ansoft HFSS code.

INTRODUCTION

Both the High Energy and Low Energy rings of PEP-II at SLAC utilize two-element drift tube type kickers in the longitudinal feedback system [1]. They have worked with success since machine commissioning and the machine is currently running above the design luminosity. Future plans for PEP-II include operation at higher currents, and we are considering the use of cavity type kickers for future use. These cavity style kickers have limited impedance outside the operating bandwidth (BW), and are potentially less subject to problems of beam-induced heating. This paper reports on a design study for a cavity type kicker suitable for PEP-II requirements.

---

[1] Work supported by Department of Energy contract DE-AC03-76SF00515

GENERAL CONSIDERATIONS ABOUT THE KICKER DESIGN

The cavity kicker design is based on the idea of using the voltage seen by the beam when it crosses a cavity gap, to provide the bunch with the proper longitudinal kick needed to damp longitudinal coupled bunch motion. As the coupled bunch modes cover a wide frequency range (up to 1/2 f_{RF} in case of every bucket filled), for good efficiency (and uniform gain across the full bandwidth of coupled-bunch modes) the cavity has to be a broadband resonator, with a Q much lower than typical values for conventional cavities. Since $Q=2\pi f_0 U/P$, where f_0 is the central frequency of resonance, U is the energy stored in the cavity volume and P is the total power dissipated in the cavity walls and in external loads, the cavity Q can be lowered by increasing the power losses.

The overdamped cavity kicker design uses strong coupling to external loads to set the value of Q at the desired value (typically in the range from 4 to 10). In this approach the external Q of the system is really defining the system bandwidth, and the external loads are available to dissipate beam-induced power.

In detail, the kicker consists of a pill box cavity with a number of waveguides (WGs) attached symmetrically on both cavity sides.

Figure1 shows a drawing of the first cavity type kicker. It was designed for the DAFNE Φ-Factory at Frascati, Italy°[2].

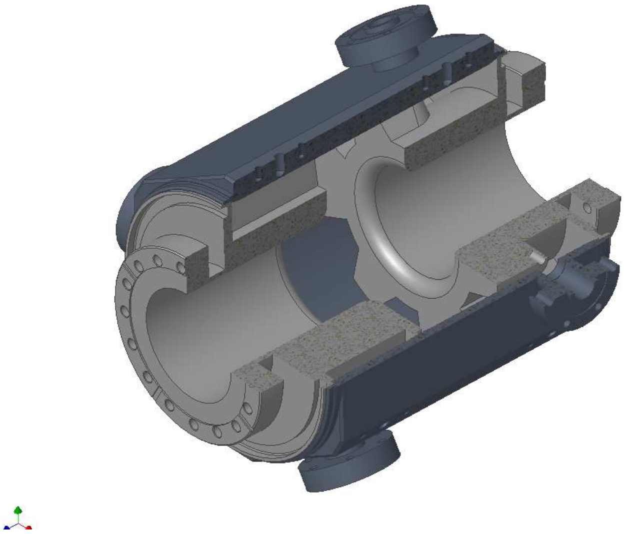


FIGURE 1. Cut view of the DAFNE longitudinal feedback kicker.

Each WG is followed by a transition to a standard coaxial line via coaxial vacuum insulators to facilitate the connection towards external devices (driving amplifiers and dummy loads). Special ridged WGs are designed to lower the cut off frequency below the frequencies of the fundamental mode band. By extending the transmission response of the transitions up to the beam pipe cut off, effective damping of all HOMs of the cavity can be obtained.

As the power losses are strongly dominated by the dissipation in the external loads, driving half the ports of the structure in phase and connecting the remaining ports to dissipative loads results in the cavity structure being perfectly matched at its central frequency. However the power reflected towards amplifiers at the edge of the working frequency band and the power released in the cavity by the beam for interaction with the fundamental and HOM impedances require the use of circulators to protect the driving amplifiers. This is in contrast to the existing drift-tube kickers, for which absorbitive low-pass filters are used to protect the amplifiers from the beam-induced HOM power, while the directivity of the drift-tube structure dissipates the majority of the fundamental beam-induced power in the terminations of the drift-tube kicker, so that the in-band power reflected back into the driving amplifiers is within the power dissipation rating of the amplifiers.

THE CHOICE OF OPERATING FREQUENCY

We have explored two possible operating frequencies for the cavity kicker: 9/4 $f_{RF}{}^{\circ}$= 1.071 GHz and 13/4 f_{RF} = 1.547 GHz (odd multiples of 1/4 f_{RF} allow the minimization of beam-induced power and help provide uniform gain across the operating band [3]. As part of this initial design study the preliminary design of a cavity- kicker at 13/4 RF was performed to better estimate the likely shunt impedance and HOM impedances, and better understand the trade-offs in choice of operating frequency [4]. The higher frequency option presents some advantages, such as the existing power amplifiers have more power output in this range of frequencies and the HOM content of the cavity is reduced to only two dipoles because of the shift of the other HOM resonant frequencies beyond beam pipe cut off. On the other hand, for the 9/4 f_{RF} solution, the increased ratio between cavity and beam pipe radii results in higher R/Q. Consequently more shunt impedance is obtainable in spite of a reduction of Q by a factor 13/9 for a fixed BW. Moreover, the current system is operating at 9/4 f_{RF} and there is no need to modify many back-end components. Finally the timing of the system is less critical at lower frequencies.

Weighting pros and cons of each option, it has been decided to design the cavity kicker at 9/4 f_{RF}.

DESIGN OF THE THREE DIFFERENT PROPOSALS

For this basic design there are two important parameters available to specify the overall design: the number of coupling ports and the coupling strengths, which determine the BW of the kicker.

The system BW requirements are depending on the bucket filling patterns. In case of by 2 filling, all the possible coupled bunch modes oscillate at frequencies contained in a span of 120 MHz (476 MHz/4). With the rough assumption that the cavity fundamental mode R/Q is constant when the cavity body profile is not changed, the BW of the cavity kicker is inversely proportional to the maximum shunt impedance. In other words it seems convenient to keep the BW as narrow as possible to maximize the shunt impedance R_s. But this dependence is less sensitive at the edge of the BW, so a BW larger than 120 MHz presents the advantage to have a better gain flatness across the operating band and a better phase linearity of the system.

The narrower bandwidth structures have higher shunt impedance, and at first glance one might assume that the voltage seen by the beam would be higher due to the higher shunt impedance. However, there is an additional issue with the QPSK modulation scheme, in which the QPSK carrier is resynchronized to the RF every 2.25 cycles, so that the effective voltage seen by the beam for the various cases studied is roughly identical [5].

In our initial studies we decided that a device having a BW of about 160 MHz would be a good compromise between the opposite demands. The first two solutions proposed have been designed with this BW value as target. A third possible design has investigated the possibility to have a wider bandwidth cavity kicker with a BW closer to the drift-tube design. The BW obtained for the third solution is 224 MHz.

For the number of coupling ports the two more feasible options are 4 or 8. Just 2 ports could not yield the required coupling for mode damping. Moreover the WGs, transitions, feedthroughs, cables, circulators and loads must be designed to be able to manage each one half the whole flowing power. More than 8 WGs cannot be allocated on the cavity surface for lack of space, and a 6 port solution does not conveniently fit the current scheme with 4 amplifiers mounted on 2 kickers.

We also considered the possibility to feed all ports instead of half of them, obtaining a ˆ2 kick voltage gain. In this approach ports on opposite sides of the cavity gap must be powered 180 degrees out of phase, and the number of circulators must be doubled as every port is connected to an amplifier. But as the circulator BW does not extend up to higher frequency modes that could remain trapped, this idea has been rejected.

An additional operation constraint has been considered. If we want to minimize the necessary changes to the installed cable plant and high-powered terminations, the alternative is between two 4 port kickers per beamline vs. a single 8 port structure.

Since, for a fixed BW, the shunt impedance does not depend on the number of ports, the total kick voltage obtainable from a pair of 4 port devices results ˆ2 times the voltage given by a single 8 port kicker. On the other hand the power per feedthrough is higher in case of a 4 port geometry and the contribution to beam coupling impedance is also doubled. Moreover a wide BW is easier to achieve with an increased number of WGs.

The first of the designs proposed has been designed with 8 ports, while the second and the third options are 4 port structures.

The first option

As a first step we considered an 8 port structure. It was not obvious to arrange 4˚WGs in the space of each cavity side wall, as the WGs cross section should be large enough to keep the frequency cut off well below the operating frequencies.

Figure 2 shows the HFSS model (1/8 of the whole structure, for the geometric and electromagnetic symmetry of fundamental mode) used as input geometry for simulations.

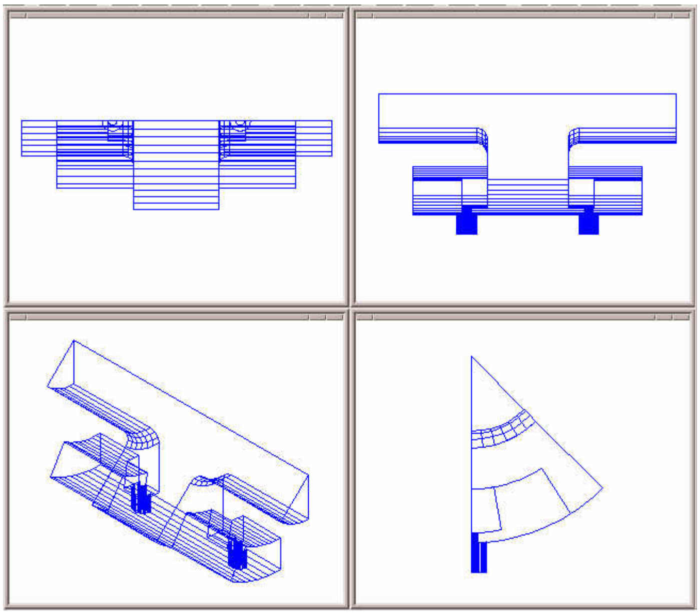
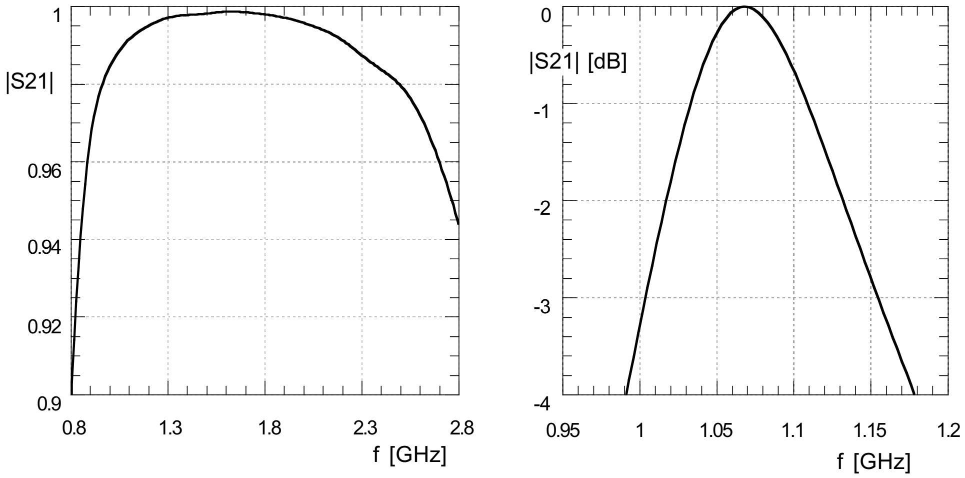


FIGURE 2. HFSS input geometry.

In Fig. 3a the transmission response of the WG and transition to 7/8" coaxial standard designed for this case is reported. To simplify the mechanical construction the WG profile has been obtained as a slice (65 degrees wide) of a hollow cylinder, which main radius is the same as the cavity radius. The ridge profile is also a cylinder slice and it is truncated in proximity of the transition giving rise to a back cavity. The length of this cavity can be tuned to center the frequency band of the transition response.

Figure 3b shows the transmission coefficient S_{21} between the 4°input ports and the 4 output ports for the cavity fundamental mode. A little adjustment of central frequency should be done since the estimated value has been 1.068 GHz. The 3dB BW is 153 MHz and the calculated shunt impedance peak value is about 950°Ω.



(a) **(b)**

FIGURE 3. Transmission frequency response of kicker (b) and of its transition (a).

The HOM characterization has revealed 4 parasitic modes (2 dipoles and 2 monopoles) remain trapped into the cavity, but they are quite damped by external loading through the coupling WGs. Table 1 summarizes what has been found in terms of frequencies, Qs and impedances.

TABLE 1. Parameter of HOM characterization.

Mode	Freq. [GHz]	Q	R
TM_{110}	1.5616	15	15.3 kΩ/m
TE_{111}	1.6819	541	60.3 kΩ/m
TM_{011}	2.2203	12	70 Ω
TM_{020}	2.4266	35	50 Ω

Various filling patterns have been considered to estimate the power released by the beam on the kicker total impedance (both of the operating mode and of HOMs) [6].

In any case the power per port never reaches 1 kW, that seems a very conservative value compared with the performances of feedthroughs, cables and loads. For this reason, the following designs concentrate on kickers with only 4 ports.

The second option

The design feasibility of a kicker having the same 160 MHz BW but just half port number of the previous one has been investigated. In this case, each single WG has to provide a doubled loading of the fundamental mode. So the transverse dimensions of the WG have been increased (the height is 4 mm more and the width is 100 degrees instead of 65). The gap between the ridge and the WG upper wall has been increased too (from 6 to 8 mm), to reduce the field intensity in this region. The capability to sustain the flowing power results increased as well. Figure 4 shows the input geometry for HFSS. WGs on opposite side of the cavity are 90 degrees rotated, to allow a better coupling with high polarity modes (particularly dipoles). A quarter of geometry had to be modeled in this case.

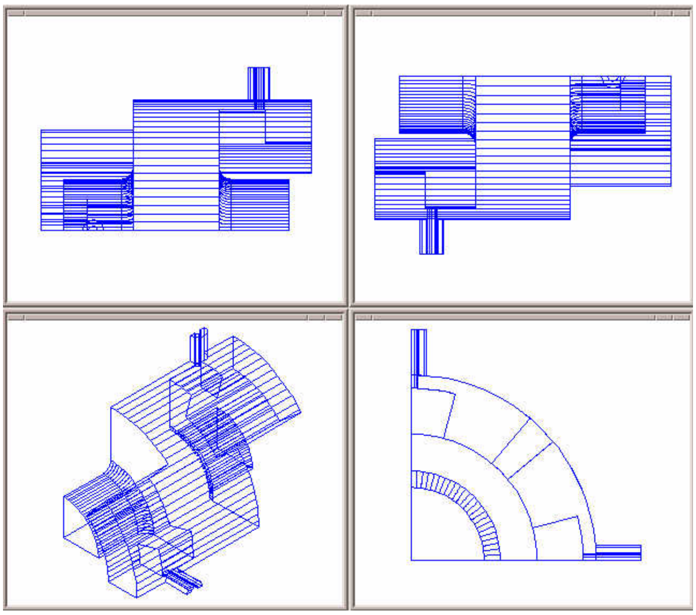
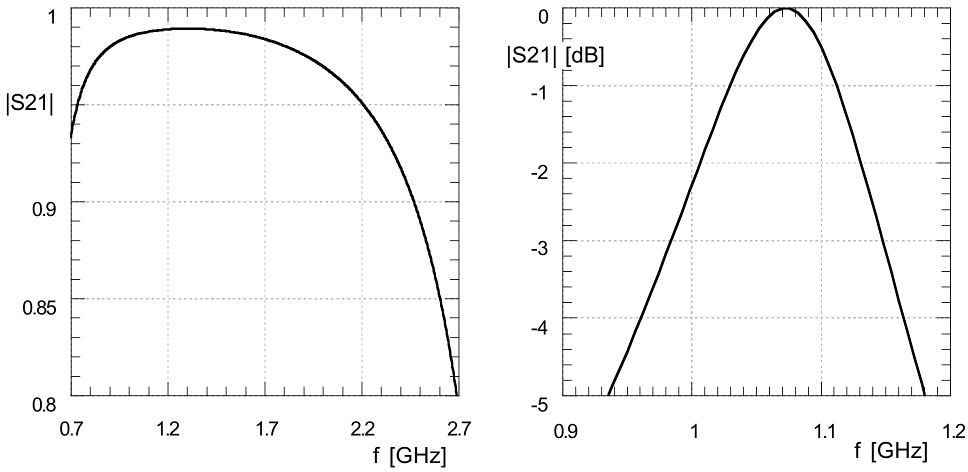


FIGURE 4. HFSS input geometry.

Figure 5 shows the transmission response of both the transition (left) and the kicker between its input and output ports (right). The transition band extends up to the beam pipe frequency cut off (approximately 2.6 GHz). The kicker BW is 165 MHz centered at 1.071 GHz, while the shunt impedance peak value is now about 890 Ω.

In Table 2 results of HOM characterization are listed.



(a) **(b)**

FIGURE 5. Transmission frequency response of kicker (b) and of its transition (a).

TABLE 2. Parameter of HOM characterization.

Mode	Freq. [GHz]	Q	R
TM_{110}	1.5264	25	18.2 kΩ/m
TE_{111}	1.6802	539	56 kΩ/m
TM_{011}	2.0568	12	61 Ω
TM_{020}	2.3848	60	69 Ω

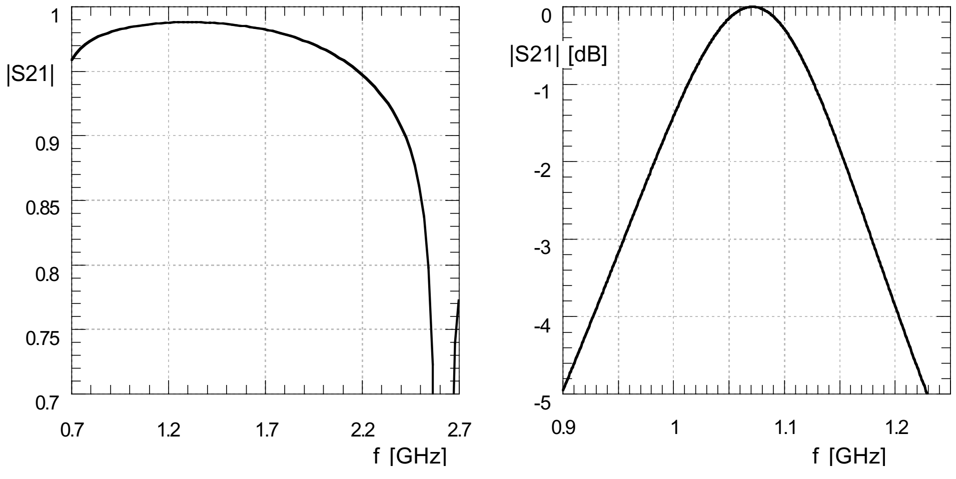
The third option

Finally a 4 port device with a wider BW (comparable to the drift tube structure) has been considered. The main difference respect to the design of the previous option is in the WG cross section, that has been further on increased (the height and the width being now respectively 41 mm and 120 degrees). Simulation results for the transition and the kicker frequency response are shown in Fig. 6. Due to the WG larger size, its transmission response presents a notch around 2.6 GHz. However, the HOM damping is not compromised as the higher frequency of the trapped HOMs is about 2.4 GHz.

The 3dB kicker BW is 224 MHz with a shunt impedance of 626 Ω estimated at the center frequency (1.071 GHz). Table 3 summarizes HOM parameters calculated for this structure.

TABLE 3. Parameter of HOM characterization.

Mode	Freq. [GHz]	Q	R
TM_{110}	1.5151	22	16.7 kΩ/m
TE_{111}	1.7114	210	19.2 kΩ/m
TM_{011}	2.0507	13	65 Ω
TM_{020}	2.4117	116	76 Ω



(a) **(b)**

FIGURE 6. Transmission frequency response of kicker (b) and of its transition (a).

SUMMARY

The design of a cavity kicker involves many details of electrical, thermal and vacuum requirements. Our group is proceeding with the detailed design of the wideband 4 port structure (third option). Ongoing efforts are centered on fine optimization of the cavity bandwidth and shunt impedance, and the consideration of the heating of the structure and feedthroughs. A study is underway to consider the possibility of multipactor effects in the structure to help select the cavity material and surface finish˚[7].We plan on completing the final design and moving to the fabrication phase in summer 2002.

ACKNOWLEDGMENTS

The authors thank Uli Weinands and John Seeman of SLAC for their support of this design, and thank Mario Serio for his consistent and supportive advice in all phases of our collaboration on longitudinal feedback.

REFERENCES

1. J.N. Corlett, J. Johnson, G. Lambertson, F. Voelker: Longitudinal and Transverse Feedback Kickers for the Als, Presented at 4th European Particle Accelerator Conference (EPAC 94), London, England, 27 Jun — 1˚Jul˚1994.
2. R. Boni, A. Gallo, A. Ghigo, F. Marcellini, M. Serio, M. Zobov: "A Waveguide Overloaded Cavity as Longitudinal Kicker for the DAFNE Bunch-by-Bunch Feedback System", Particle Accelerators, 1996, Vol. 52, pp. 95-113, 1996.
3. A. Gallo, A. Ghigo, F. Marcellini, M. Migliorati, L. Palumbo, M. Serio : Simulations of the Bunch By Bunch Feedback Operation with a Broadband RF Cavity as Longitudinal Kicker , DAFNE Technical Note G-31 April 1995.
4. M. Tobiyama, private communication, summarized in the December 2001 Cavity Kicker Design Review.
5. D. Teytelman, private communication, summarized in the December 2001 Cavity Kicker Design Review.
6. J. Fox, private communication, summarized in the December 2001 Cavity Kicker Design Review.
7 P.A. McIntosh, H. Schwarz, private communications.