

A SECOND HARMONIC (6-16 MHz) RF SYSTEM WITH FEEDBACK-REDUCED GAP IMPEDANCE FOR ACCELERATING FLAT-TOPPED BUNCHES IN THE CERN PS BOOSTER

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Introduction and Summary

Since all experimental and theoretical evidence indicates that the beam intensity in the PSB is at present limited by the Laslett Q shift after trapping, a second harmonic accelerating system is being added with the aim of producing flat-topped bunches. Calculations indicate that the resulting improvement in bunching factor should permit an intensity increase of 25 to 40 %. Additionally, the bucket area is increased by 25 to 45 % depending on intensity.

A general description of the new cavities, which operate over a frequency range of 6-16 MHz with a maximum gap voltage of 8 kV, is given together with a description of associated power amplifiers and low level electronics. A notable feature is the use of a fast feedback system to reduce the gap impedance seen by the beam by an order of magnitude, incorporating a 130 W wide-band transistor amplifier with a total delay of about 5 ns.

Initial performance with beam of the first system installed confirms theoretical expectations in terms of bunching factor and increased intensity limit. An expected improvement in beam stabilization by Landau damping from the strongly non-linear accelerating wave shape did not occur; on the contrary, Landau damping is lost even at low intensities, and harmful longitudinal bunched-beam modes of orders as high as sextupole ($m = 3$) and decapole ($m = 5$) have been observed and partly cured.

Bunching Factor, Bucket Area and Landau Damping

The applied focusing wave shape is

$$V(\phi) - V_0 = V_1(\sin \phi - a_2 \sin 2(\phi - \phi_s) - \sin \phi_s) \quad (1)$$

where $eV_0 = eV_1 \sin \phi_s$ is the energy gain per turn, V_1 the amplitude of the fundamental voltage, ϕ_s the phase of the synchronous particle, and $a_2 = V_2/V_1$ the relative amplitude of the second harmonic voltage. The second harmonic has been phased so as to provide zero voltage for $\phi = \phi_s$.

If we assume an elliptic energy distribution, the stationary line density $\lambda(\phi)$ is proportional to the potential¹ which is the integral of the focusing wave shape above, and can thus be found analytically.

For $a_2 \leq 0.5 \cos \phi_s$ the line density has one peak for $\phi = \phi_s$, while for $a_2 > 0.5 \cos \phi_s$ there will be two peaks at $\phi = \phi_\alpha$ and $\phi = \phi_\beta$, both values are roots of $V(\phi) - V_0 = 0$. For $\phi_s = 0$ the bunching factor for full buckets can be expressed analytically as a function of a_2 , while for $\phi_s \neq 0$ and $a_2 > 0.5 \cos \phi_s$ the bunching factor must be determined numerically, as the roots ϕ_α and ϕ_β must be found by iteration.

$$B_F(a_2) = \begin{cases} \frac{1}{2} + \frac{a_2}{4} & \text{for } 0 \leq a_2 \leq 0.5 \\ (1 + \frac{a_2}{2}) / (1 + \frac{1}{4a_2} + a_2) & \text{for } a_2 > 0.5 \end{cases} \quad (2)$$

Surprisingly, the optimum voltage ratio is $a_2 = 1$, or twice the value which produces maximally flat-topped bunches: $a_2 = 0.5$. The optimum is, however, very flat, and by choosing $a_2 = 0.67$ only about 3 % lower B_F 's result.

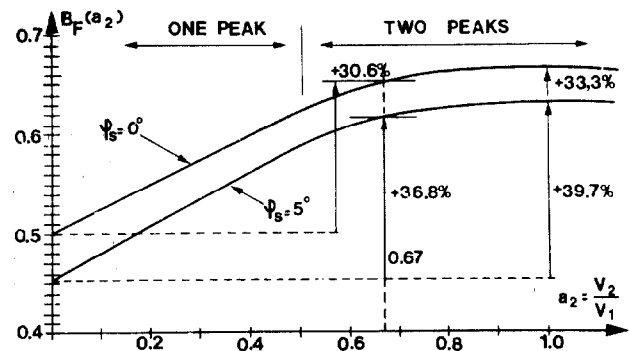


Fig. 1: Bunching factor versus a_2

As $V_1 = 12$ kV and $f_1 = 3$ to 8 MHz, we need $V_2 = 8$ kV and $f_2 = 6$ to 16 MHz to obtain an almost optimal increase in bunching factor (Figs. 1 and 2).

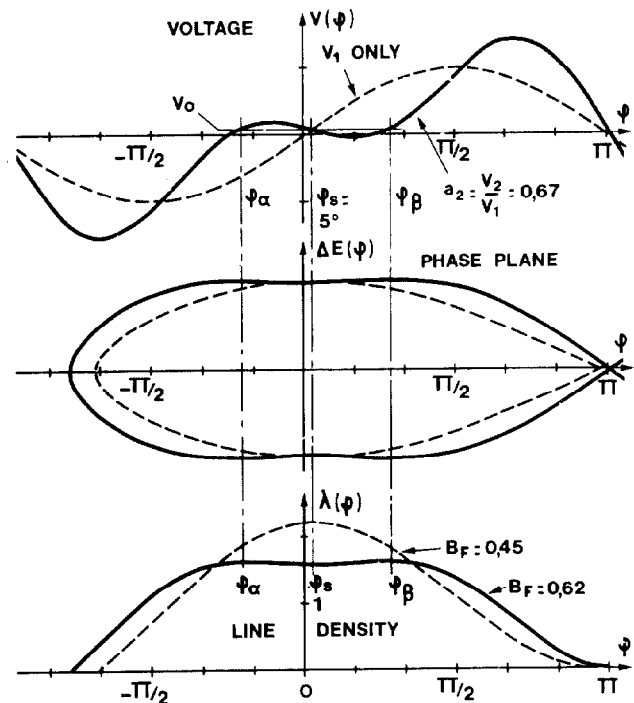


Fig. 2: Accelerating wave shape, bucket shape, and line density

For the elliptic energy distribution the bucket area (Fig. 3) including space charge effects is easy to calculate as space charge does not change the shape of the bucket, only its height¹.

From the synchrotron frequency distribution (Fig. 4) with the second harmonic voltage added it is seen that the highly non-linear bucket provides plenty of frequency spread and thus Landau damping for amplitudes up to about 1.5 radians. For a full bucket, however, the flat maximum near 2 radians turns out to be particularly harmful as a strong density gradient is normally found in this region of the phase plane, resulting in substantially lower thresholds for longitudinal instabilities.

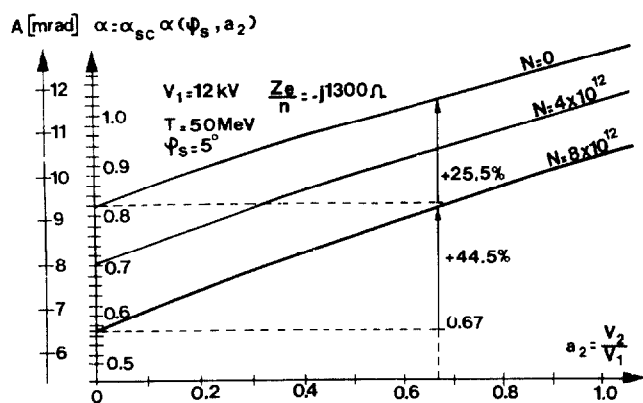
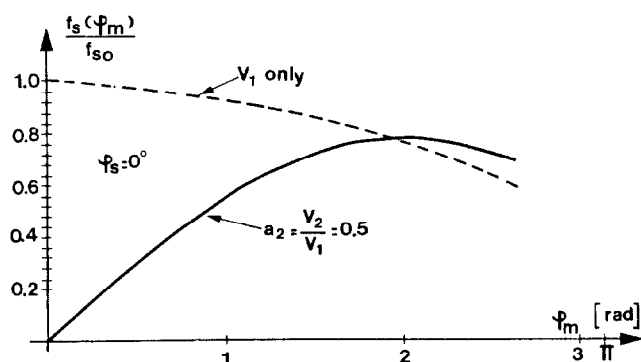


Fig. 3: Bucket area versus second harmonic voltage

Fig. 4: Synchrotron frequency versus amplitude²

Cavity and Amplifier Design

The relatively small distance (360 mm) between the four superposed rings of the PSB imposes rather severe constraints on the design of the accelerating cavities and their associated final RF power stages, Figs. 5 and 6. Closed circuit air cooling is used for both, and their design generally follows that of the fundamental system³. For the 6-16 MHz frequency range a different type of ferrite was, however, necessary, and Philips 4 M was chosen.

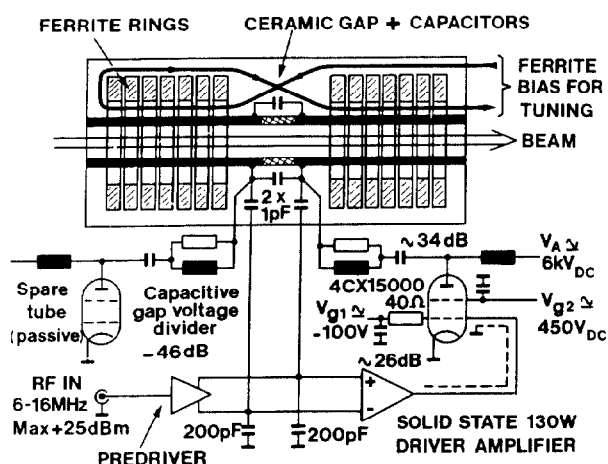


Fig. 5: Simplified schematic of cavity and amplifier

In order to obtain the somewhat higher bias field required by this material, each cavity has four figure-of-eight loops which carry the bias current and also provide RF coupling between the two ferrite cores, Fig. 6.

The anode of a 4CX15000 tetrode is connected to each side of the gap via a DC blocking condenser and a parallel RL combination which helps to damp some secondary resonances of the cavity and amplifier. A further damping of these resonances was obtained by connecting series RC circuits between nominally 'cold' points of the bias loops and the cavity walls.

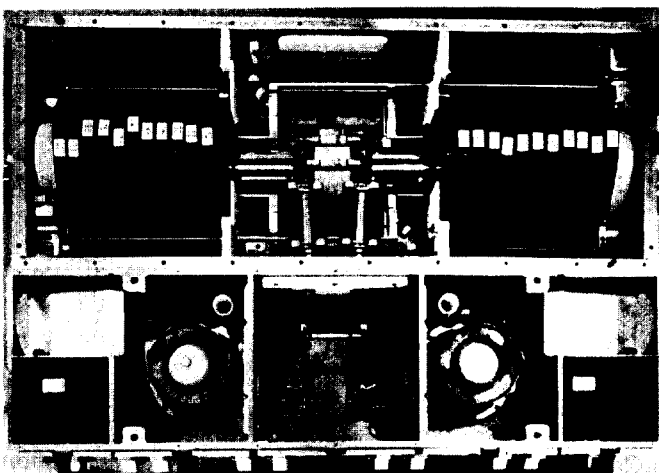


Fig. 6: Cavity and amplifier assembly

In normal operation only one tetrode is active, the other serving as a spare while maintaining capacitive balance.

In order to eliminate instabilities of the beam, cavity, and its associated loops⁴ under conditions with high relative beam loading, the final tube is driven by a feedback amplifier, whose inputs are connected to the gap via capacitive voltage dividers (1:200), thus forming a feedback loop with an open loop gain of 14-22 dB (5-12×), which reduces the effective impedance by the same factor. This technique has previously been successfully used in the ISR⁵, and in the AA.

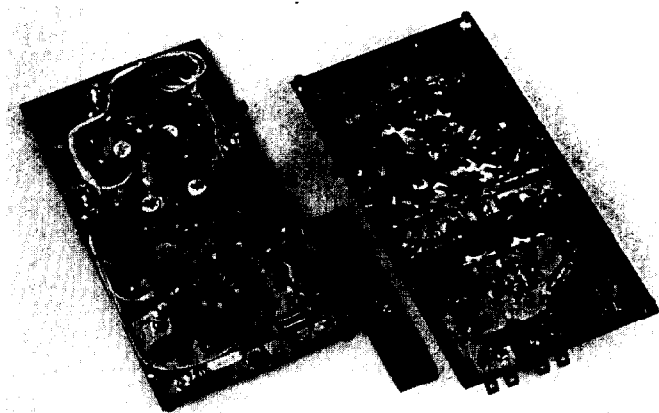


Fig. 7: Solid state driver amplifier

A linear, broadband solid state amplifier (Fig. 7) utilizing VMOS RF power transistors was designed specifically for this purpose with special attention to the very short propagation delay (5 ns) required to ensure loop stability over the 5-17 MHz frequency range. The input stage gate capacitance and predriver output capacitance form the 200 pF bottom capacitor in the gap voltage divider. Power is 130 W and bandwidth 150 MHz.

Low Level Electronics

Three control loops control relative phase, amplitude, and tune of the second harmonic cavity, Fig. 8.

