# Presentation 57

# RF Implications

## By G. Geschonke

### 57.1 Copper system

The installed LEP RF acceleration system uses a coupled cavity scheme consisting of accelerating and storage cavities. This implies the use of two RF frequencies, leading to an oscillation of stored RF energy between storage and accelerating cavities as shown in fig 57.1. The particles to be accelerated obviously have to pass the accelerating cavities at the peak of the beat amplitude. The beat frequency is adjusted such, that a maximum of 8 bunches of positrons and electrons can be accommodated.

If one wants to go beyond $2 \times 8$ bunches, the RF energy oscillations have to be disabled, which can be done by operating the RF system with one frequency only. This, however, leads to a loss in available accelerating voltage of 28 %, thus lowering the maximum circumferential voltage to 288 MV.

### 57.2 Installation of separators in straight sections

The separators will be installed in the straight sections of all even points immediately after the arc, adjacent to QS 11. At points 2 and 6 the space necessary for this installation is presently occupied by accelerating cavities. At least two of these have to be removed for one separator.

The RF power for LEP is provided by klystron amplifiers of 1 MW output power each, the power is split by magic T two way splitters in 3 levels down to 125 kW (Figure 57.2) . This arrangement requires the number of cavities fed by one Klystron to be a power of 2. Without major rebuilding of the RF power distribution, removing 2 cavities out of one unit therefore means, that one has to replace them by RF absorbers. This results in a loss of 12 % of accelerating voltage per unit involved and a maximum dissipation of 250 kW in these loads.

For operation in 1991 two cavities have been removed from each of RF units 231 and 631. In a second stage in 1992 two more cavities will be removed from each of units 271 and 671, so that 4 out of the 8 installed RF units will be affected.

In order to avoid asymmetric RF voltage distribution around the ring, in particular during 1991, the RF units concerned will have to be run at higher RF voltages than the others. The exact scheme will be determined during startup.

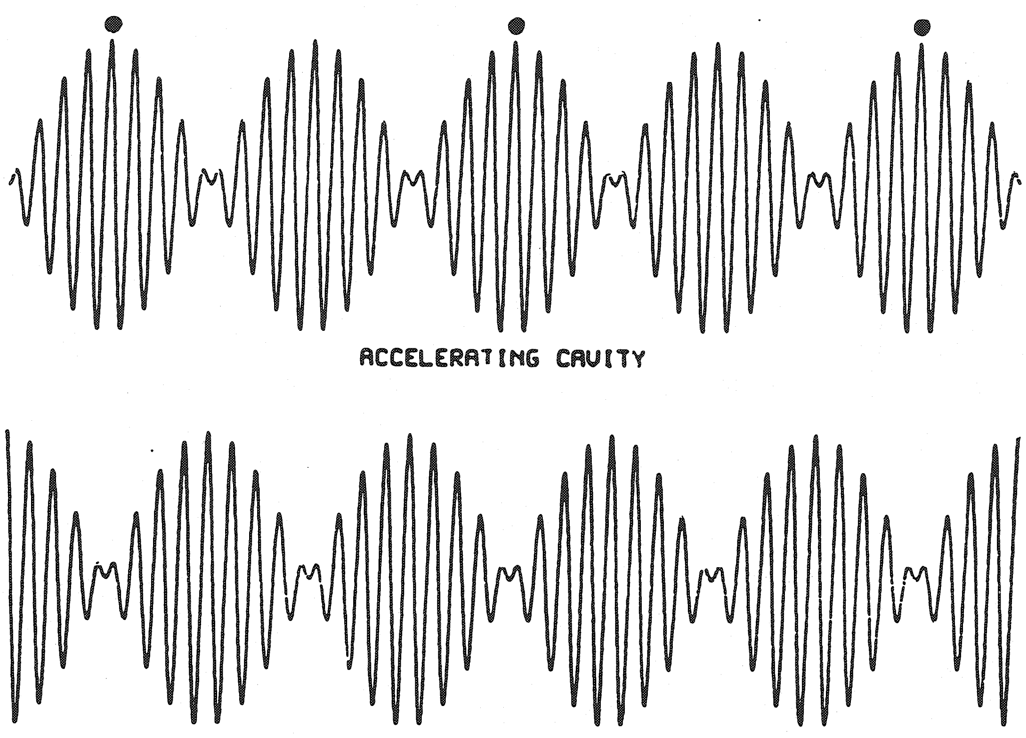


Figure 57.1: Schematic view of RF energy oscillations between accelerating and storage cavities.

## 57.3 Superconducting cavities

### 57.3.1 Higher harmonic mode (HOM) couplers

Superconducting cavities are equipped with HOM couplers which damp beam excited resonances. One limitation on total beam current in LEP comes from the power handling capability of installed HOM couplers.

Calculations done by B. Zotter (preliminary results are shown in Figure 57.3) show that for a bunch length of 2 cm for modes below the cut-off frequency of the beampipe (1.15 GHz) the loss factor is 0.22 V/pC. This gives a HOM power of 10.9 W/bunch of 0.75 mA. For 2 counter-rotating beams of 4 bunches each, between 87 and 175 W are expected per cavity. The uncertainty comes from the fact, that the electrons and positron bunches don't pass the cavities simultaneously, but there is a certain time delay between them depending on the distance from the interaction point. Measurements done by E.Haebel, J. Tückmantel and G.Geschonke gave a power of 110 W/cavity, indicating, that the counter-rotating bunches can be (almost) treated as individual bunches. On a spectrum of HOM's measured during a physics run (Figure 57.4) one can clearly see, that fields excited by the counter-rotating beams show a beatwave pattern; as a function of frequency they add or cancel. Cavity resonances follow this pattern. Therefore some resonances are not or little excited because they fall on a frequency where the fields of the two beams cancel, some others are excited coherently.

For $2 \times 8$ bunches of 66 nC each, by extrapolation from these measurements, we can expect 220 W per cavity.

The 4 cavities of module 1, already installed in LEP are equipped with HOM couplers of "type 1" which allow 300 W HOM power to be extracted from the cavities (E. Haebel, priv. comm.). The

8 cavities (Cu/Nb) of modules 2 and 3 to be installed for 1991 operation are equipped with HOM couplers "type 5" , which are designed for the power to be expected with 8 bunch operation. The 20 solid Nb cavities being produced by industry will be equipped with "type 1" couplers again, however with improved connectors to increase the power handling capacity.

The other limitation coming from HOM couplers lies in the damping coefficient of dangerous modes. For $2 \times 8$ bunch operation the damping is still sufficient (E.Haebel), but for more bunches it has to be increased.

### 57.3.2 Higher harmonic modes above cutoff

As can be seen from B. Zotter's calculation in Figure 57.3, the loss factor below cut-off of the beam tube is only a fraction of the total loss. The total loss may be three times as high.

At present we do not know where this power is dissipated. Problems might arise, if part of it is lost in the bellows between individual cavities, or in the conical transitions which reduce the beam pipe diameter from 198 mm (cavity flange) to 100 mm and serve as a transition between liquid He and room temperature.

The newly installed cavity modules will be equipped with temperature sensors on these critical parts, so that soon after LEP startup data on this point should become available.

## 57.4 RF power considerations

At the LEP design current of $2 \times 3$ mA and operation at 5 MV/m, 45 kW of RF power will be needed for each cavity at a synchronous phase angle of 120°. Under the same operating conditions 90 kW will be needed if the current is doubled.

This raises two problems:

i) the main power coupler feeding the cavities with RF power has been designed for operation at 45 kW. It will certainly be able to handle higher power, but the question of the power limits and reliability will have to be studied.

ii) In the present layout one klystron with 1 MW RF power feeds 16 cavities. Therefore if more than 60 kW are needed per cavity, a second klystron has to be installed per unit.

The power coupler for superconducting cavities is adjusted to a certain coupling strength, expressed through the coupling coefficient $\beta$ (external Q-value $Q_{ext} = Q_0/\beta$ , with $Q_0$ the unloaded Q-value of the cavities). The coupling strength is chosen such, that at nominal beam current the reflected RF power is minimum and all the available RF power is transferred to the beam. Figure 57.5 shows the required RF power as a function of coupling coefficient $\beta$ for $2 \times 6$ mA total current. 192 superconducting cavities are assumed to be operating at a gradient of 5 MV/m and a synchronous phase angle of 116°. One can see, that the optimum coupling coefficient is around 1760. The couplers are for the moment adjusted to $\beta$=1250, corresponding to $2 \times 4$ mA. With this setting the extra power required is 620 kW more than in the optimum case.

The power couplers installed for the moment allow no adjustment at all once they are manufactured. Variable power couplers where the coupling can be modified by changing the penetration of the coupler antenna are therefore highly desirable. They are presently being developed and will soon be tested.

## 57.5 Conclusions

- The present copper RF system is limited to a maximum of 8 bunches per beam, it can be used for more bunches at the price of a reduction in circumferential voltage.
- The superconducting cavities which are installed should work with 8 bunches, however the HOM couplers in module 1 are at their limits.
- The problem of HOM power above cavity cut-off needs further study.

- Each superconducting RF station has to be equipped with two klystrons.
- Variable power couplers for superconducting cavities are highly desirable.

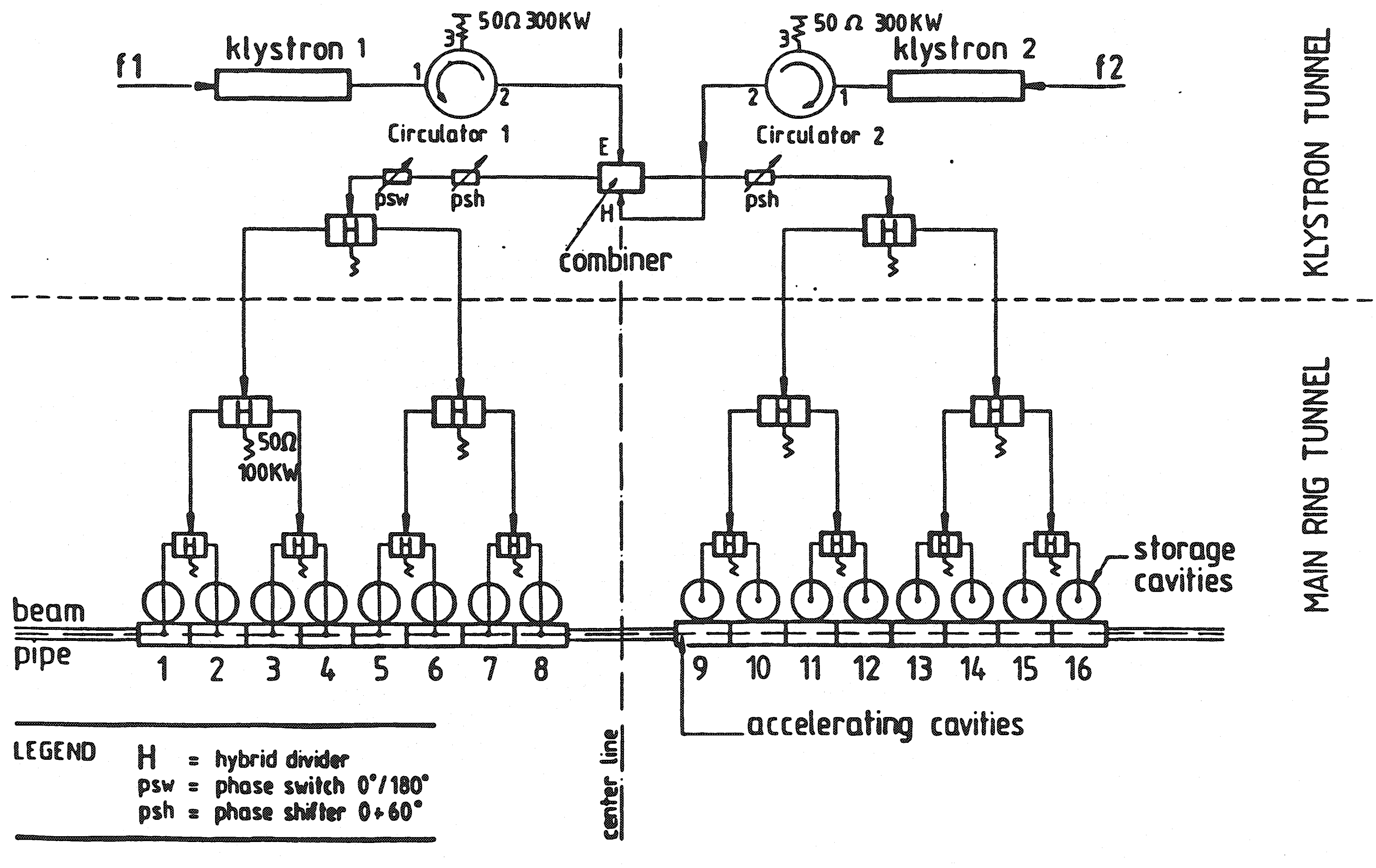


Figure 57.2: Distribution of RF power from MW klystrons to cavities via Magic T splitters.

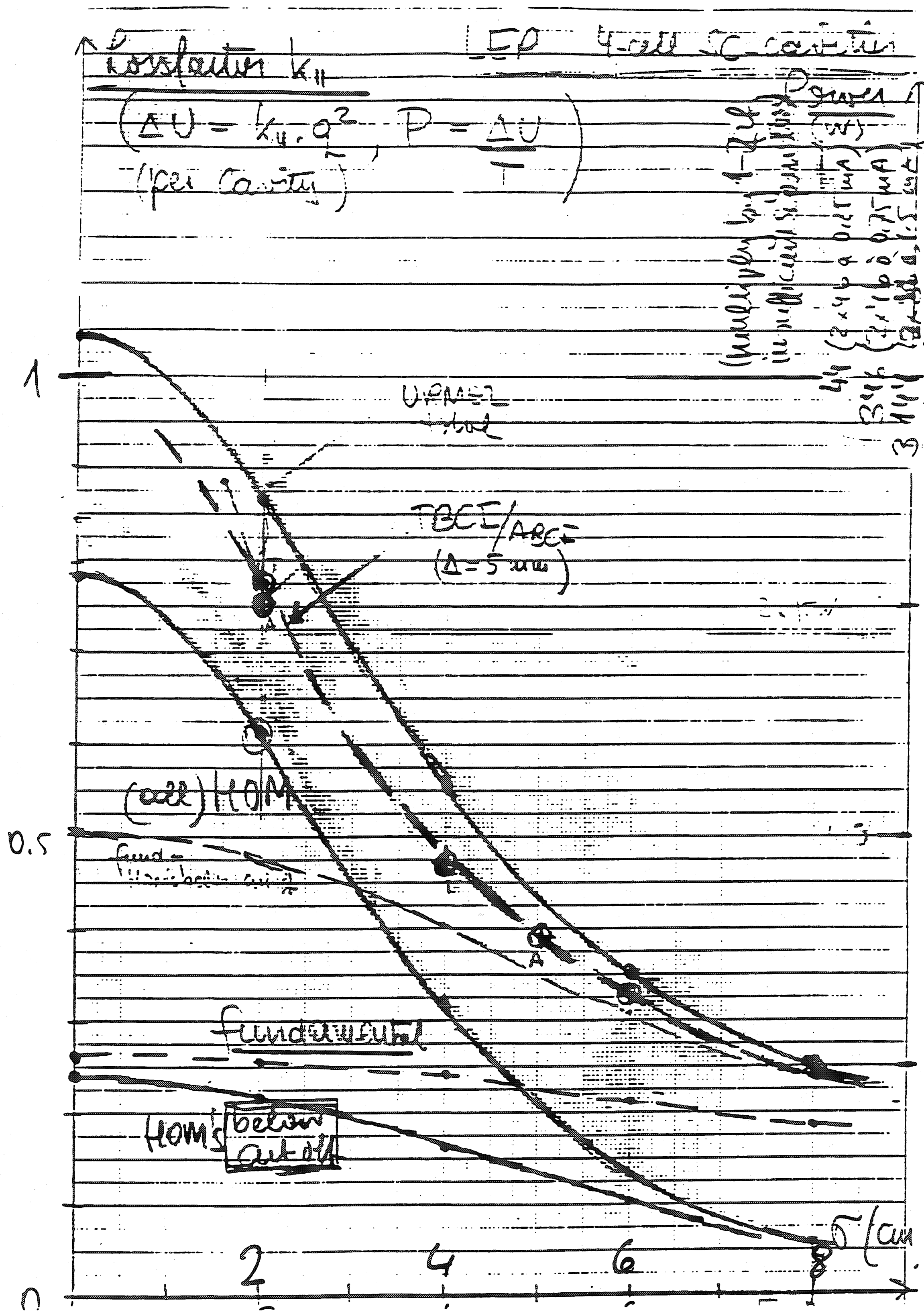


Figure 57.3: Preliminary results for parasitic mode losses.

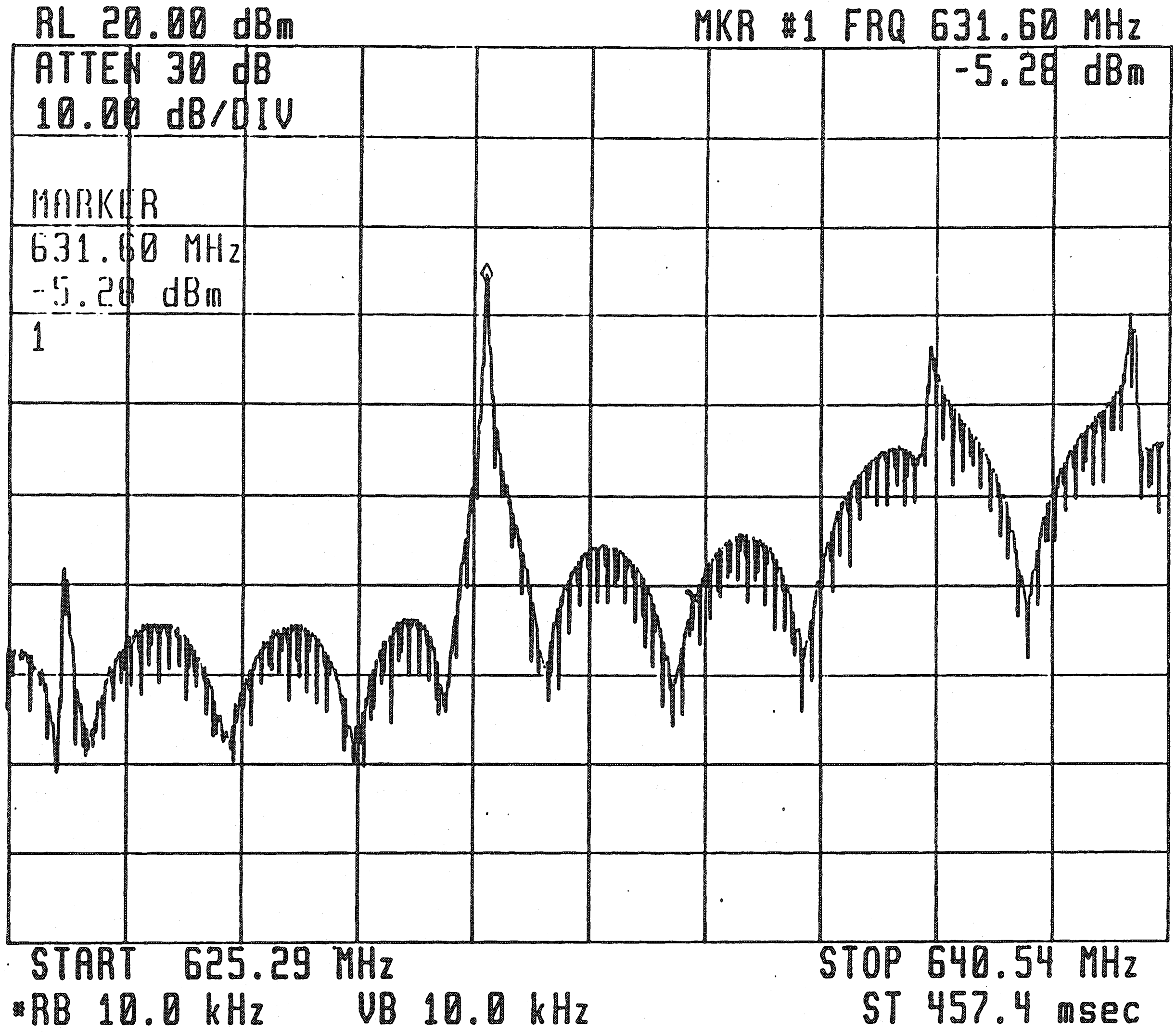


Figure 57.4: Higher Order Mode spectrum excited by beam, measured during a physics run.

beamloading

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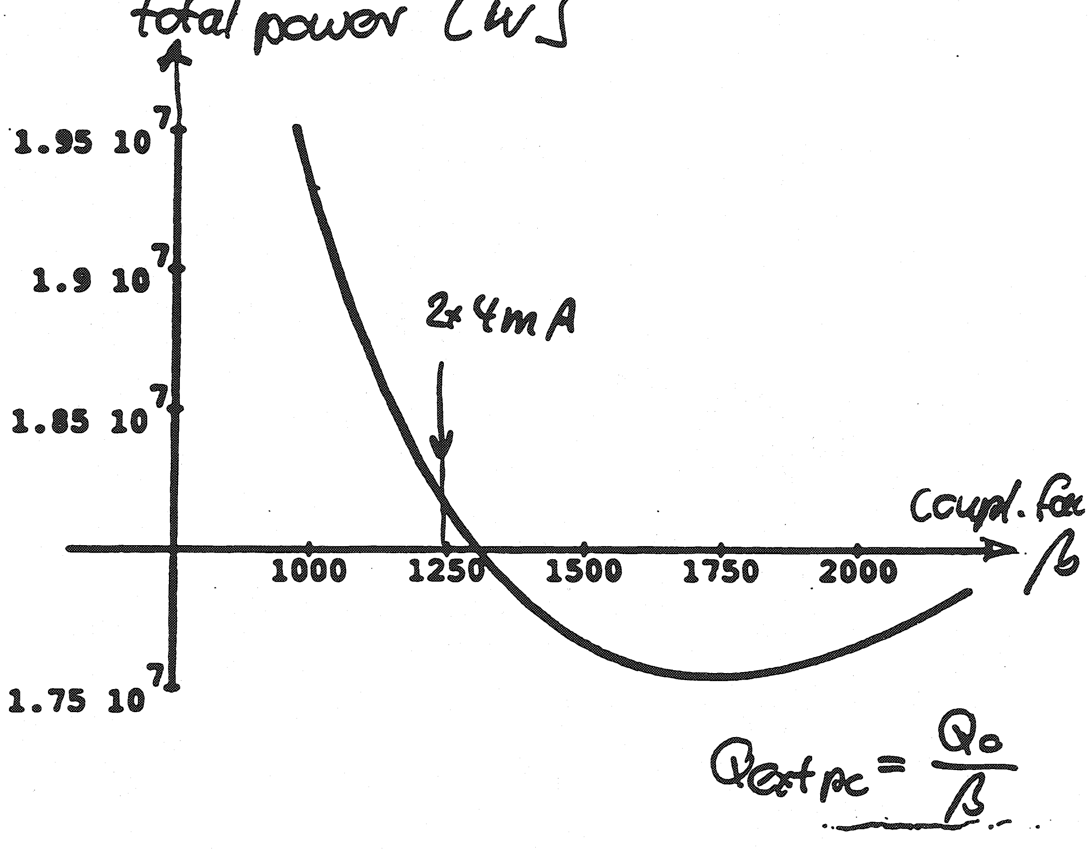


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Figure 57.5: Total RF power necessary for $2 \times 6$ mA total current as a function of the coupling coefficient of the input coupler.