RF Pulse Compression.

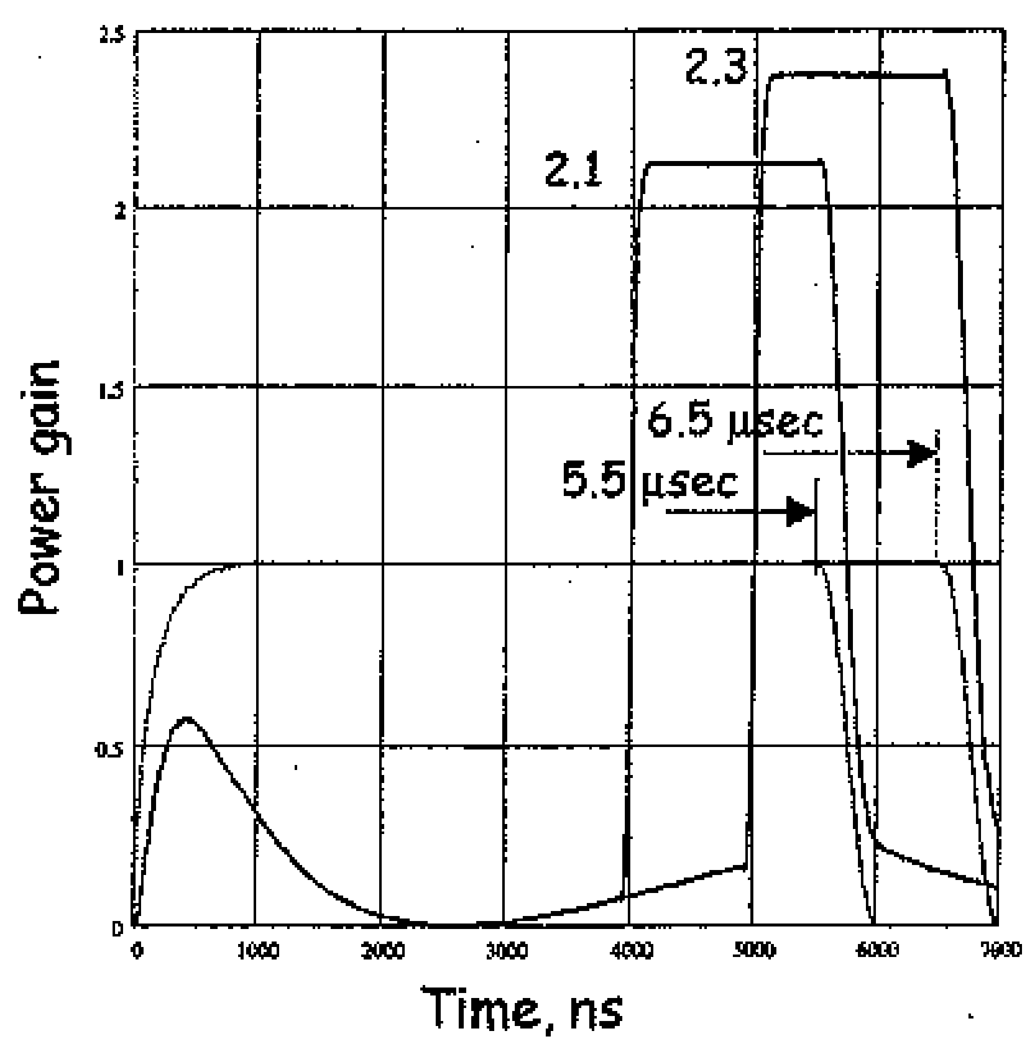
I.Syratchev

- RF Pulse Compression is the only way to increase RF power level from the number of klystrons available for CTF#3.

- RF phase/amplitude modulation is the tool to control the RF pulse shape in a system - klystron plus "SLED"-like RF pulse compressor.

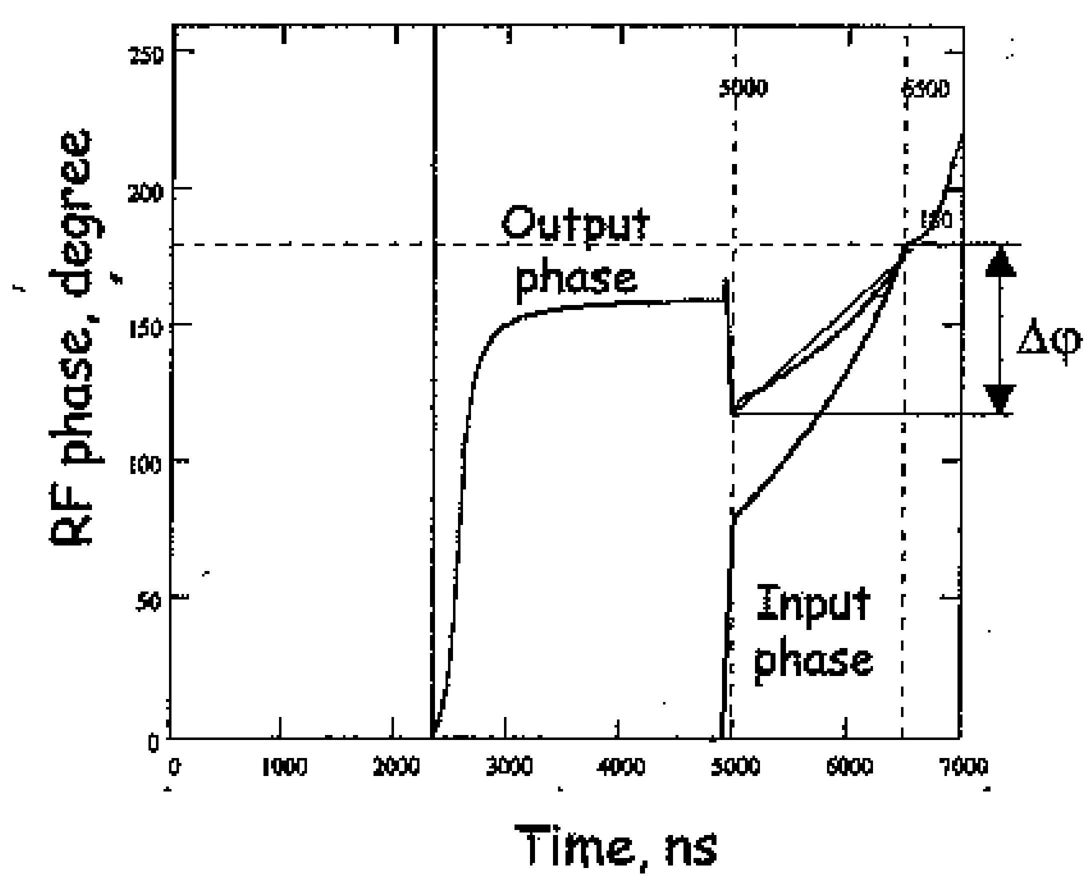
The flat pulse after the cavity based pulse compressor (LIPS), with modulation of the input RF phase (PM).

LIPS cavity Q_0 =1.8x10^5, β=8



The linear part of the phase slop will be compensated with the frequency shift:

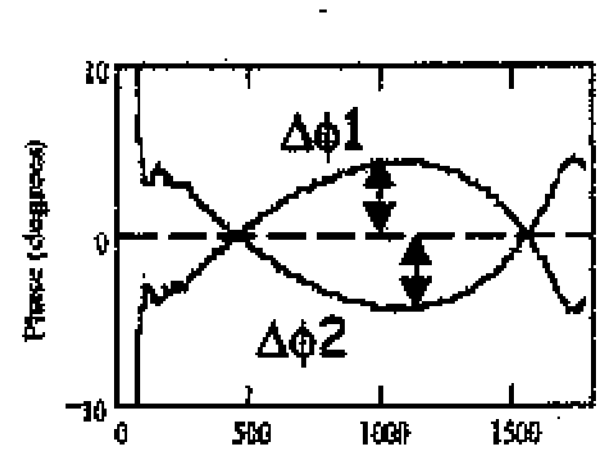
$$\pm\Delta\omega T_{out} = \pm\Delta\varphi$$



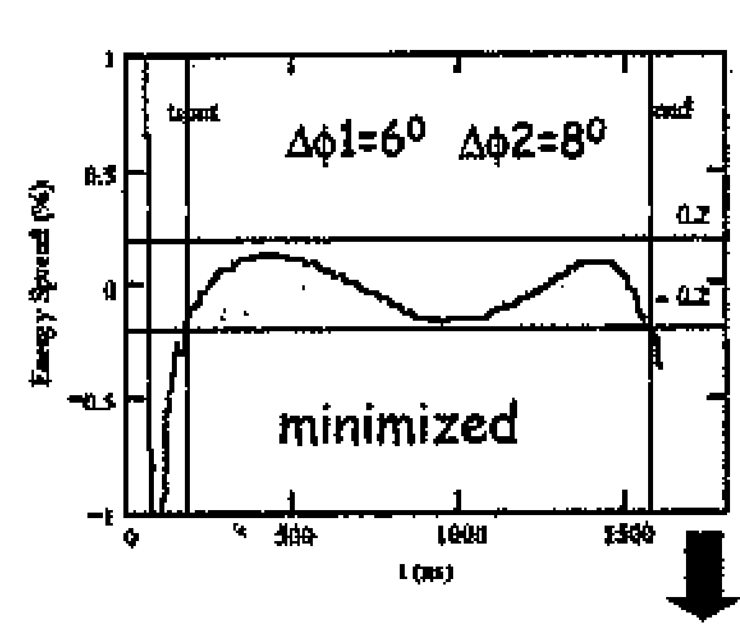
RF Pulse Compression system for CTF3.

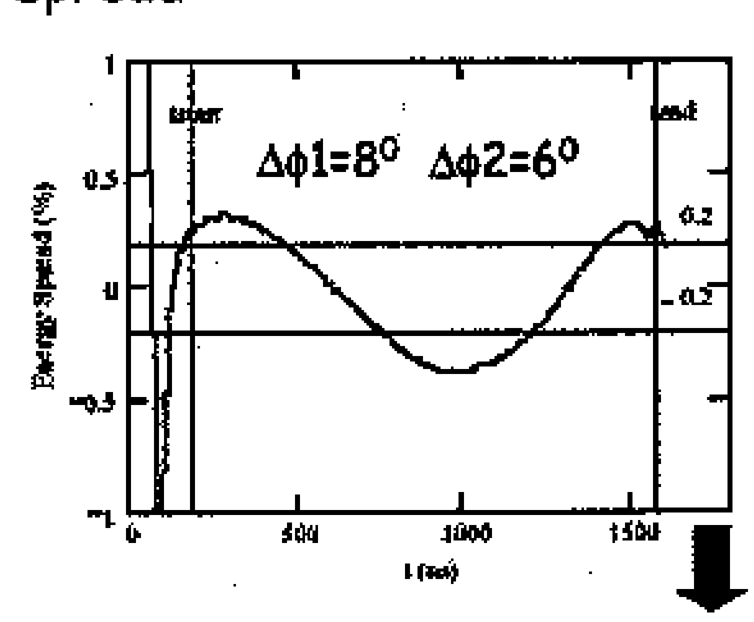
The effect of residual RF phase sage and energy spread. R. Corsini

The residual phase envelops after two RF stations

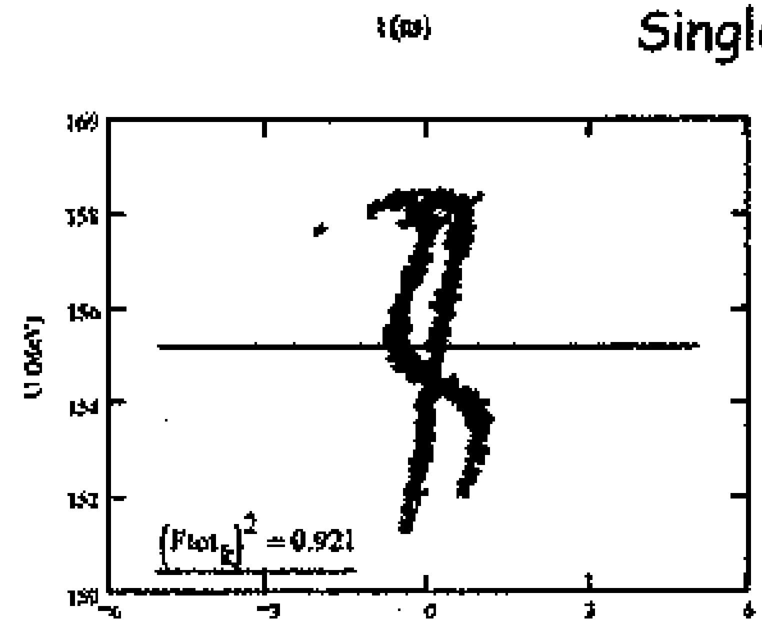


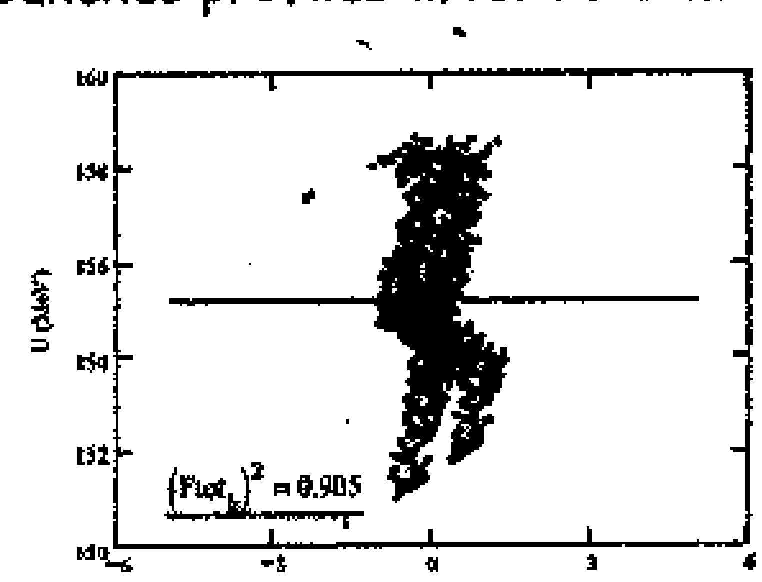
Energy spread

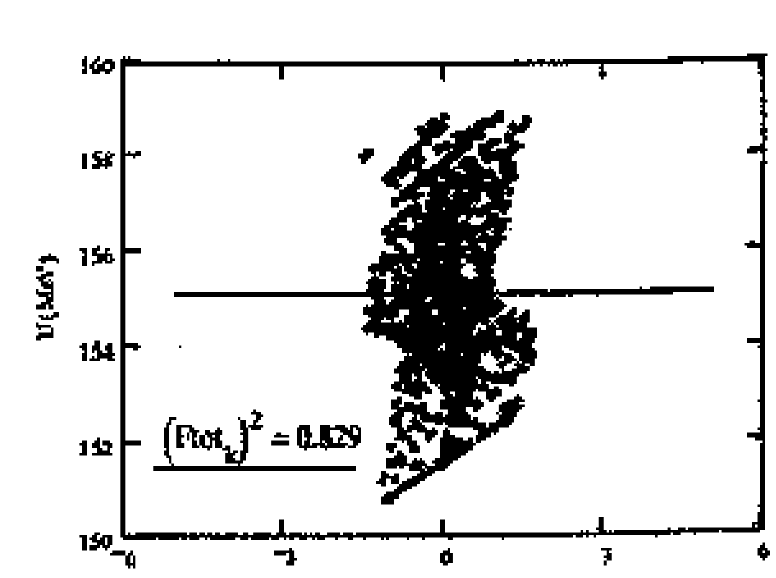




Single bunches profiles after re-combination.

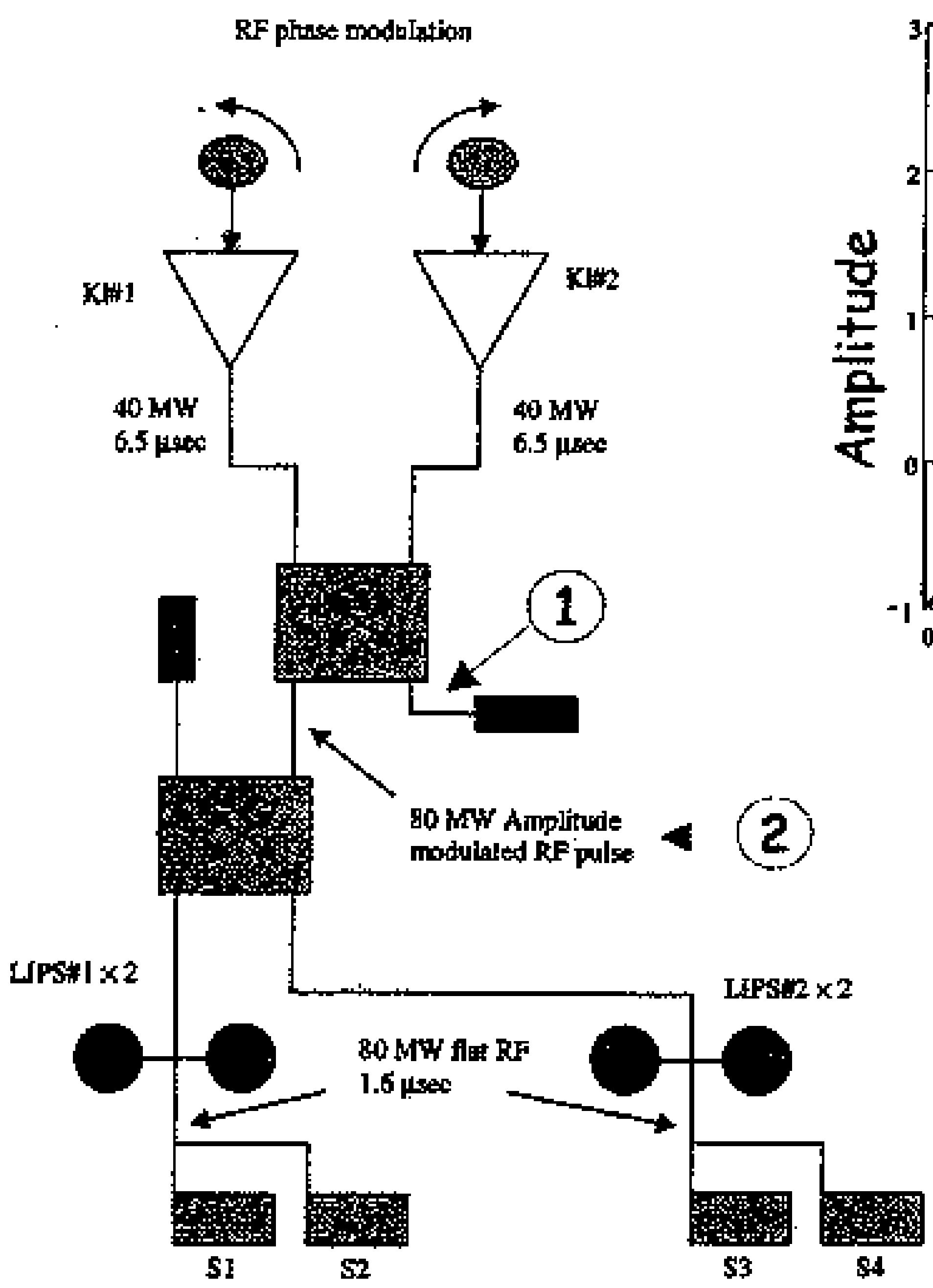


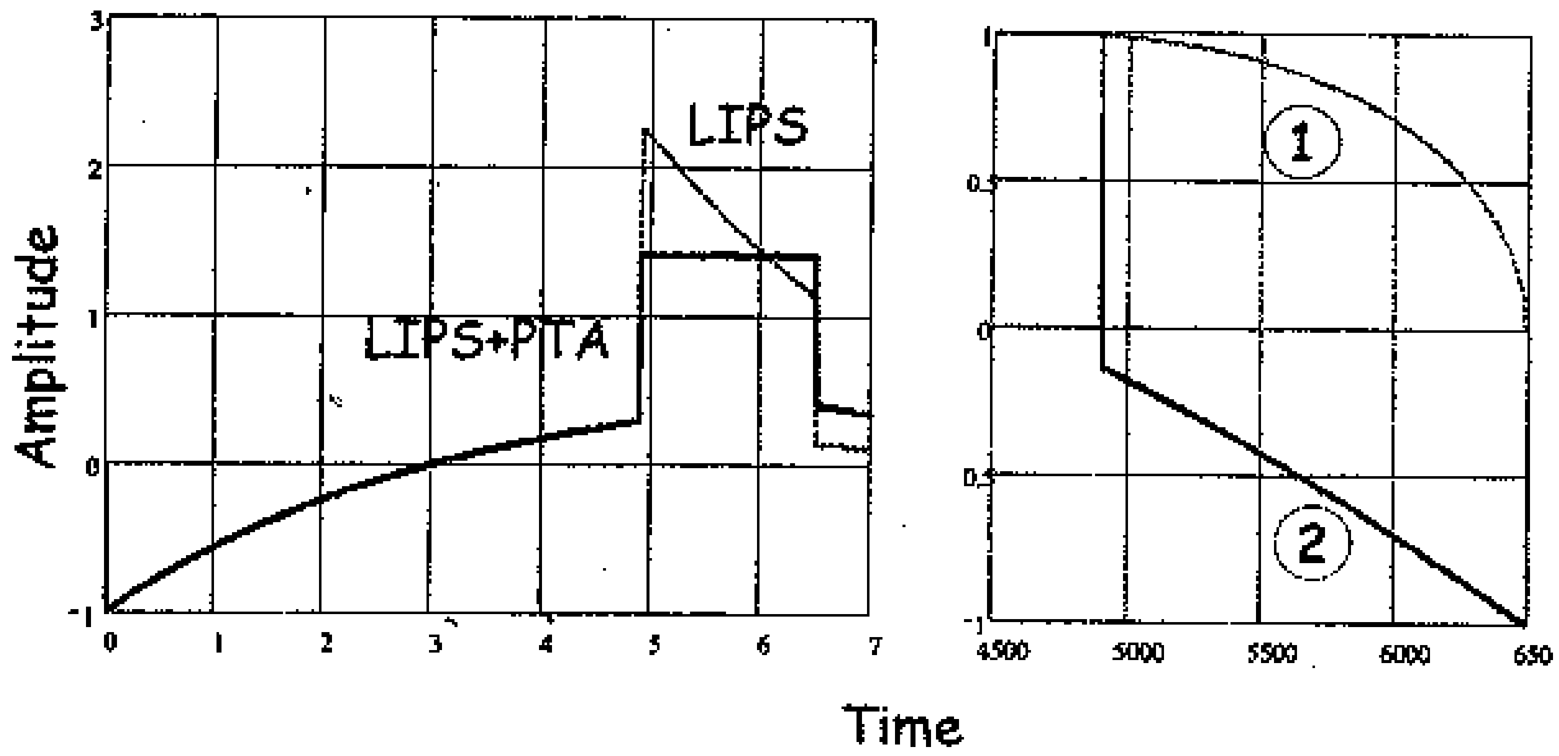




No energy spread

The flat pulse after the cavity based pulse compressor (LIPS), with modulation of the input RF phase-to-amplitude (PTA).





Comparison between PTA and PM

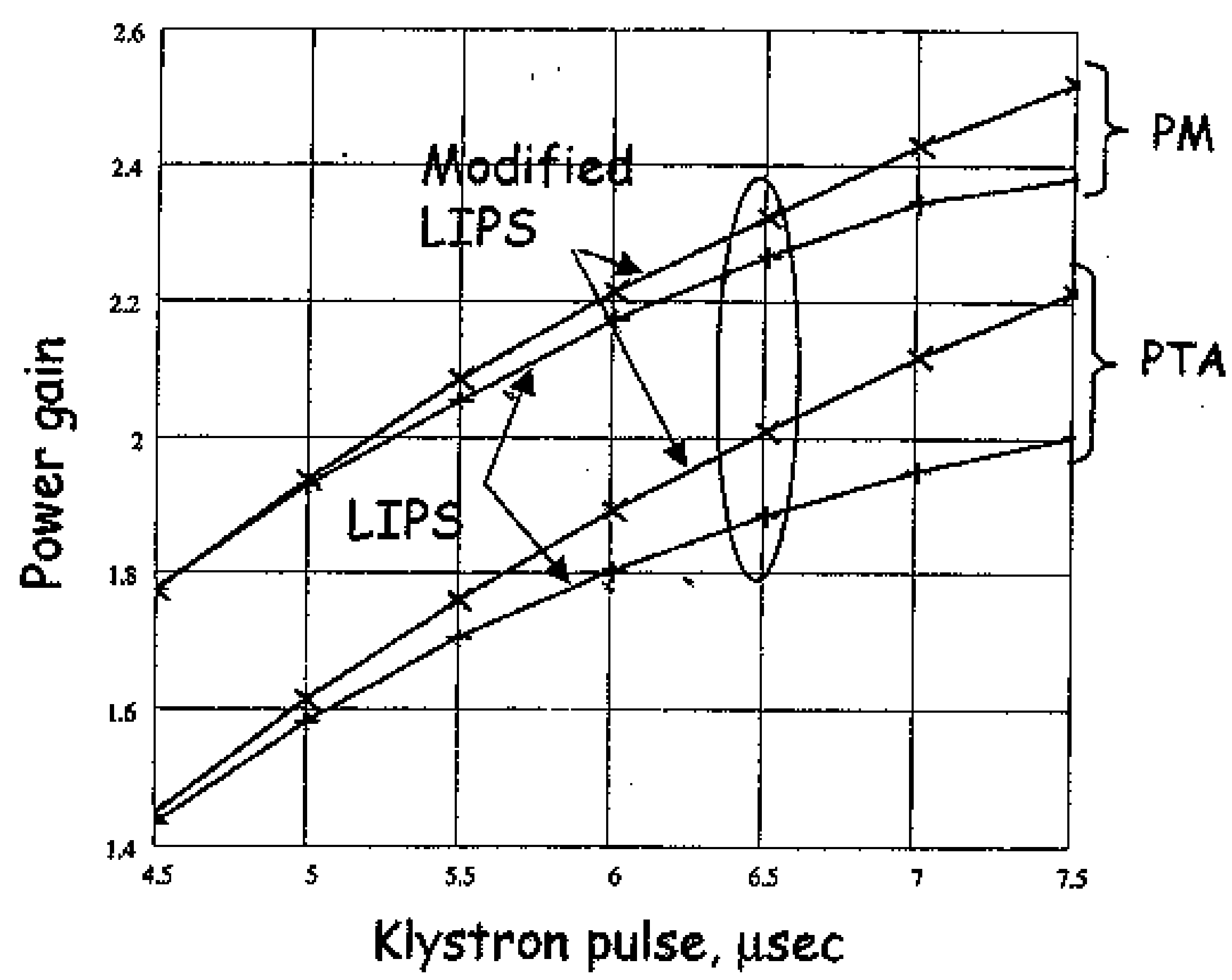
Pros:

- Output pulse flat both in RF amplitude and phase.
- Easy RF power level control.
- Better stability of operation.

Cons:

- Less efficient (~10%).
- Two klystrons needed.

Power gain.



LIPS modification is mainly the adjusting of the cavity coupling.

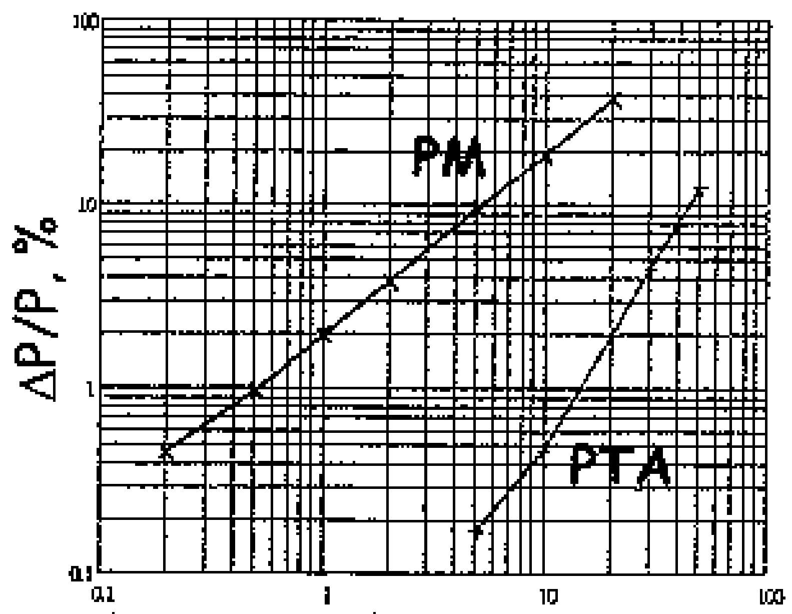
System operation stability.

Because of the energy spread, the demand on the compressed pulse flatness is:

$\Delta P/P < 2\%$

The main sources of instability:

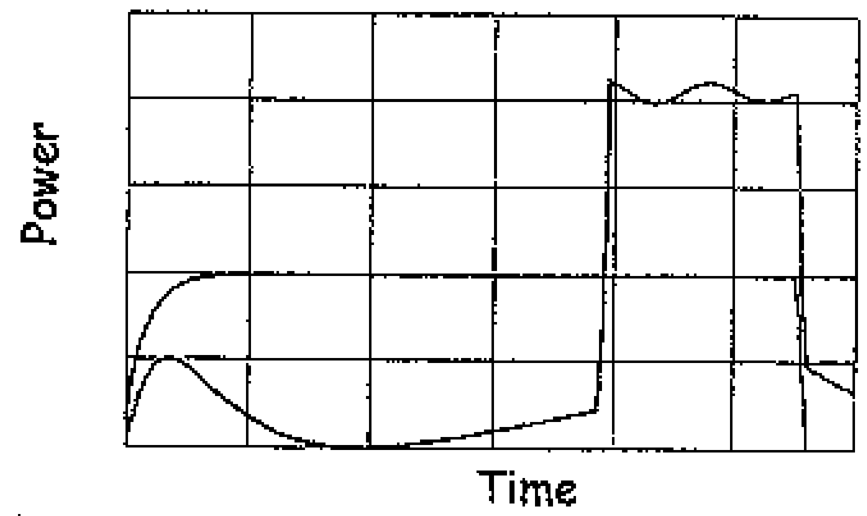
① Klystron RF phase and amplitude jitter as result of HV supply instability.



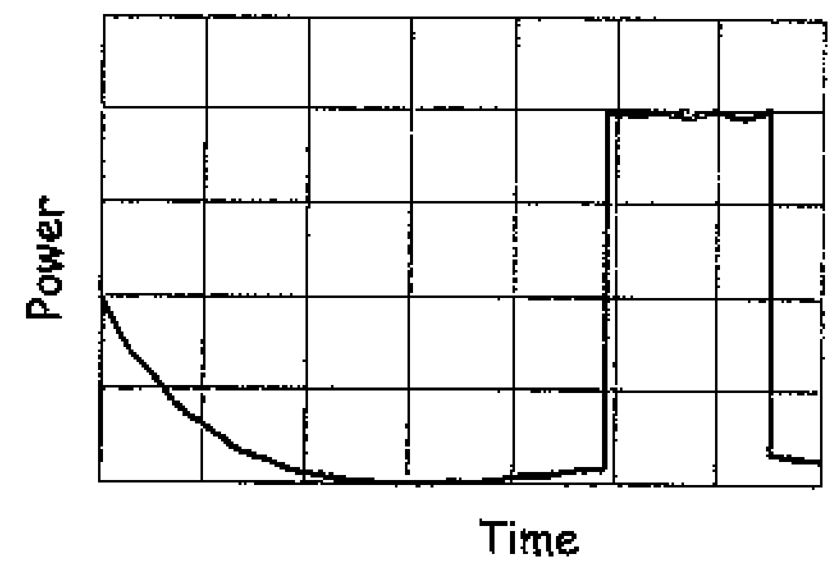
Klystron's RF phase amplitude of ripples, degree.

The examples of the compressed RF pulse distortion due to the klystron RF phase ripples.

a) RF Phase modulation. Klystron RF phase ripples 3° peak-to-peak.

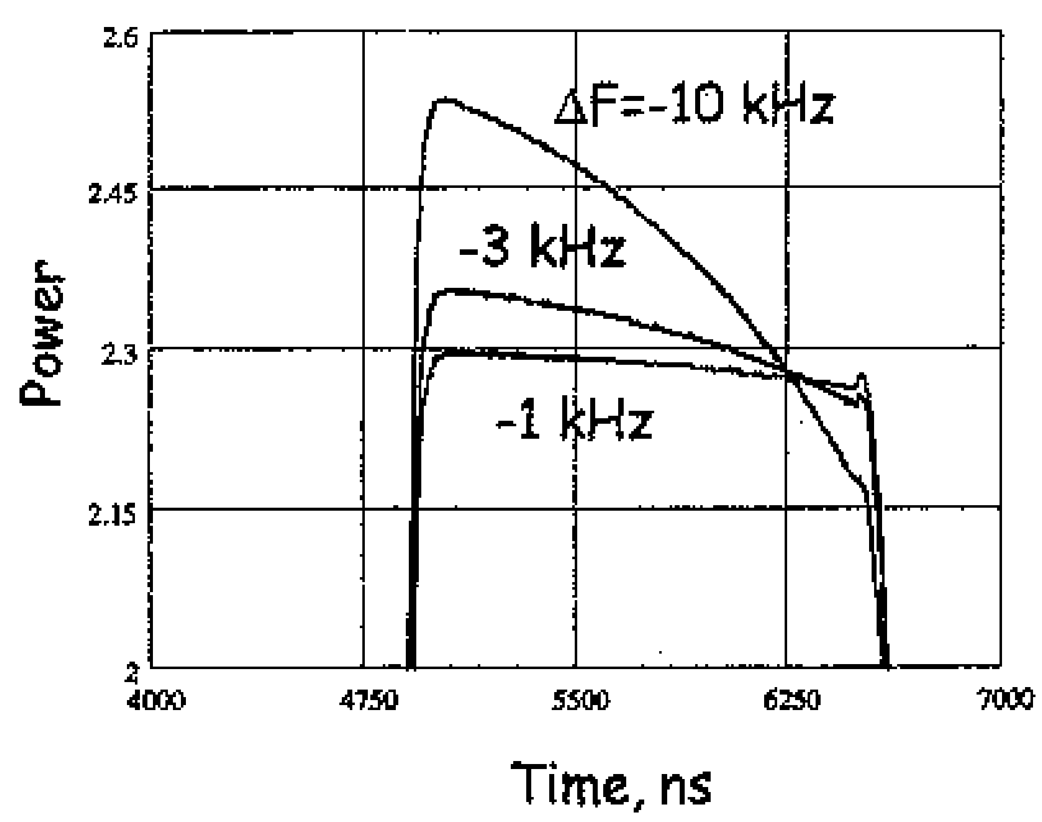


b) RF Phase-to-amplitude modulation. Klystron RF phase ripples 10° peak-to-peak.

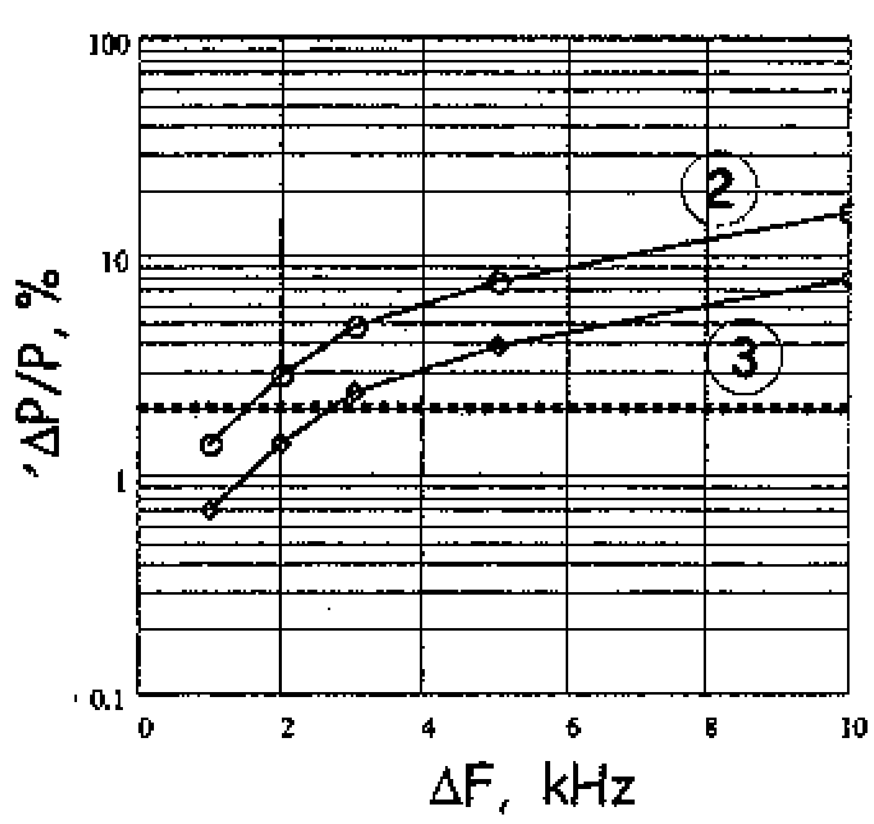


System operation stability.

② The frequency deviation of the storage cavity, mainly because of the temperature variation.



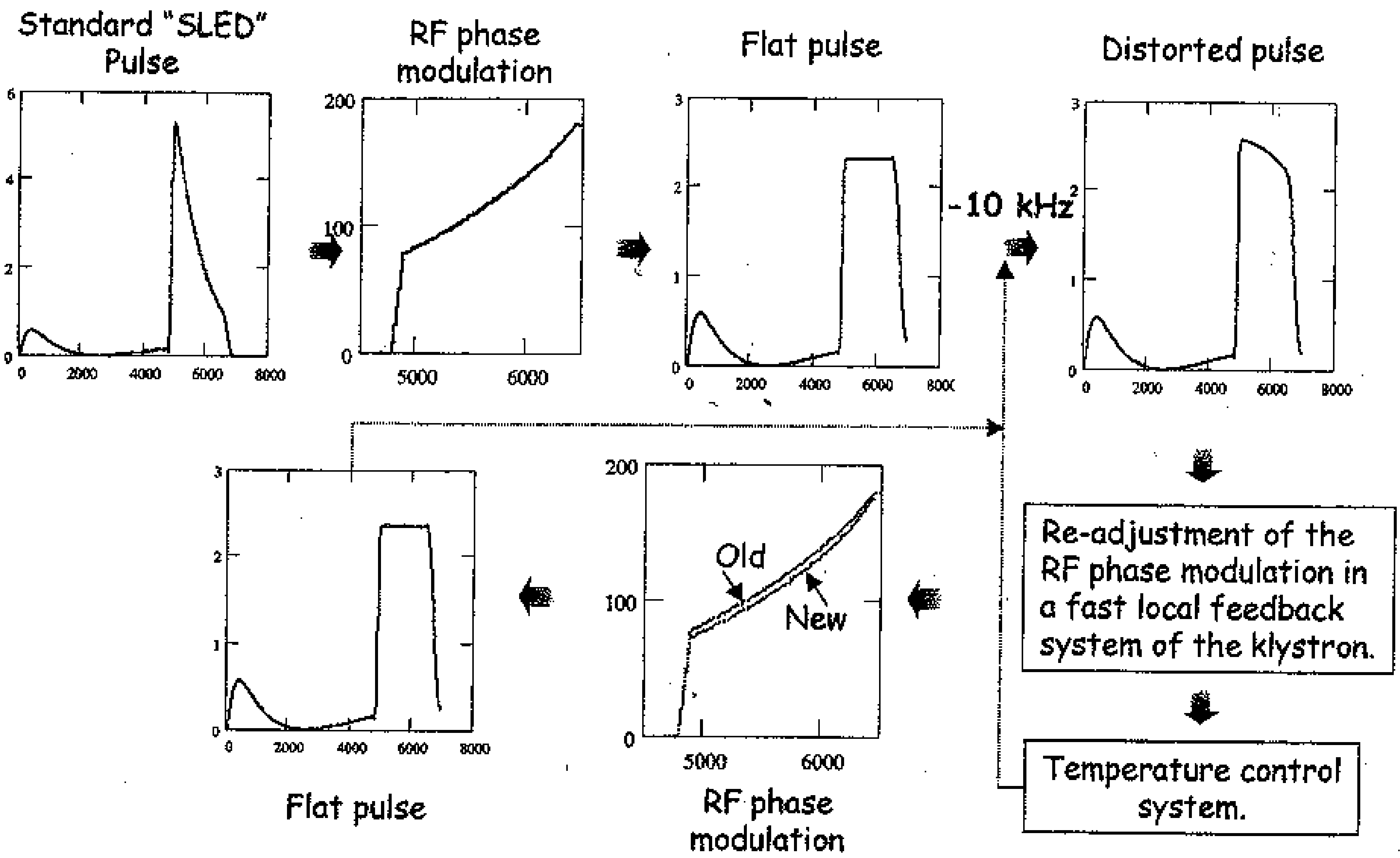
③ The identity of the LIPS cavities resonant frequencies.



To keep the flatness of the compressed pulse within specified ΔP/P, the temperature stabilization of the cavity must be < ± 0.04 °C.

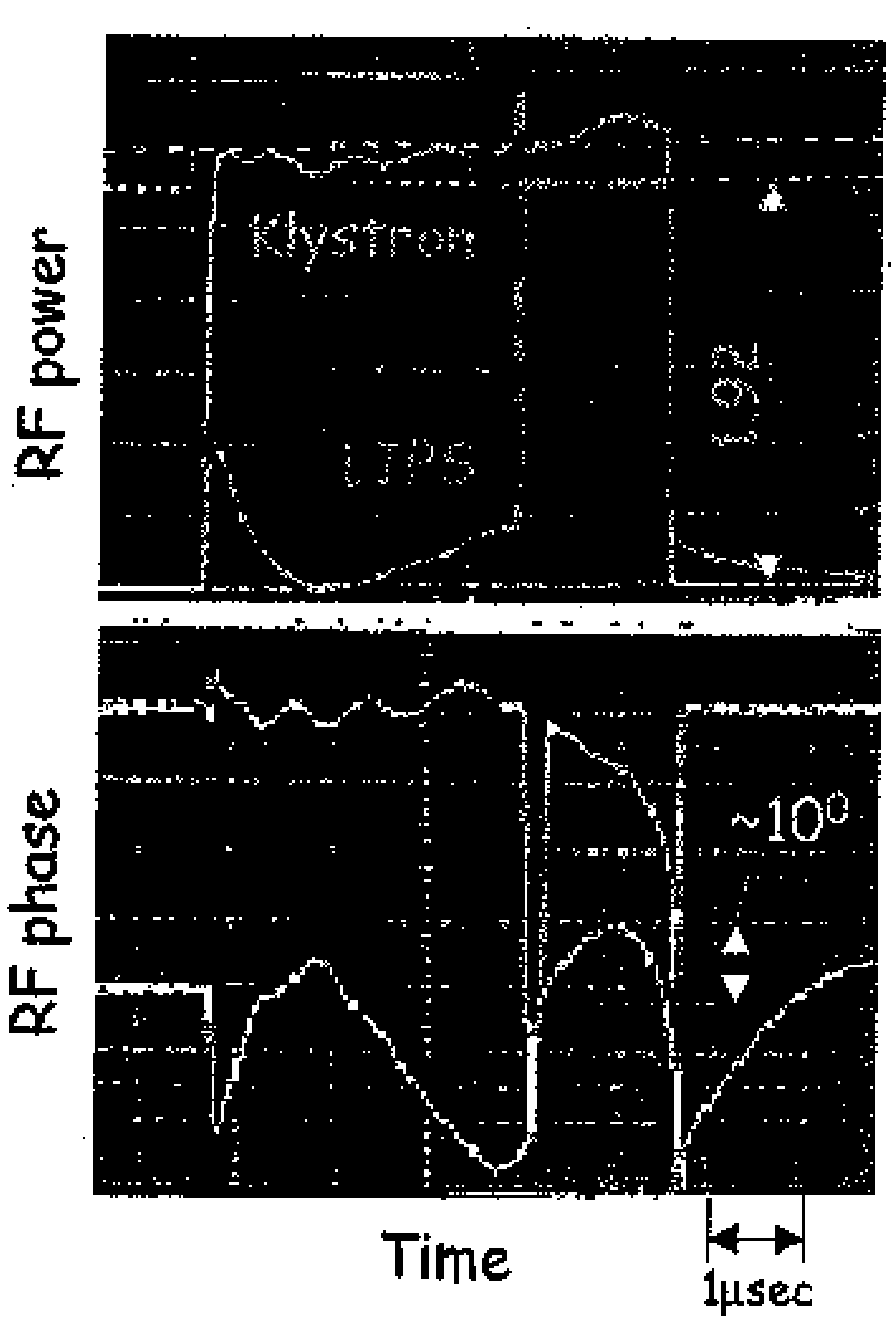
System operation stability.

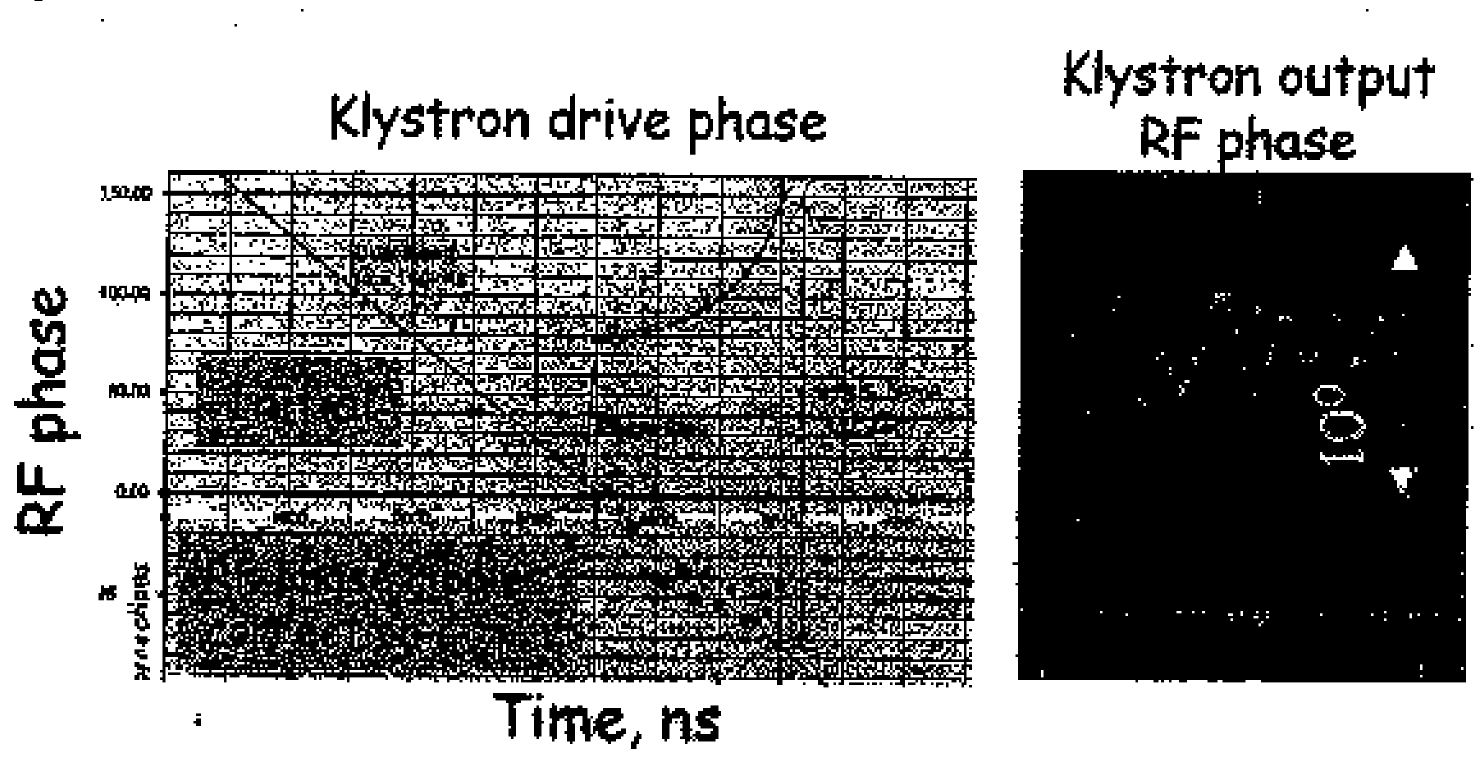
Algorithm of the fast correction of the cavity frequency shift.



RF Pulse Compression system for CTF3.

Experiments at a high RF power level. R. Bossart, December 2000.

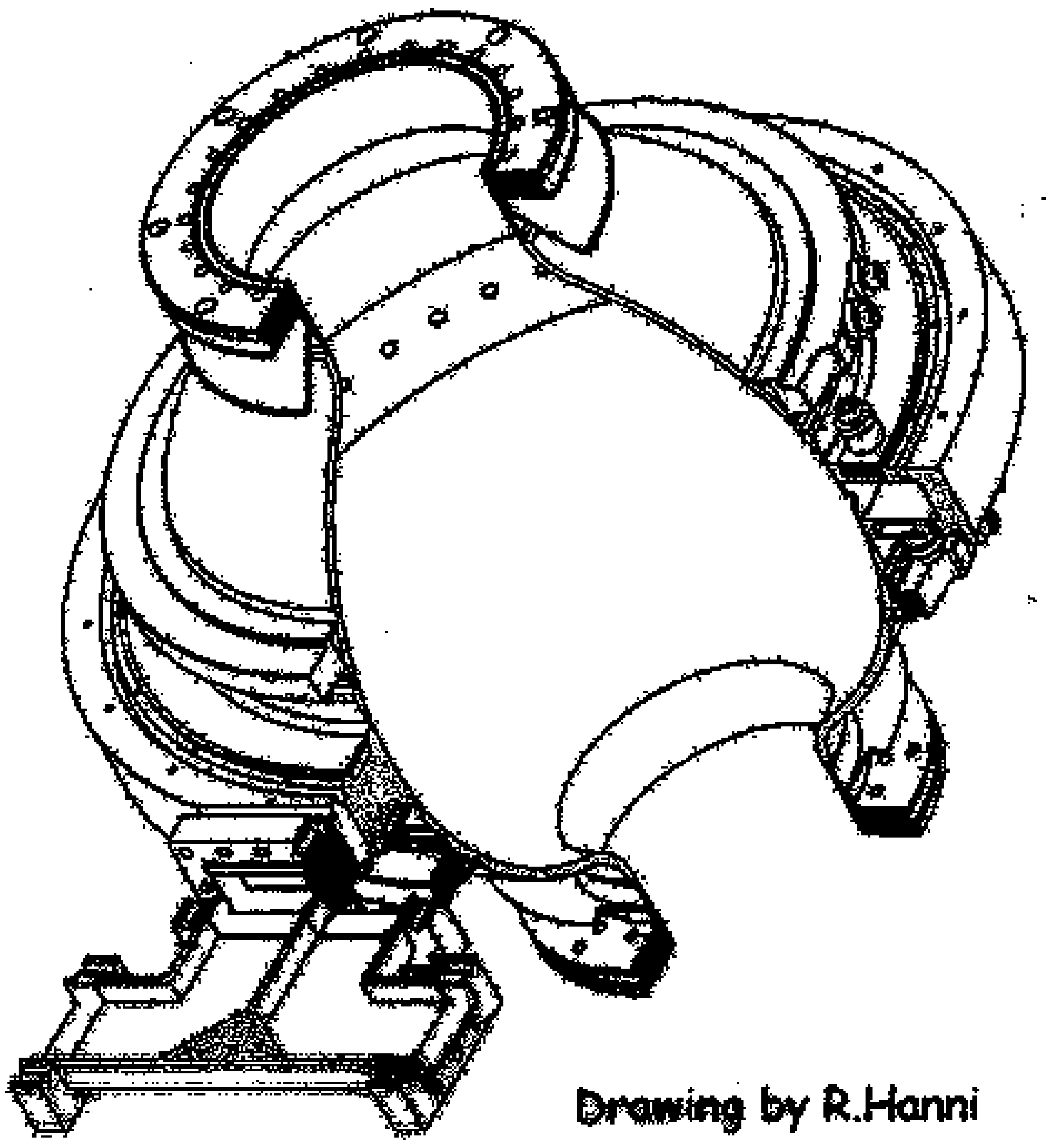




Parameters:

Q unloaded	1.6×10^5
Coupling	8.0
Tin	5 µsec
Tout	1.4 µsec
P out/in	34.7/18 MW
P gain/teor.	1.92/2.04
ΔP/P	< 1%

3 GHz Barrel Open Cavity pulse compressor.



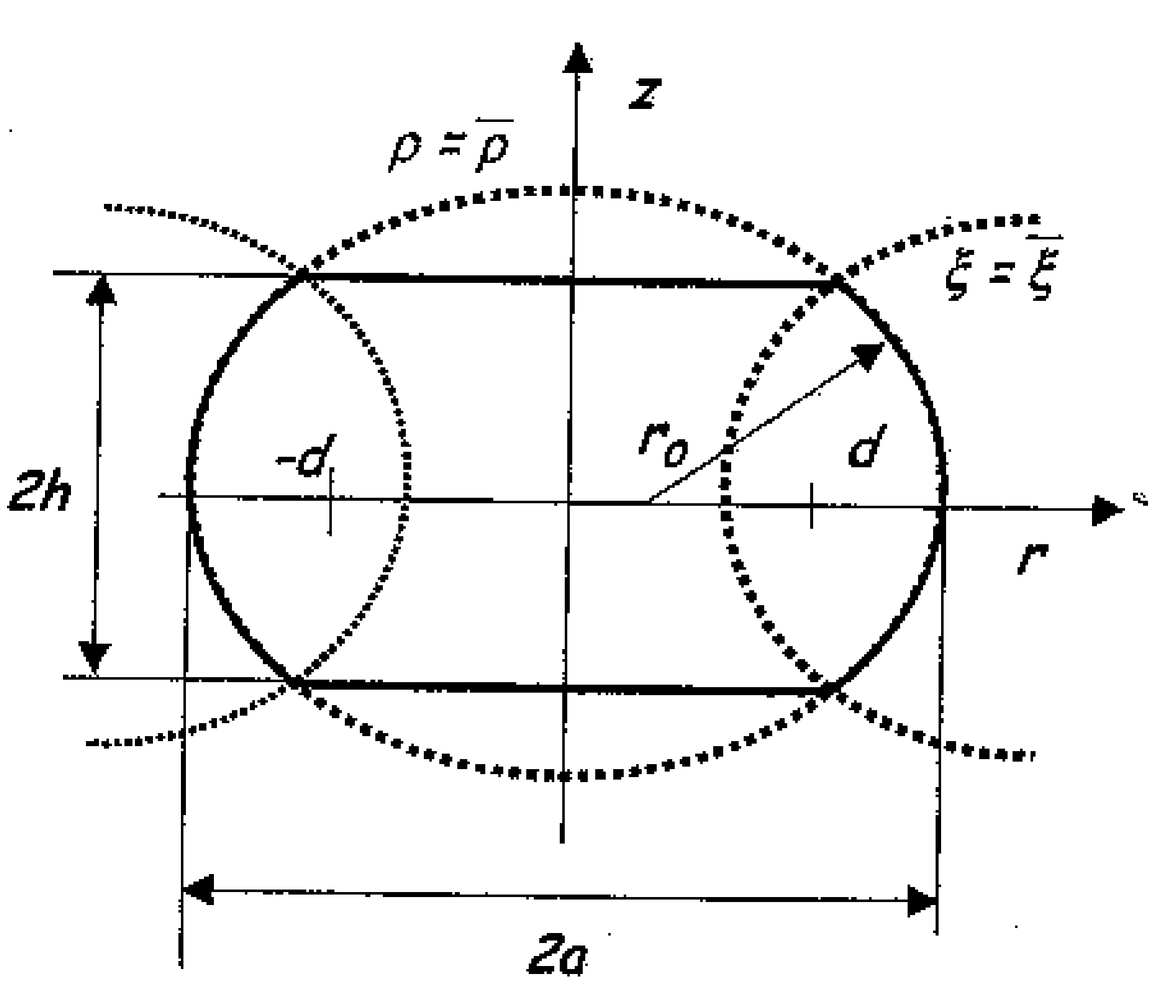
Drawing by R.Hanni

#1. We need at least four more RF Pulse Compressors.

#2. BOC Compressor operates in a TW regime utilizing single cavity:
- no needs for additional 3 db couplers and doubling the cavities,
- the system is more stable in operation.

RF Pulse Compression system for CTF3.

The Barrel-cavity brief theory.



Cavity profile

$$z=\sqrt{ar_0\left\{1-\left(\frac{r}{a}\right)^2\right\}}$$

The eigen-frequency of the Barrel cavity with E_{mnq} oscillation is the solution of the next equation:

$$ka=\nu_{mn}+\frac{(q-1/2)\alpha}{\sin\theta}$$

ν_{mn} is a root of the Bessel function that for the big m can be approximated as:

$$\nu^0_{mn}=m-\mu t^0_n \qquad (n=1,2,\ldots),$$

$$-t^0_n=[(n-0.25)1.5\pi]^{2/3}, \qquad \mu=\left(\frac{m}{2}\right)^{1/3}.$$

The optimal radius r_0, when the external caustic has the smallest height comes from: $r_0=2a\sin^2\theta$ where α and θ are derived from:

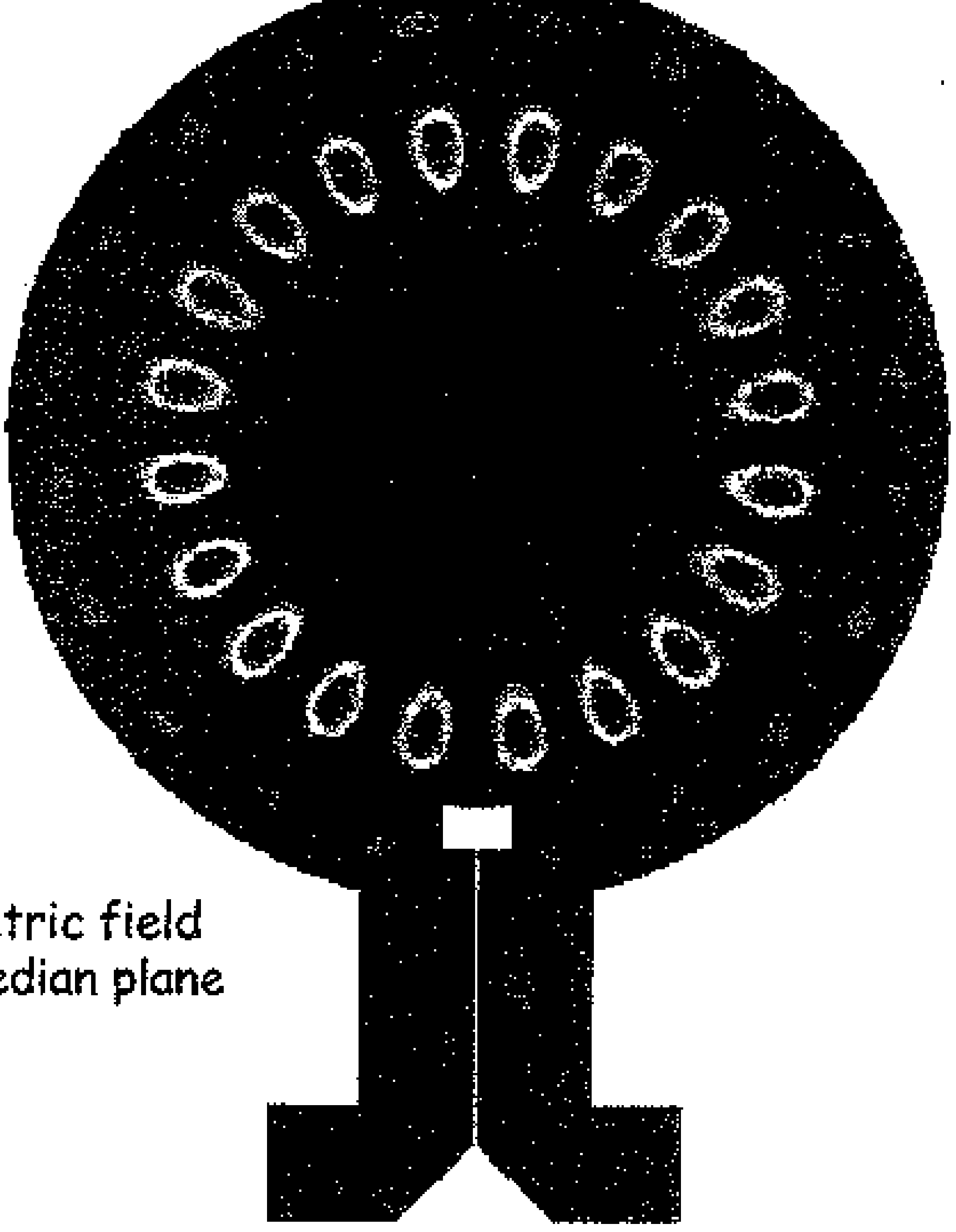
$$\sin\alpha=\sqrt{\frac{a}{r_0}}\sin\theta \qquad \cos\theta=\frac{m}{\nu_{mn}}$$

Finally the height of the external caustic and Q-factor of the cavity are:

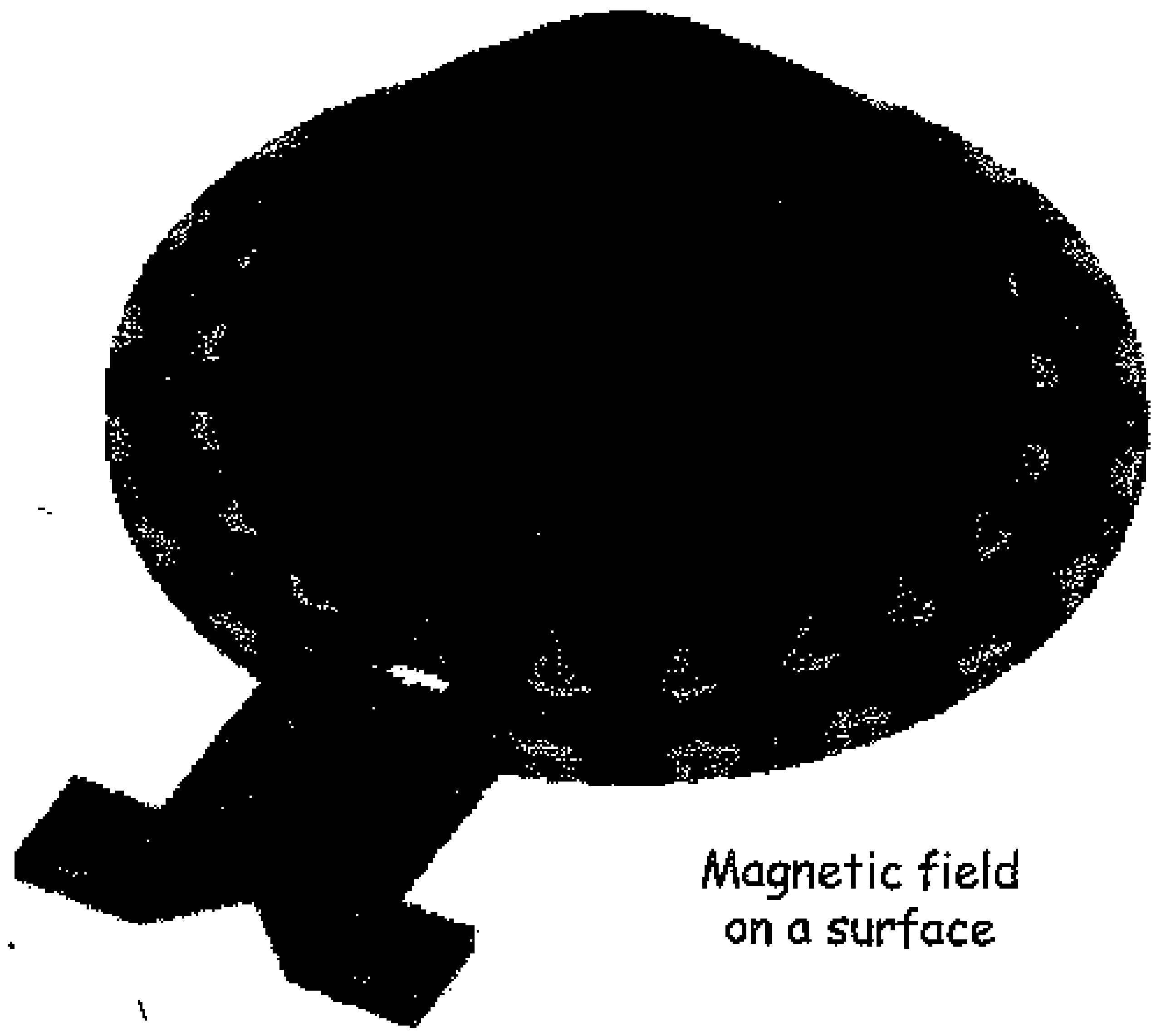
$$z_{q-1}=2\sqrt{(q-1/2)\frac{a\sin\theta}{k\sin 2\alpha}}$$

[redacted]

RF fields plots with BOC operating in a traveling wave regime (rotating $TM_{10,1,1}$ mode)

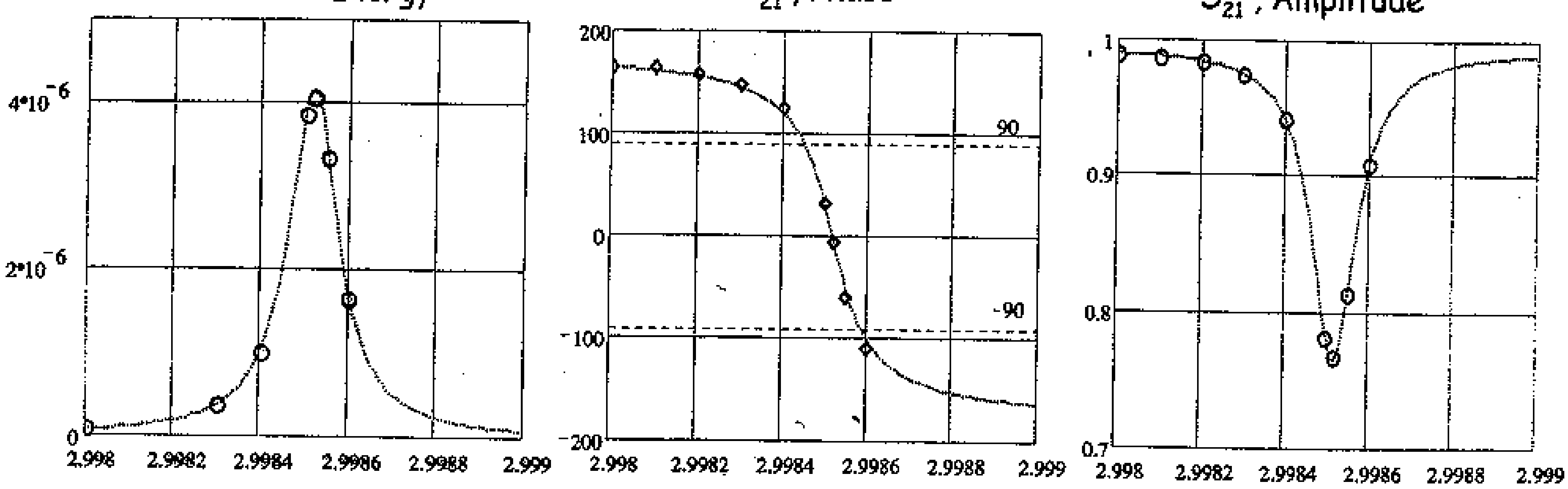


Electric field at median plane



Magnetic field on a surface

Analytical (dash) and HFSS (circles) calculation of the loaded Q-factor for the BOC with 15 mm diameter coupling holes,



$$W(f)=\frac{W_{\infty}}{1+(Q_L\Omega(f))^2} \qquad \Psi(f)=\frac{Q_L\Omega(f)}{1+(Q_L\Omega(f))^2} \qquad \Gamma(f)=\sqrt{1-\frac{\alpha^2(\beta)/\beta}{1+(Q_L\Omega(f))^2}}$$

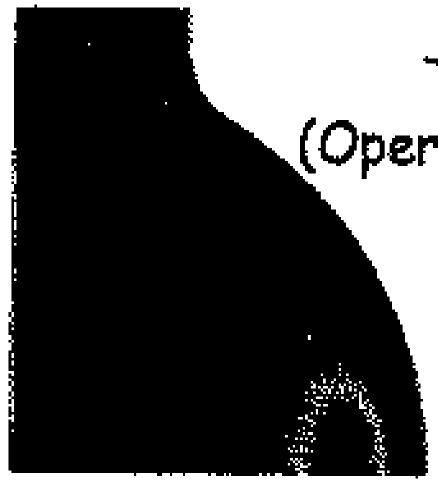
$$W_{\infty}=\tau(\beta)\times\alpha(\beta)\times P_{RF} \quad \Omega(f)=\frac{f}{f_0}-\frac{f_0}{f} \quad \tau(\beta)=\frac{2Q_0}{\omega(\beta+1)} \quad \alpha(\beta)=\frac{2\beta}{\beta+1} \quad Q_L=\frac{Q_0}{\beta+1}$$

$Q_0 = 1.95\times10^5$, F_0=2.99852 GHz, $\beta = 7.8$

RF Pulse Compression system for CTF3.

Modes separation.

$TM_{10,1,1}$ (Operation mode)

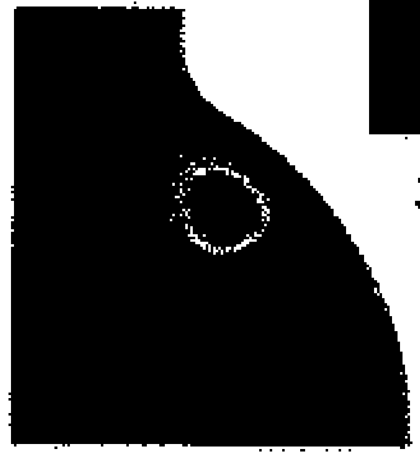


2.998 GHz

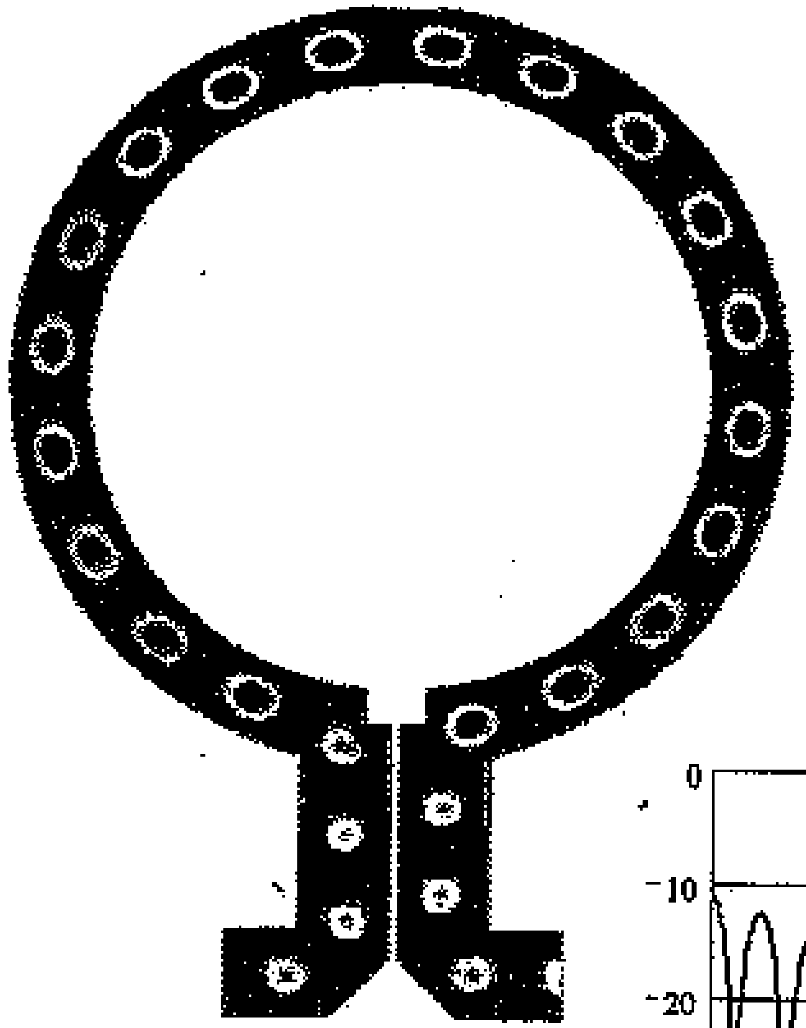
$TM_{8,1,3}$

3.0134 GHz

$TM_{6,1,5}$



3.0215 GHz



Waveguides matching.