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COMPRESSOR SYSTEM**

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ABSTRACT

This paper deals with the design of high Q_0 TE resonators for high efficiency RF pulse compression.

The aim of our study was the development of a storage resonator to be used for an energy doubler (similar to the one used on the STANFORD LINAC ENERGY DOUBLER [SLED] to increase the Beam energy of the STANFORD LINAC to 53 GeV) but to be used for a LINAC having a quite long filling time of 1.2 μ sec.

For this reason the storage resonator must be designed for an unloaded Q_0 of roughly 10^5 .

By using our OSCAR2D computer code (which compute the resonant frequency, Q_0 and geometry factor for any reasonable TE or TM monopolar mode of cylindrically symmetric RF cavities) we found an optimized resonator geometry.

On this geometry we get the benefit of a Q_0 about 10% higher than the Q_0 of an ideal cylindrical cavity together with the splitting of TE_{0mn} like and TM_{1mn} like modes which in a cylindrical cavity are coalescent.

1. INTRODUCTION

Dealing with the design of an energy doubler R.F. System for the Frascati LINAC based upon the sound design developed at SLAC [1] we need to find the best storage cavity design in order to cope with the quite long filling time of the LINAC sections and the need for a sound and simple mechanical design to build a reliable and cheap R.F. pulse compression system.

Taking into account the 1.2 μ sec filling time of a Frascati LINAC section, a minimum Q_0 of $1.4 \cdot 10^5$ is needed to get the maximum gain for the compression system.

This Q_0 value is 40% higher than the one used in the original SLAC system ($Q_0 = 10^5$) because the filling time of a section of the SLAC LINAC is only 0.83 μ sec.

For that reason the need arises for an investigation of the most suitable storage cavity shape.

Our paper presents a discussion on the benefits of some different cavity shapes in order to choose the optimum (in our case) resonator geometry.

To achieve our goal a wide number of resonator models and geometries have been investigated, to get information about the pattern of the resonant frequencies of the different modes.

2. RF SYSTEM PARAMETERS FOR A SLED TYPE ENERGY DOUBLER FOR THE FRASCATI LINAC

The parameters for a STANFORD LINAC ENERGY DOUBLER type (1) for the Frascati Linac and those for its cavities are briefly discussed.

A Sled Type Energy Doubler for a Linac is formed by a pulse compressor which increases the input peak power for the accelerating sections of the Linac reducing the RF pulse length by means of a fast 180° phase shifter, a 3db hybrid-coupler and two high Q_0 resonant cavities operating at the same frequency as the Linac section.

The basic layout of the device is shown in figure (1).

We mark E_S , E_K and E_I the signals applied to the phase-shifter, the KLYSTRON and the Linac section respectively.

Accordingly to Farkas et al (1) the energy multiplication factor in the case of constant gradient structure is given by

$$V = \gamma \cdot e^{-\frac{T_a}{T_c}} \cdot \left[1 - (1 - g)^{\nu+1} \right] \left[g(1 + \nu) \right]^{-1} - (\alpha - 1)$$

where

β = cavity coupling coefficient

α = $2\beta / (1+\beta)$

g = 0.806

T_a = filling time of the structure

T_c = $2.Q_0/\omega (1+\beta)$ = cavity filling time

Q_0 = cavity unloaded quality factor

$$v = \left(\frac{T_a}{T_c} \right) \left[\ln (0.194) \right]^{-1}$$

γ = $\alpha (2 - e^{-\tau_1})$

τ_1 = t_1 / T_c

t_1 = starting time of the compressed RF pulse (see figure 1)

ω = radian frequency

It is known (1,2) that V as a function of coupling β has a broad maximum. The value of V optimum as well as β optimum depends on the ratio T_a/T_c .

For the Frascati LINAC the Klystron gives a 5 μ sec RF output pulse, the filling time of the structure is 1.2 μ sec.

Figure 2 shows the energy gain of the SLED System as a function of the coupling coefficient β for a linac filling time of 1.2 μ sec, and an overall RF pulse length of 4.2, 5.2 and 6.2 μ sec and a Q_0 of the storage cavities of 10^5 .

Figure 3 shows the same situation for a Q_0 of the storage cavity of 1.4×10^5 .

From the two figures it can be seen that a gain of about 1.6 could be easily obtained for a pulse length of 6.2 μ sec for Q_0 ranging from 10^5 - 1.5×10^5 and coupling factors between 3 and 4.

3. CHOICE OF THE SHAPE AND OPERATING MODE FOR THE CAVITY

From the design considerations of section 1 it follows that a Q_0 value of 1.4×10^5 at the operating frequency of 2856 MHz is needed for a good operation of the pulse compression-linac system.

It is well known that the Q_0 value of a resonator can be written as:

$$Q_0 = \frac{G}{R_S} \quad (1)$$

where

$$R_S = \sqrt{\frac{\pi f \mu_0}{\sigma}} \quad [\Omega] \quad (2)$$

is the surface resistance of a conductor of electrical conductivity σ at the frequency f (μ_0 is the magnetic permeability of the vacuum).

The magnetic geometry factor G where H is the modulus of the magnetic field inside the cavity and $H_{//}$ is the modulus of the component of the magnetic field tangent to the cavity surface.

$$G = \mu_0 \omega \frac{\int H^2 dV}{\int_s H_{//}^2 ds} = \pi \sqrt{\frac{\mu_0}{\epsilon_0}} \frac{2}{\lambda} \frac{\int H^2 dV}{\int_s H_{//}^2 ds} \quad [\Omega] \quad (3)$$

is a characteristic parameter of a Resonator depending only on the cavity shape and the resonant mode, but independent from the cavity frequency. [3]

For a copper cavity at our operating frequency of 2856 MHz (the frequency of the Frascati LINAC) the value of R_s is

$$R_s = 1.3 \times 10^{-2} \Omega.$$

assuming

$$\sigma = 5.81 \times 10^{+7} \Omega^{-1}.$$

The minimum value of the Geometry factor for a cavity to be used in our RF pulse compression system is:

$$G = R_s \times Q_0 = 1950 \Omega.$$

This value for the magnetic geometry factor is assumed as goal for the electromagnetic design of our resonators.

Nevertheless to design a reliable storage cavity we need to take into account also some different problems coming from the possible degeneracy of unwanted low Q modes with the operating one, and the need for a sound and simple mechanical design to get high operational reliability at a cheap production cost since in our case for the (n) Linac sections we need to build (2n) identical storage resonators.

For the reasons above we investigated different cavity shapes to have a wide set of possible resonators.

First we restricted our choice of the operating mode for our storage cavity to TE monopolar modes because for these modes (due to the field distribution) [4] the r.f. losses are lower than in any other TE or TM modes.

Second we restricted ourselves to spherical and cylindrical resonator in order to deal with simple and sound building techniques as deep drawing or spinning of metal sheets.

4. SPHERICAL RESONATOR

It is well known [3,4,5,6] that a spherical cavity is the resonator having the highest geometry factor because a sphere is the geometric body with the highest volume to surface ratio.

The magnetic geometry factor is in effect roughly proportional to that ratio.

The value of G for a spherical resonator is 835 for the first TE monopolar mode and 1090 for the second one.

The reported G values are not high enough for our aims and resonant modes higher than the reported ones are needed.

But as the order of the operating mode increases, the mechanical complexity of the system increases too because mode stabilizers are needed to obtain the right mode polarization and to avoid the degeneracy with unwanted low Q_0 modes [6].

5. CYLINDRICAL RESONATOR

The cylindrical resonator is a simple and cheap solution for a storage cavity, because the barrel of the resonator can be easily obtained by rolling a metal sheet and the end caps are obtained by simple flat flanges.

Also the problem of removing the accidental degeneracy of the high Q_0 TE_{0mn} modes with the low Q_0 TM_{1mn} modes can be easily mastered by a simple machining of the end plates.

Furthermore the tuning of the right frequency of the resonator can be done by slightly changing the end plates position by a suitable pressure.

Finally, the shape of the cavity could be chosen with some freedom, selecting the best diameter (2R) to length (L) ratio in order to accommodate the resonator dimensions to an existing experimental space.

Anyway in so doing we need to get the best compromise between the resonator dimensions and the lowering of the Q_0 due to a 2R/L ratio different from the unit value.

In fact the Q_0 or G value for the TE_{0mn} modes exhibit a broad maximum for $2R/L = 1$ [3]

On the basis of the previous considerations we decide to restrict further on our choice to cylindrical cavities operating on a suitable TE_{0mn} mode.

6. OPTIMIZATION OF THE RESONATOR

To get the maximum available Q_0 value for a given TE_{0mn} mode, an optimization of the resonator shape was tried by using our OSCAR2D [8] code.

For a given mode, the geometry factor G is the parameter to be maximized.

The way to optimize the cavity shape comes from our observation that cutting the outer corner of the cross section of the cavity gives rise to a further increase of the geometry factor of an otherwise optimized ($2R/L = 1$) cylindrical cavity.

A typical cross section of a modified cylindrical cavity is shown in figure (4).

The a and b length in the figure are the parameters we changed to find the maximum G value of the resonator.

The values of G for a given TE_{0mn} mode are reported in figures (5,6,7) as a function of a/R value for a given b/R value.

It is straight-forward to see from the aforementioned figures that for a given mode, in our modified TE_{0mn} cavities, a clear maximum of the G factor exists for a well specified (a/R ; b/R) couple.

The maximum value is always higher than the G value for the unmodified cavity ($a/R=0$) and also usually higher than the maximum G value for a $TE_{0,m,n+1}$ (unmodified) cavity. (At

least for $m \geq 3$). The optimization we performed allows us to obtain a storage cavity with a G value of 1950Ω using a TE_{031} -like modified cavity removing, at the same time in our

modified geometry, the accidental degeneracy between the TE_{0mn} and TM_{1mn} modes.

The figure 8 reports the field distribution for the TE_{031} storage cavity modified.

As shown in figure (7) the couple $a/R \simeq 0.71$, $b/R=4/7$ gives the highest value of G for the modified cavity operating on the TE_{031} mode.

Finally we used the URMEL-T code (courtesy of T.WEILAND DESY [7]) to check the frequency distribution of dipolar and quadrupolar modes to check the degeneracy of our "storage mode" with low Q_0 modes.

Table I reports a list of the frequencies of the TE Storage modes and the frequencies of the Hybrid dipolar modes for the geometry selected shown in fig.8. The first column refers to the first fifteen TE modes of the cavity as computed by OSCAR2D code for a geometry having the

TE₀₃₁ mode (the storage one) at 2856. MHz.

The Hybrid dipolar modes for that geometry are reported in the second and third column of the table.

The TE storage modes are identified by the usual classification of the TE modes of a cylindrical cavity.

Even though this classification holds only for small perturbations of the cylindrical cavity we use it for cavities which are strongly perturbed.

In fact, in our case the size of the cut is comparable to the distance between the nodes of the E.M. fields inside the cavity.

Nevertheless for the first 12 modes a correspondance with the modes of an unperturbed cylindrical cavity is clearly shown by the field maps.

The remaining ones are simply identified by ordering them with ascending frequency.

For the dipole modes of cylindrically symmetric cavities with arbitrary cross section in the (r,z) plane the TE and TM classification no longer holds, because to satisfy the boundary conditions both E_z and H_z are needed.

Even though classifications of hybrid modes exists, in our case a clear identification of the dipole modes, due to the cavity geometry, is quite difficult and in some case ambiguous.

For that reason we prefer to name the modes with the identification system used by T.Weiland in the URMEL code.

So the column marked even dipoles refers to Hybrid dipolar modes with electric fields having even symmetry respect to the cavity midplane (1-EE-n); the odd dipoles column refers to modes with odd symmetry respect to the cavity midplane (1-ME-n).

Where the first index is the φ index of the mode, the two letters refer to the boundary conditions used on the mid plane and on the end plate of the cavity respectively, and the last index is the mode number in ascending order of frequency.

This mode pattern refers to our optimized TE₀₃₁ like cavity.

Our modified resonator retains all the advantages of a simple cylindrical resonator.

In fact all the parts of the resonator can be easily obtained by metal sheet rolling.

The degeneracy with low Q_0 modes does not exist in our geometry, as shown in Table I.

The cavity can be still tuned by applying a suitable pressure on the end flanges, and finally we maintain some freedom in the 2R/L choice, because our optimization works for any reasonable 2R/L ratio.

- CONCLUSIONS

On the basis of our computer simulations a storage cavity was designed. The main parameters of that cavity are reported in Table II.

TABLE II

f = 2856 MHz	
L = 365.4 mm	
b = 104.4 mm	
a = 130.5 mm	
G = 1950	Q ₀ = 1.4 10 ⁵

A prototype cavity at this frequency was built.

The results of the tests on our model cavity confirmed once again the results of our design giving us a G value of 1900, which agrees with our simulations within our knowledge of the resistivity of the brass we used to build our prototype (for sake of preciseness within 2%).

FIGURE CAPTIONS

Figure 1
Basic Layout of a Sled Type pulse compression System.

Figure 2
Energy gain of a SLED System as a function of the coupling coefficient β for $g=0.805$, a linac filling time of 1.2 μsec for an R.F. pulse length T of 4.2, 5.2, 6.2 μsec and a Q₀ of the storage cavity of 10⁵.

Figure 3
Same situation of figure 2 for a Q₀ of the storage cavity of 1.4 x 10⁵.

Figure 4
Cross section of a modified TE cylindrical storage cavity.

Figure 5
G value versus a/R plot for TE_{01n} modes
(n = 1,4) for b/R = 3/7 (\square), b/R = 4/7 (+), b/r = 5/7 (\circ) and b/r = 6/7 (Δ).

Figure 6
Same plots of figure 5 but for TE_{02n} modes (n=1,4).

Figure 7
Same plots of figure 5 and 6 but for TE_{03n} modes (n=1,4).

Figure 8
TE₀₃₁ Modified Storage cavity with superimposed field distribution.

TABLE CAPTIONS

Table I

List of the frequencies of the first 15 TE monopolar modes and the first 30 Hybrid dipolar modes fo the cavity shown in Fig.8.

Table II

Main parameters of the prototype storage cavity built to test our optimization.

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FIG. 1

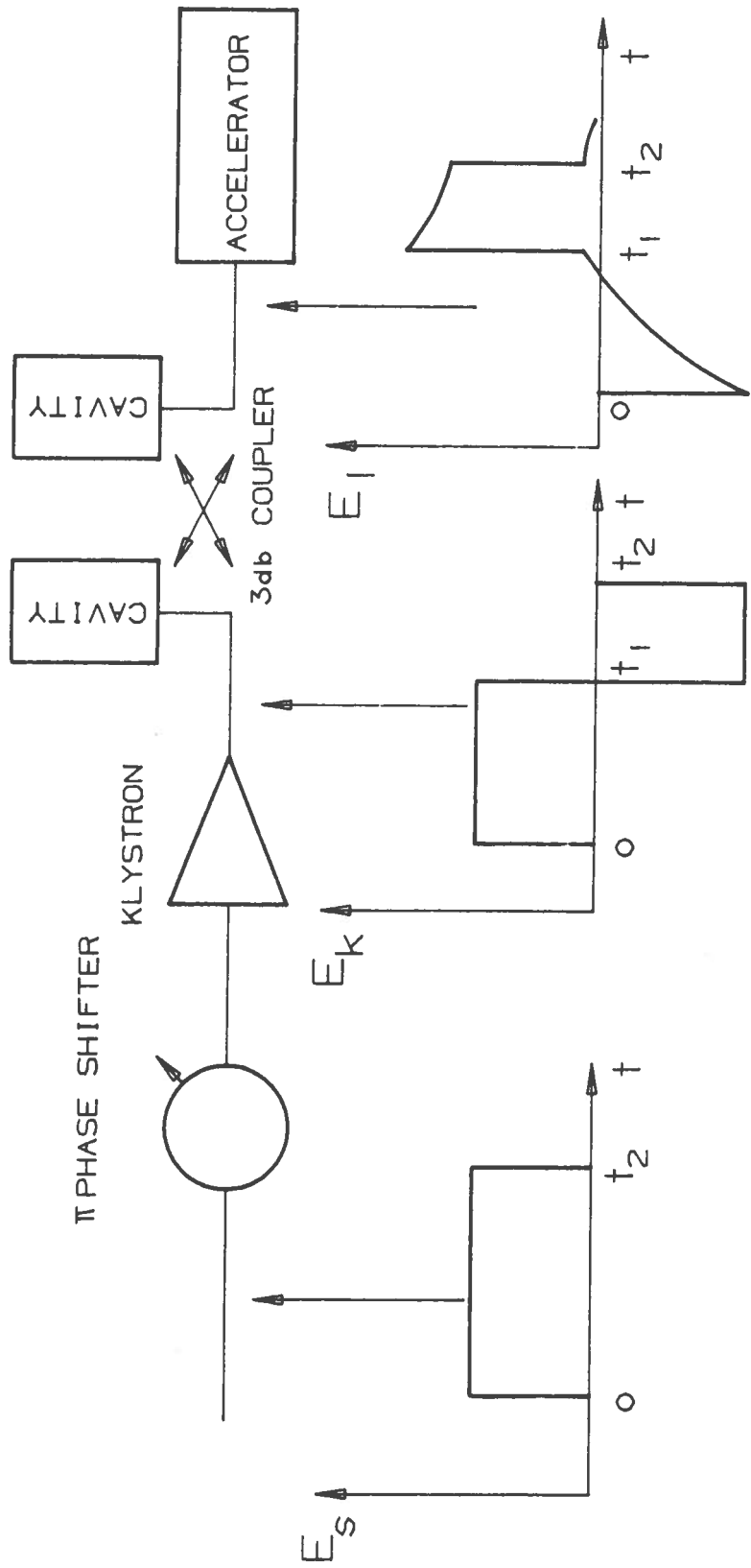


FIG. 2

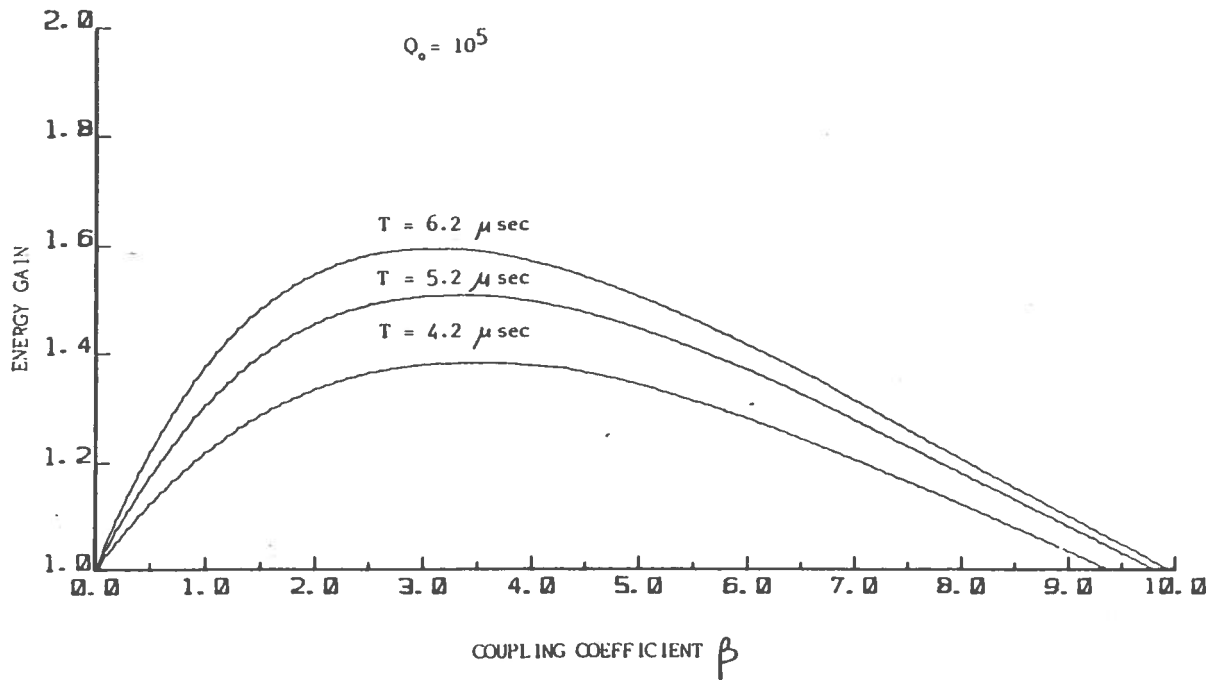


FIG. 3

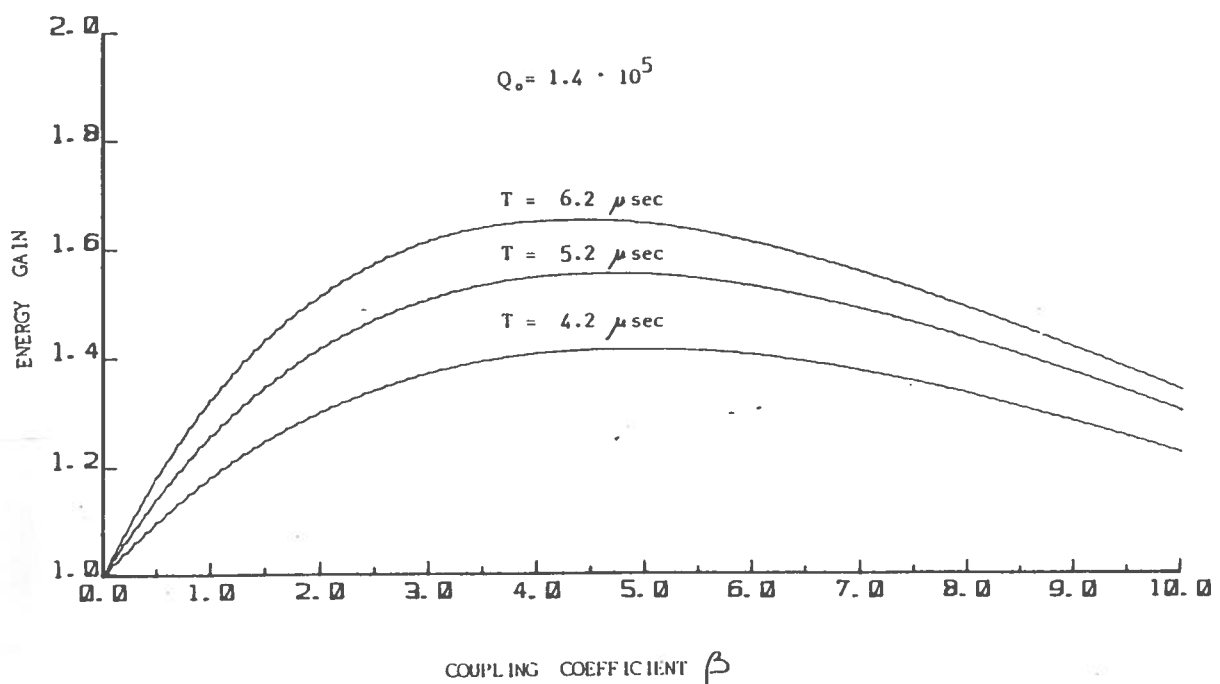
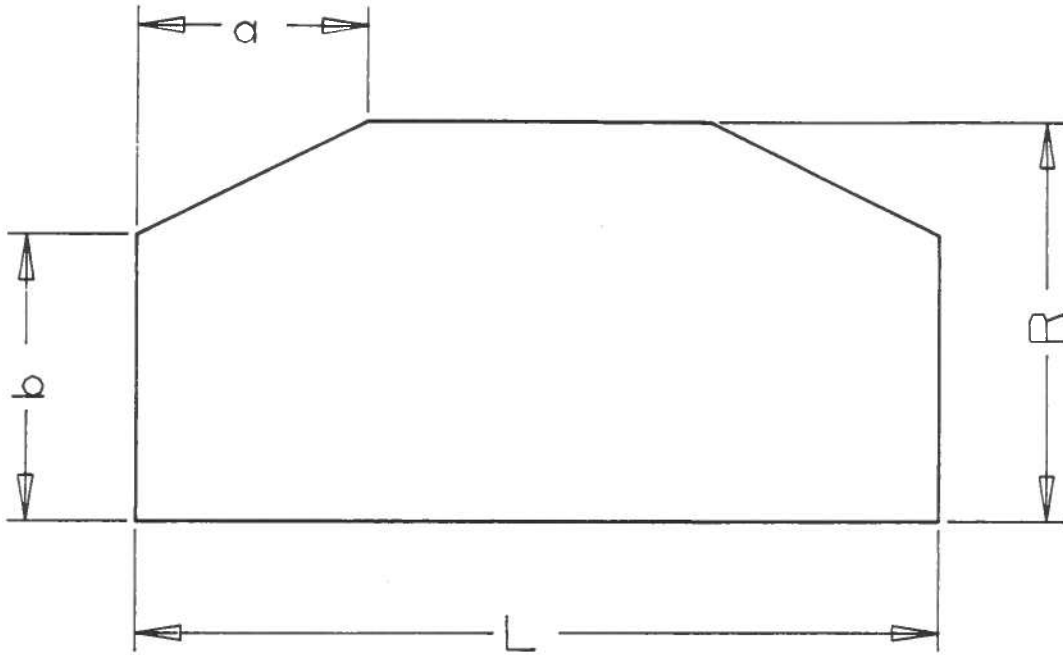


FIG. 4



PART.	DENOMINAZIONE	QUANT.	MATERIALE	TRATTAMENTO	
	TE STORAGE CAVITY FOR SLED TYPE PULSE COMPRESSOR			NOME	DATA
		DISEGN.	PARODI R.		
		CONTR.			
		SOSTITUISCE IL			
		SCALA			
	ISTITUTO NAZIONALE DI FISICA NUCLEARE SEZIONE DI GENOVA			GRUPPO-SIGLA	

FIG. 5

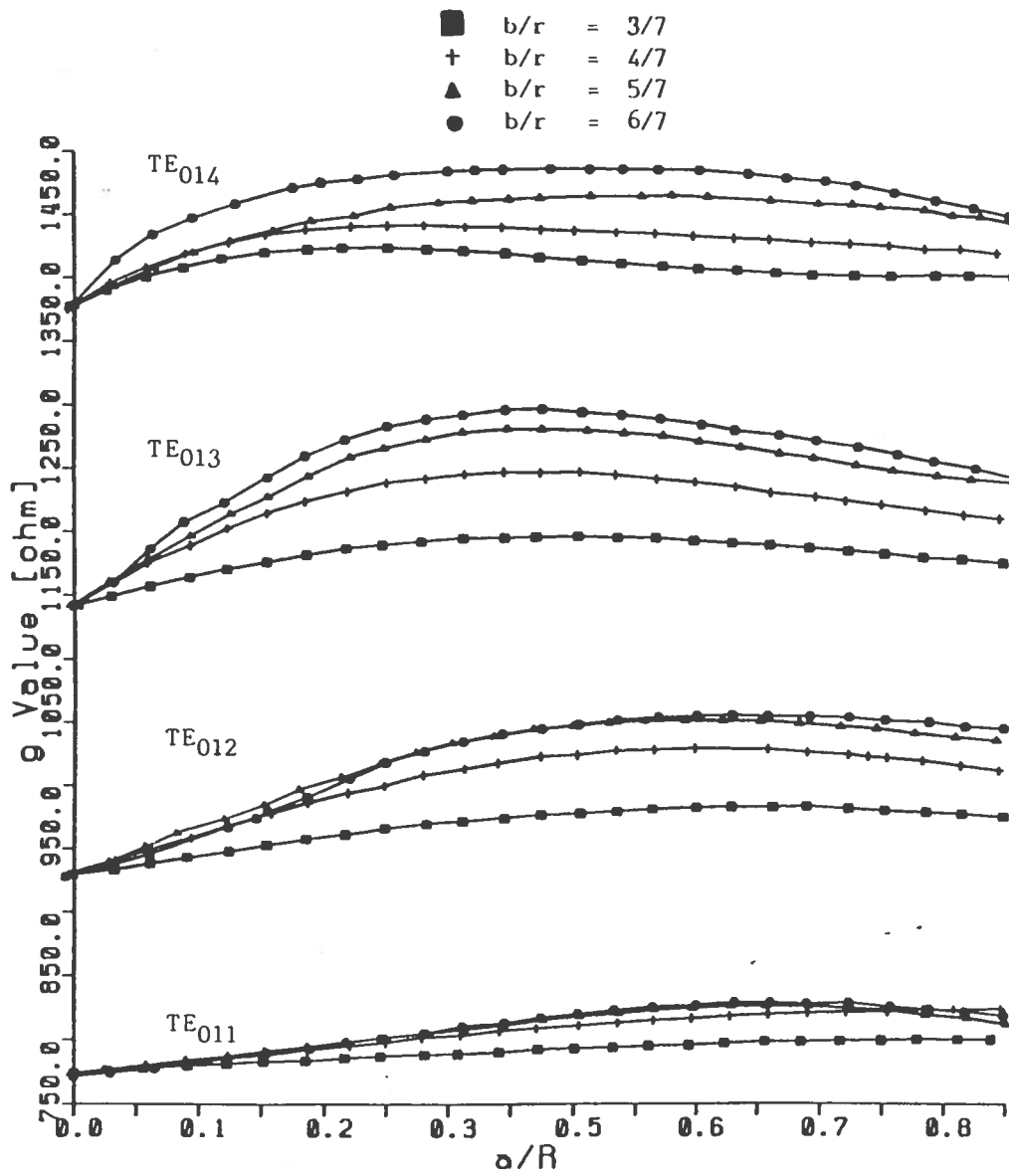


FIG. 6

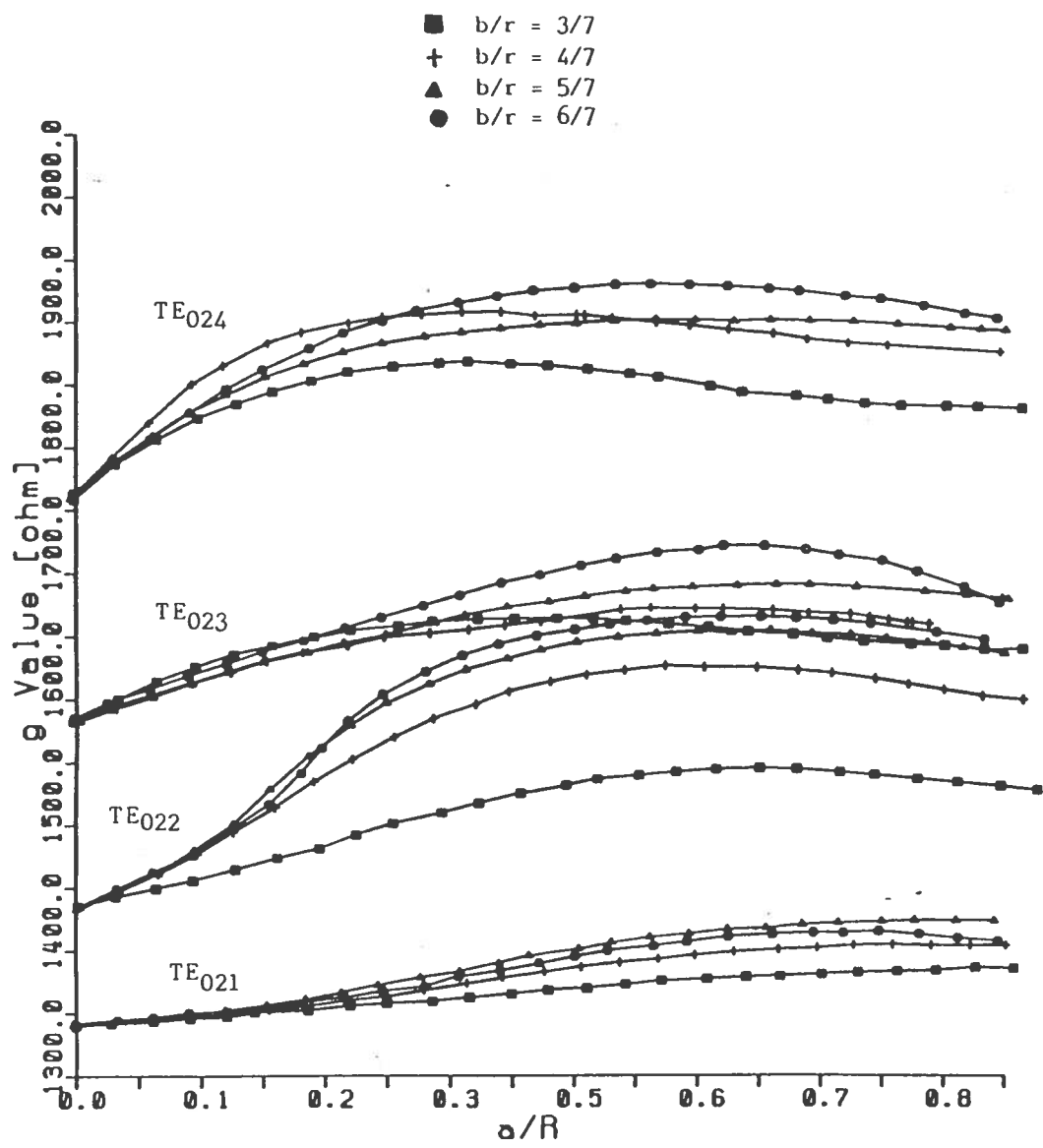


FIG. 7

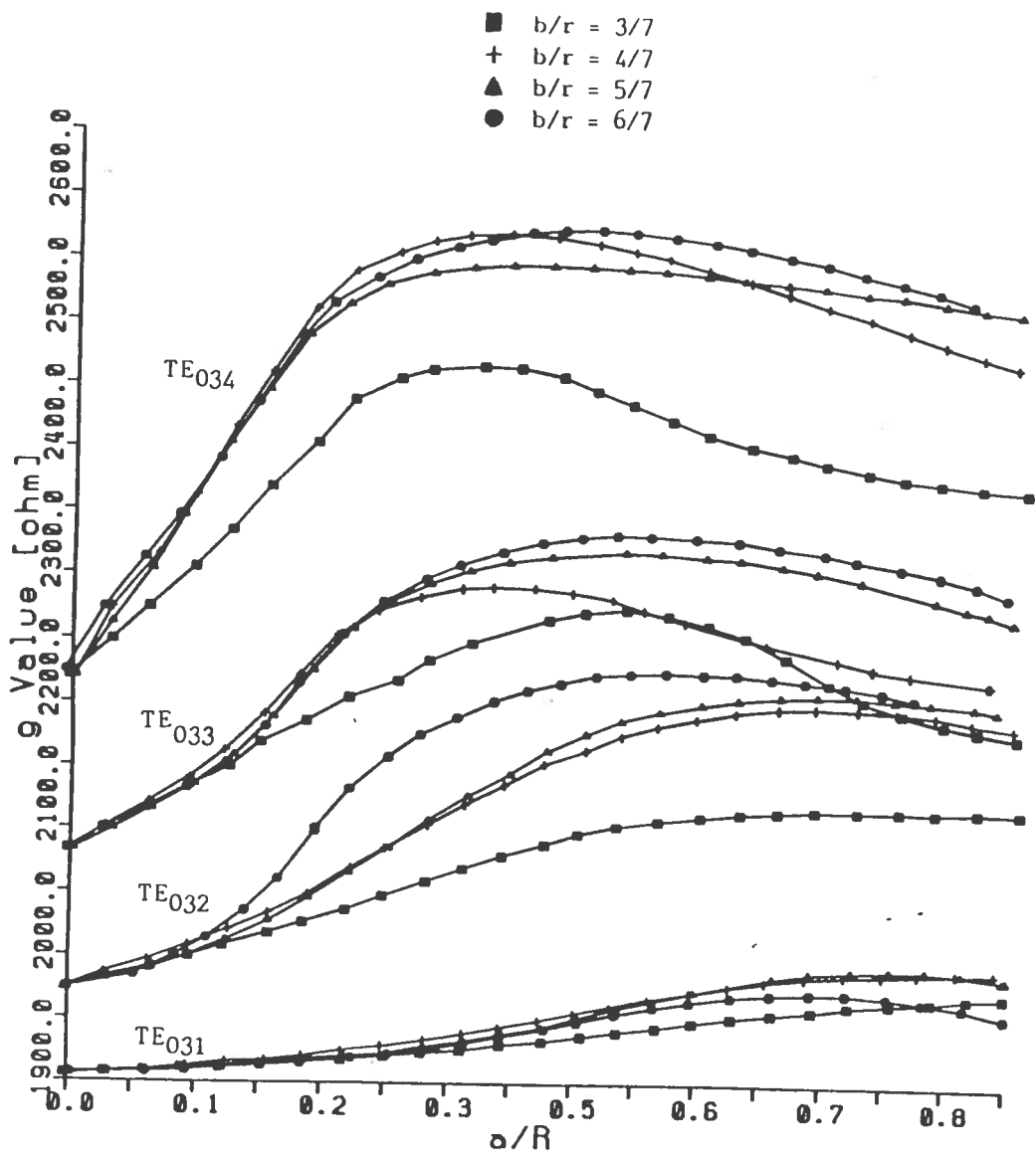


FIG. 8

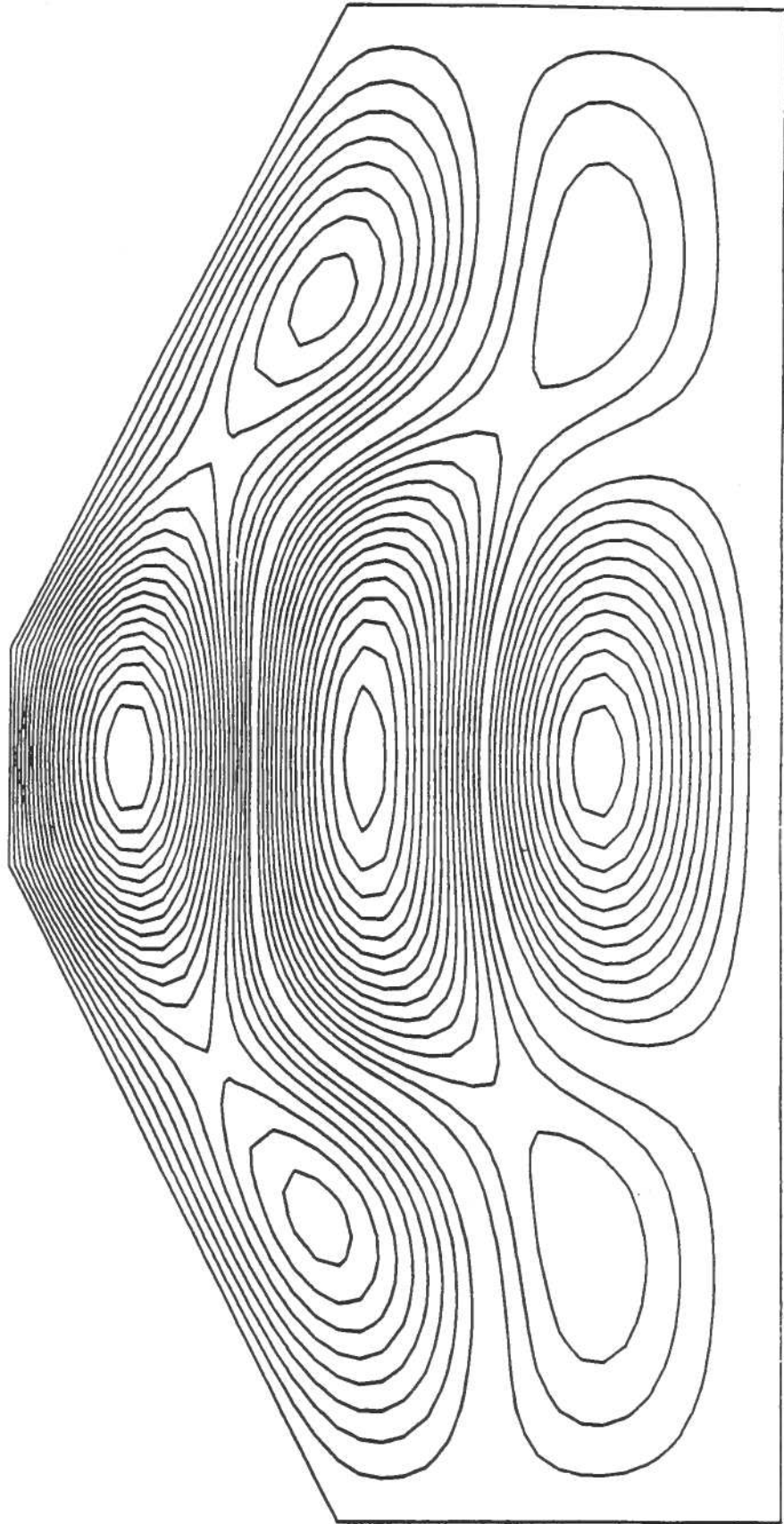


TABLE I

=====					
storage te modes		even dipoles	frequency	odd dipoles	frequency
=====					
storage frequency fo=2856 Mhz					
=====					
	Mhz		Mhz		Mhz
TE011	1187.61	1-EE-1	974.99	1-ME-1	689.19
TE012	1495.62	1-EE-2	1135.12	1-ME-2	1276.48
TE013	1759.57	1-EE-3	1556.53	1-ME-3	1438.54
TE021	2032.72	1-EE-4	1741.95	1-ME-4	1555.76
TE014	2061.07	1-EE-5	1859.18	1-ME-5	1746.16
TE022	2372.15	1-EE-6	1955.72	1-ME-6	2059.15
TE015	2375.59	1-EE-7	2045.36	1-ME-7	2172.94
TE023	2625.76	1-EE-8	2333.84	1-ME-8	2216.23
TE016	2688.59	1-EE-9	2533.81	1-ME-9	2352.23
TE031	2856.00	1-EE-10	2606.99	1-ME-10	2390.92
TE024	2910.40	1-EE-11	2714.25	1-ME-11	2632.27
TE017	2998.13	1-EE-12	2757.93	1-ME-12	2764.06
TE-13	3190.83	1-EE-13	2927.64	1-ME-13	2862.51
TE-14	3218.41	1-EE-14	3024.95	1-ME-14	3017.67
TE-15	3440.23	1-EE-15	3334.11	1-ME-15	3128.77
=====					