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# PARALLEL COUPLED CAVITY STRUCTURE*

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## Summary

A parallel coupled RF cavity structure which provides favorable solutions to all of the requirements for use in an $e^+e^-$ storage ring is described. Properties of this structure have been determined mathematically and through measurements on S-band models. An L-band prototype is being constructed and will be tested at high power.

## Introduction

An RF cavity structure suitable for use in Cornell's proposed CESR $e^+e^-$ storage ring must satisfy a number of requirements. These are summarized in Table I.

TABLE I STRUCTURE REQUIREMENTS

| |
|---|
| Operate at 500 MHz |
| Maximize shunt impedance in the available space (four spaces, 6 meters each) |
| Minimize number of separately powered modules |
| Avoid passband mode overlap |
| Minimize sensitivity of amplitude and phase to individual cell frequency errors |
| Obtain intrinsic thermal stability |
| Provide adequate cooling |
| Provide simple means for tuning the structure to compensate for loading by the beam |
| Provide sufficient loading of all important $TM_0$ and $TM_1$ modes to prevent cavity-induced instabilities |
| Minimize construction costs |
| Avoid transverse gradients in the longitudinal electric field |

## Description of the Cavity

We have developed a parallel coupled structure which satisfies all of these requirements well. Parallel coupled structures have been used previously[1], but exhibited substantially different properties from the present structure. Fig. 1 shows a perspective view of this structure, and Fig. 2 shows a side sectional view. The principal elements of the structure are fourteen cells, a coaxial coupling line, a waveguide-to-coaxial transition and quarter-wave transformer at one end of the coaxial line, and a notch filter and higher mode load at the other end of the coaxial line. Fig. 1 also shows the water tank in which the structure is housed. Fig. 3 shows the equivalent circuit of the structure. All cells, shown as R, L, and C, are effectively in series with the coupling line at half-wavelength intervals. The coupling iris adds an effective inductance L' in series with each cell.

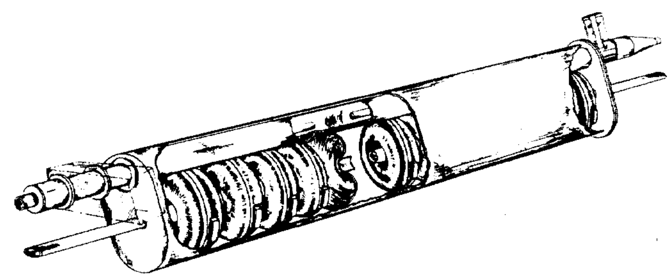

Fig. 1. Parallel coupled cavity structure, including water tank used for cooling.

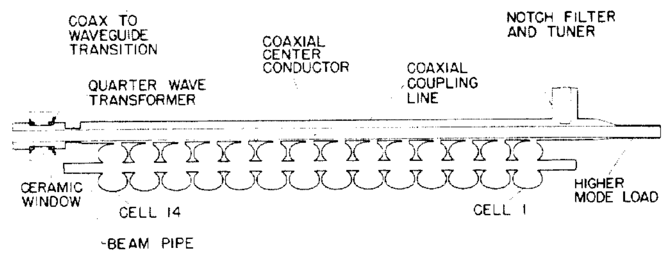


Fig. 2. Side sectional view of parallel coupled cavity structure.

## Cavity Properties

The principal properties of the parallel coupled structure are as follow. The shunt impedance is maximized through use of optimized cell shapes[2] and the use of copper. Only one feed point is used for all fourteen cells. Overlap of the modes in the passband, a common problem when many cells are incorporated in one π-mode cavity, is eliminated because there is only one mode in the passband. A single mode occurs because the power does not propagate serially through the cells in the usual fashion; other modes do occur in the coupling line, but their frequencies are sufficiently removed from the cell resonant frequency that a negligible fraction of the energy appears in the cells.

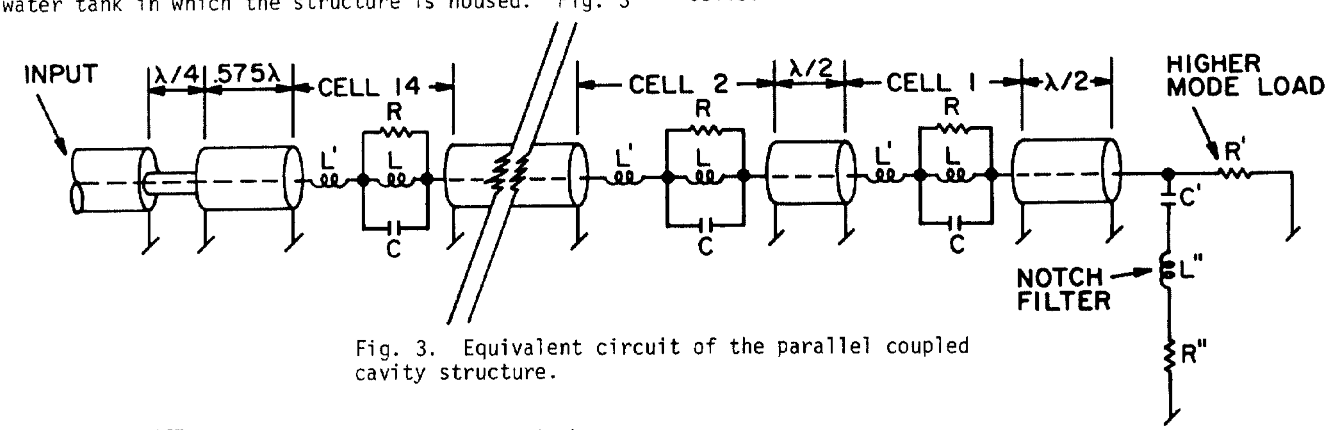


Fig. 3. Equivalent circuit of the parallel coupled cavity structure.

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Unlike previous parallel coupled structures[1] in which it was practical to have the cells effectively in shunt with the coupling line, the cells in this structure are effectively in series with the coupling line. As a result, the present structure does not have intrinsic stability against cell tuning errors. The cells behave almost independently, leading to a very poor cell-to-cell phase and amplitude variation with individual cell tuning errors. This problem is solved by using the coupling line to pull the resonant frequency of the structure. Stabilization by frequency pulling can be understood as follows: when the cells are operated at their resonant frequency, their high Q causes the magnitude and phase of their admittance to change rapidly with frequency; when the cells are operated several bandwidths off resonance, the unbalanced L and C dominate the admittance, and the magnitude and phase of the admittance become insensitive to frequency changes. The frequency pulling is controlled by the location of the quarter wave transformer which matches the input line to the structure. The structure frequency can be higher or lower than the cell resonant frequency. By making it higher than the cell resonant frequency, intrinsic thermal stability is achieved.

The notch filter closely approximates a short at the operating frequency. The tuning angle of the structure can be adjusted to compensate for variations in the beam loading by moving the tip of the center conductor of the notch filter parallel to the beam direction. This avoids the need for mechanical tuners in each cell.

Heavy coupling of all important $TM_0$ and $TM_1$ higher modes into the coaxial coupling line is achieved by use of a suitable size and location of the coupling iris, and through use of a pair of protuberances on each cell. The protuberances serve two functions. They control the polarizations of each pair of $TM_1$ modes so that both polarizations are heavily coupled to the coaxial line. They also compensate for the vertical gradient in the longitudinal accelerating field caused by the presence of the coupling iris. Averaged over any adjacent pair of cells, they yield no net horizontal gradient in the longitudinal accelerating field. Higher modes, which propagate in the coupling line in waveguide as well as coaxial modes, pass the notch filter and are absorbed in the higher mode load. Comparison of the measured coupling strengths of the higher modes into the coaxial line with theory[3] indicates that all higher modes are sufficiently damped that they will not cause either longitudinal or transverse instabilities. Properties of the higher modes are shown in Table II.

TABLE II HIGHER MODE PROPERTIES

| Mode | Freq. MHz | Measured Coupling β | Minimum Required Coupling β |
|---|---|---|---|
| $TM_{010}$ | 500 | 26.5 | - |
| $TM_{011}$ | 779 | 18.5 | 3.23 |
| $TM_{110}$ | 871 | 64.94 | 1.68 |
| $TM_{020}$ | 1131 | >234 | None |
| $TM_{111}$ | 1138 | 6.50 | 1.79 |
| $TM_{022}$ | 1356 | 15.6 | None |
| $TM_{120}$ | 1625 | 6.50 | None |

## Modeling

The behavior of this cavity has been studied numerically using the equivalent circuit shown in Fig. 3. This is done by assuming a particular current at the notch filter and solving along the coupling line until a value for the input current is found; all currents are then renormalized to unit input current. The validity of the model has been verified by measurements made on S-band models of the structure. The sensitivity of the structure to various errors has been determined using the equivalent circuit and also, where feasible, using the S-band model. The results of this study, and some other parameters, are shown in Table III.

TABLE III CAVITY PROPERTIES

| | |
|---|---|
| Cavity frequency | 499.7615 MHz |
| Cell frequency | 499.0000 MHz |
| Cell shunt impedance $ZT^2/Q$ | 884Ω/m |
| Cell $Q_0$ (at 20°C) | 31700 |
| Cell shunt impedance $ZT^2$ | 28.0 MΩ/m |
| Cavity shunt impedance $ZT^2$ | 27.1 MΩ/m |
| Number of cells | 14 |
| Cavity length | 4.20 m |
| Mode | π |
| Cavity shunt impedance $ZT^2L$ | 114 MΩ |
| Total CESR shunt impedance | 456 MΩ |
| Coupling of cells to line (β) | 26.5 |
| Effective coupling hole reactance | 6.75jΩ |
| Fractional p-to-p field amplitude error due to systematic cell spacing error (worst case) | .041 $mm^{-1}$ |
| Fractional field amplitude error per unit fractional error in cell β ($Q_0$ fixed) | 1. |
| Fractional field amplitude error per unit fractional error in cell $Q_0$(β fixed) | -1. |
| Fractional field amplitude error due to cell frequency error (This is equivalent to an intercell coupling factor k = .069 for a linearly tilted error distribution in a conventional π-mode cavity) | .00126 $kHz^{-1}$ |
| Cell phase error due to cell frequency error | .0124 mrad/kHz |
| Displacement of notch filter short required to change tuning angle from 0° to -45° at an input β of 4.22 | ± .95 cm |
| Fractional p-to-p field tilt, no perturbations | .0000193 |
| Phase shift error, end-to-end, no perturbations (this is 415 times smaller than that of a conventional end-fed π-mode structure having the same $Q_0$ and having k = .10) | .000258 radians |

The structure exhibits some rapid variation in impedance as a function of frequency near the cell natural frequency, but there are no true resonances associated with this phenomenon, and hence there are no problems caused by this behavior.

## Prototype Construction

A method of construction has been chosen which minimizes material usage and machining, and provides excellent cooling. Half cells are formed from 6.4 mm copper sheet by stamping with a force of $3.1 \times 10^6$ newtons (350 tons). Two protuberances and a coupling iris are then electron beam welded to one of each pair of half-cells, and drift tubes are beam welded into the beam holes. A pair of half cells is shown in Fig. 4.

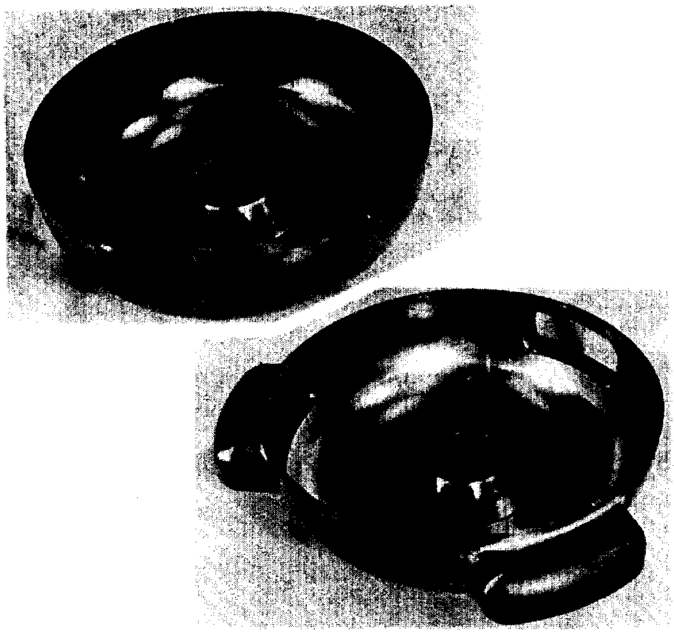

Fig. 4. Pair of half cells, with drift tubes beam welded to noses, and protuberances and coupling irises beam welded to one of the two half cells.

After a pair of half cells has been welded back-to-back to a common drift tube, coarse tuning is performed by machining the cell noses. Full cells are then formed by MIG welding half cells together, using silicon copper wire. The bottom of the coupling line outer conductor is attached to the coupling irises by brazing using a TIG torch with silver-copper eutectic wire. The remainder of the outer conductor, a portion of which is shown in position in Fig. 5, is MIG welded to the lower portion.

Copper plated stainless flanges, brazed to the coupling line, will be used to attach the notch filter, higher mode load, quarter wave transformer, and coax-to-waveguide transition. Fine tuning is accomplished with external side bars, seen in Fig. 5.

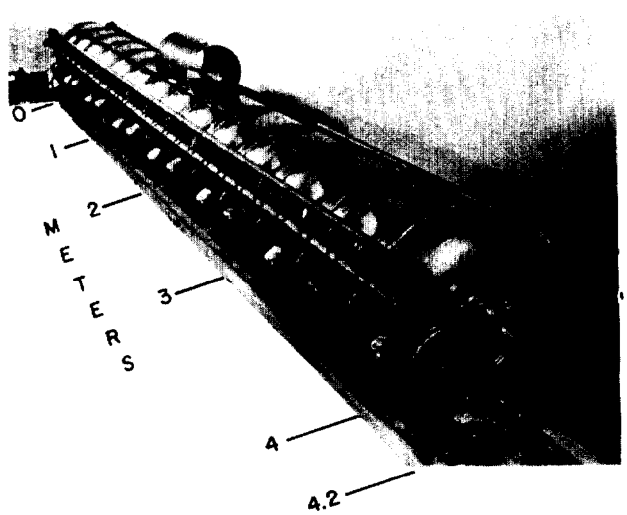


Fig. 5. 500 MHz prototype. Partially assembled fourteen cell parallel coupled structure in position on its welding jig. Protuberances are visible on the lower half of each cell, and stiffening and tuning bars are visible along upper halves of cells. The lower portion of the coupling line is welded to the coupling irises, and a short length of the upper portion of the coupling line outer conductor is shown in position (for purposes of illustration).

Cooling will be provided by inserting the structure in a water tank, shown in Fig. 6. Some end components, which protrude from the tank, have separate water jackets. A 63 liter per second (1000 gpm) pump and heat exchanger will be used to circulate and cool the water.

Initial high power testing will be performed using a 250 kW klystron. Four cavities, each having fourteen cells and each powered by a 500 kW klystron, are planned for use in CESR.

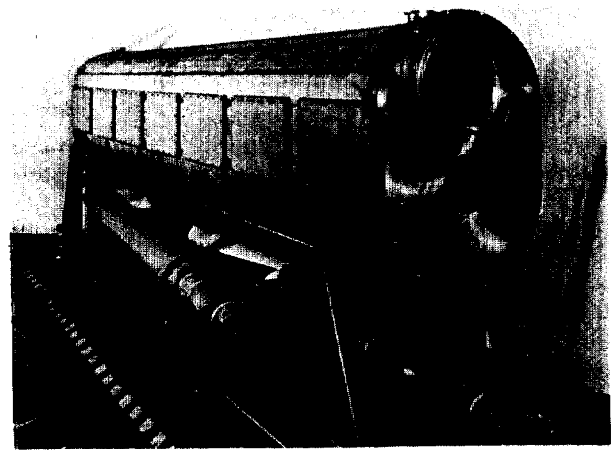

Fig. 6. Water tank for 500 MHz prototype structure. The heat exchanger and 63 liter per second water pump are mounted below the tank. The cavity structure, while under vacuum, can be inserted into the water tank. The beam pipe and coupling line emerge through the flanges at each end of the tank.

## Conclusion

The parallel coupled structure exhibits a number of significant advantages for use in an $e^+e^-$ storage ring. Most important among these are its strong cell coupling, single passband mode, insensitivity to individual cell tuning errors, simple means for dynamic mechanical tuning, simple means for adequately damping all higher modes, intrinsic thermal stability, and good cooling of all RF surfaces. The RF properties of the structure, studied using the model described, are in excellent agreement with S-band measurements. Construction of a 500 MHz prototype cavity is almost completed, and high power testing will begin in the near future.

## References

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