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CROSSBAR AND CLOVERLEAF STRUCTURES AT RUTHERFORD

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For the last couple of months we have not done any new work on structures because of the work on the design of our new Tank 1 for the P.L.A. Consequently, I'll go over the paper I wrote for the Dubna Conference. We are considering two possible projects. One is a linac injector for a 300 GeV machine at CERN, and the other is a possible pion factory. The essential difference between the two is one of duty factor and beam intensity. In the case of a pion factory, we think in terms of a few milliamps, but in the case of the injector we are thinking of as much as 200 milliamps. We are most concerned with the linac at energies above 200 MeV, for I think there's no question that the Alvarez structure is quite efficient up to that energy.

The kind of requirements that we have for the linac are (1) efficiency, as measured by the effective shunt impedance, (2) field tolerances, both rf and mechanical, (3) freedom from spark breakdown, (4) ease of manufacture, (5) particle dynamics, (6) measurement and calibration, (7) radial focussing. The last requirement is no longer a difficult one in terms of structures, because of the suggestion of Lloyd Smith for inter-tank focussing. We don't have to go to drift tube structures, in order to put quadrupoles inside the drift tubes.

To satisfy these criteria, what frequency and mode should we operate on? If we use the economic criterion that Dr. Wheeler stated in the Yale Y-6 report for the pion factory, then we obtain a frequency in the range of 400 to 800 Mc/sec for the region of structures above 200 MeV, and an acceleration rate of the order of 2 to 3 MeV/m. It happens that in this range of frequencies, we also satisfy most of the dynamical requirements in terms of tolerances on injection, phase trapping, phase and radial coupling and the rest.

It is pretty clear that we'll operate in π-mode, rather than in the travelling wave mode, for the following reasons: in a linac consisting of many tanks, one must control the phases and amplitudes of the individual tanks very accurately. We can do this in a standing wave tank, particularly a π- mode tank (if the tank is not too long) providing αL is small, where α is the attenuation constant and L the length of the tank. We are thinking in terms of αL of the order of 0.2 to 0.3. If this is true, then there is very little phase or amplitude change along the length of the tank. We then consider each tank to be a single resonator so we can control amplitude and phase by a single device. In the case of the travelling wave tank there is a phase change along the structure as well as a field change which makes control very complicated. Also, in a standing wave tank, the main effect of beam loading is to decrease the field amplitude and this can be controlled, for example, by choice of the right feed point, and control of the amplitude of the pulse. In the travelling wave case, there is also beam loading, but it varies along the tank. The reactive detuning of beam loading also varies along the tank, and all these add extra complications in terms of feed and control mechanisms.

So we are seeking structures of 400-800 Mc/sec frequency, operating in the π-mode. One can show, by treating the π-mode structure as a coupled system that, if the structure has small loss, then the propagation constant per unit length is $\theta = \alpha + j\beta$ and

$$\ell\beta = (Q_\pi K)^{-1/2} \text{ , and}$$

$$\ell\alpha = \pi - (Q_\pi K)^{-1/2}$$

where ℓ is the periodic length and K is the bandwidth, here defined as

$$K = \frac{2|\omega_\pi - \omega_o|}{(\omega_\pi + \omega_o)} \quad .$$

Q_π is the Q-value at π-mode. Keeping αL small then obviously requires that K, or Q_π or both, be large. It can be shown, that at a frequency of the order of 400 Mc/sec, one wants K to be of the order of 20%. We also require a high value for Q_π. When we couple two cavities together, we want the π-mode to be the unperturbed mode, for then, Q_π is greatest.

We have looked at three possible structures. The first is the disk-loaded structure, which was a copy of the "Stanford Guide", in order to check shunt impedance at phase velocities less than c. Figure 1 shows the shunt impedance of the disk-loaded guide. One curve uses measured values of Q, the other uses the theoretical values. For both curves, the values are not quite realistic because the technique of measuring Q-values depends on the fact that by taking measurements on two structures, one can eliminate the end plate loss. In the case of the $2\pi/3$ mode, one takes 2 plus 2 halves, then 5 plus 2 halves, and so on, to determine this loss. In this particular case, the Stanford people appear to have measured only 2 plus 2 halves and thus the Q is going to be rather low because of the undetermined end plate loss. On the other hand, the theoretical Q curve used was for simple pillbox cavities tied together with no coupling holes. So one is too low, and the other too high. We tried to measure this waveguide in the laboratory and we got points just between the two. In this work we define shunt impedance to be the ratio of the square of the amplitude of the synchronous harmonic divided by the total power loss due to the total travelling wave.

Other structures we looked at were the Cloverleaf, which, as can be seen in Fig. 1, is better than the disk-loaded waveguide; and the Crossbar π-mode structure, which is spectacularly better at low velocities than the disk-loaded waveguide. The Alvarez structure on the plot is a scaled version of one which we have designed as a possible extension to the P.L.A. All shunt impedances are scaled to 2856 Mc/sec, which is the operating frequency of the Stanford Guide. This is not to say that all these structures would necessarily work at this frequency. Certainly the Crossbar structure would be much too small because the beam coupling hole would be a millimeter or so in diameter.

The disk-loaded waveguide, which has the obvious advantage of being geometrically very simple, has a bandwidth of the order of about 1 1/2%, which is too small for practical

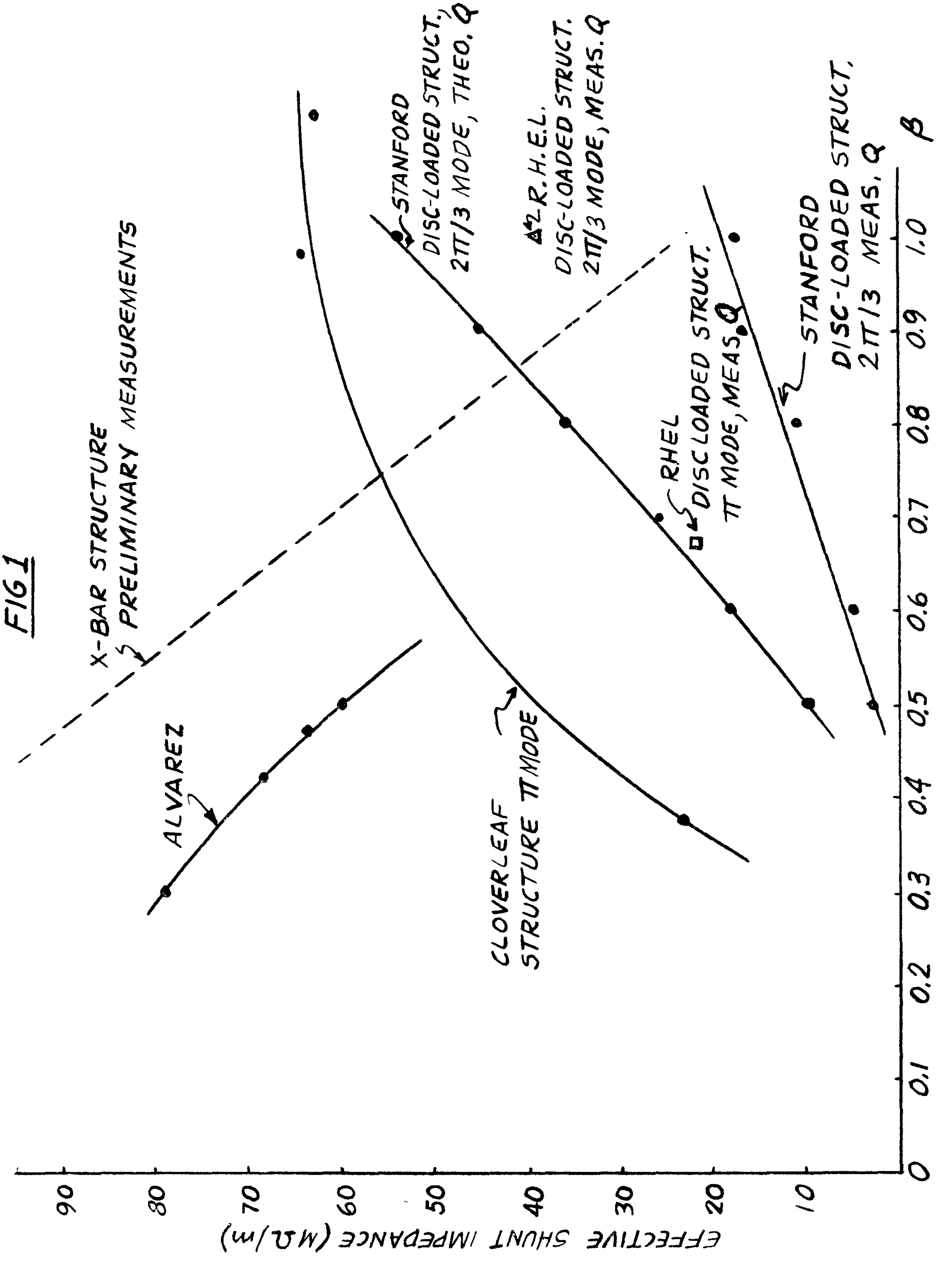
FIG 1
X-BAR STRUCTURE
PRELIMINARY MEASUREMENTS
ALVAREZ
CLOVERLEAF
STRUCTURE π MODE
STANFORD
DISC-LOADED STRUCT.,
2π/3 MODE, THEO. Q
R.H.E.L.
DISC-LOADED STRUCT.
2π/3 MODE, MEAS. Q
RHEL
DISCLOADED STRUCT.
π MODE, MEAS. Q
STANFORD
DISC-LOADED STRUCT.
2π/3 MEAS. Q
β
EFFECTIVE SHUNT IMPEDANCE (MΩ/m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
10
20
30
40
50
60
70
80
90

use. One can improve the shunt impedance by reducing the diameter of the central coupling hole, but to do this results in the rapid increase in the attenuation of the guide. The problem is to increase the coupling in the structure by some other means, and the Cloverleaf is one of the ways of doing it, as shown in Fig. 2. One cavity is defined between the coupling plates and has four "nose cones" projecting into it as shown, to distort the azimuthal magnetic field into the Cloverleaf pattern. If we rotate adjacent cavities by 45° we can arrange things so that the phase of the rf magnetic field is changed by 180° between adjacent cavities in the 0-mode. One cavity of the Cloverleaf has four nose cones and eight slots. The magnetic field is distorted into the Cloverleaf pattern, so that in a given cavity the current travels at right angles to a slot. In the next cavity, in the 0-mode, since it is turned 45° on the other side of this coupling plane (as defined by the plane of the paper in Fig. 2), the currents must go round the slots. This increases the inductance of the cavity and lowers the resonant frequency. In the case of the π-mode, the currents on either side of the slot are in antiphase so the current will go from one cavity through the slot into the next cavity. The inductive effect of the slot is almost zero, so that the π-mode is unperturbed. This is what we are seeking because it gives a high Q-value. We can write down the equivalent circuit of the Cloverleaf, albeit a crude one. It can be seen in Fig. 3a that each cavity of the Cloverleaf is shown as the usual L-C circuit, and coupling between cavities will be done by slots which will themselves have a resonance.

This particular representation is not very good because

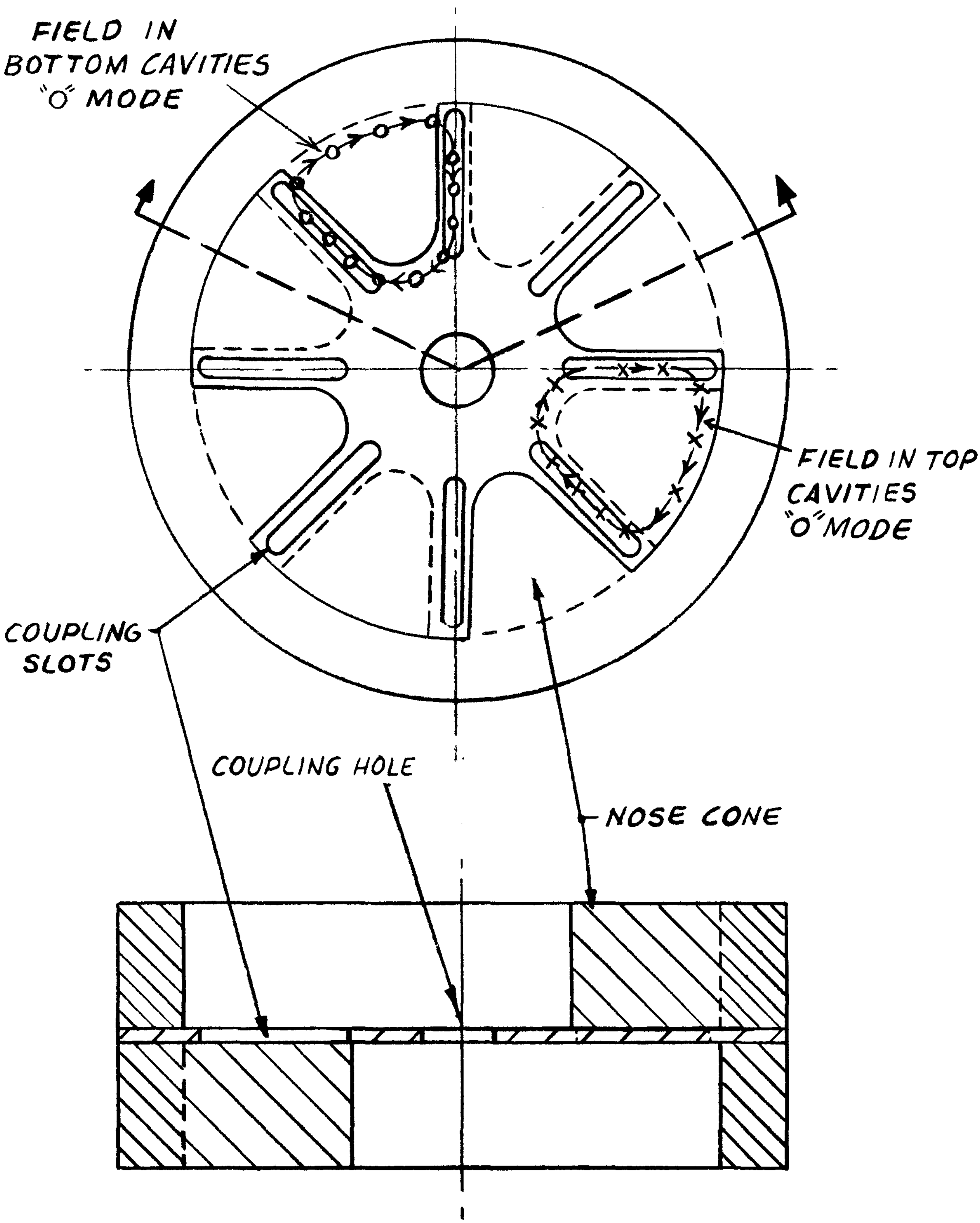
FIELD IN
BOTTOM CAVITIES
"O" MODE
FIELD IN TOP
CAVITIES
"O" MODE
COUPLING
SLOTS
COUPLING HOLE
NOSE CONE

FIG. 2

it assumes that all the cavity coupling is through the slots. We can improve it by using instead the equivalent circuit shown in Fig. 3b. The inductance $L_{1/2}$ in Fig. 3a is replaced by the two inductances $NL_{1/2}$ and $(N/N-1)L_{1/2}$ of Fig. 3b, where now approximately $1/N^{th}$ of the circulating current links the slots

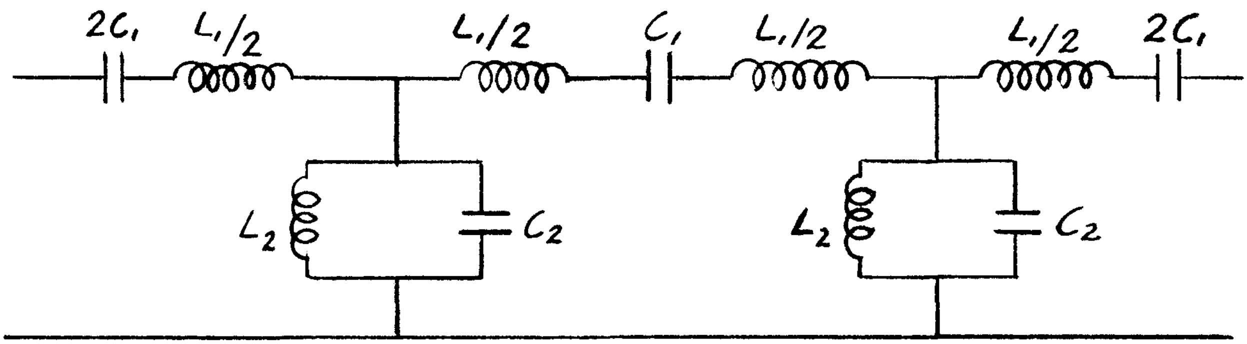

FIG. 3A

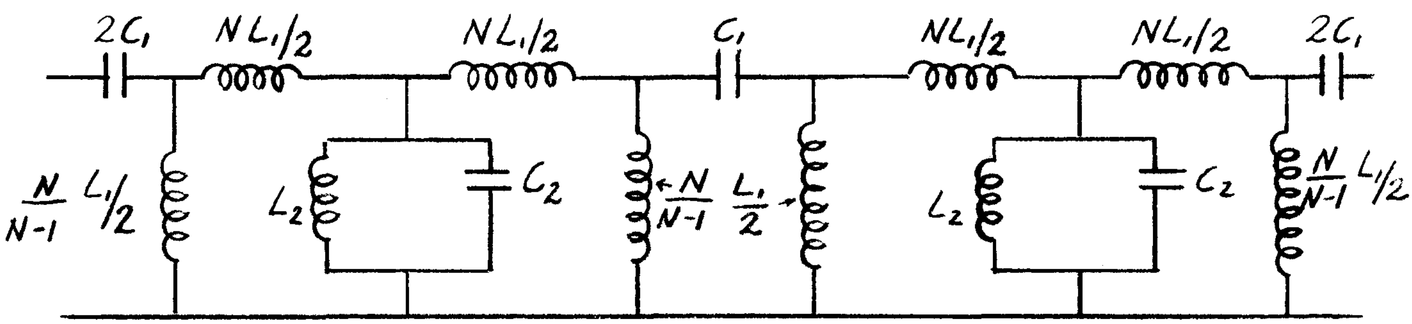

FIG. 3B

From Fig. 3b, we can write down the following phase equation:

$$\cos \varphi = -1 - \frac{1}{2K} \left(1 - \frac{1}{\omega_o^2}\right) \left(1 - \omega_o^2 R^2\right)$$

where K is a constant and is a function of N, (1/N is the fraction of the circulating current coupled through the slots); R is the ratio of cavity resonance to slot resonance ω_c/ω_s, and ω_o is the "reduced cavity frequency", ω/ω_c. All the terms of the right-hand side of the equation are negative because of the phase change of 180^o produced by turning adjacent cavities through 45^o.

From this equation we get three conditions. When $R < 1$, we have two separate passbands, when the slot resonance is well removed from the cavity resonance itself. At π-mode, when $R = 1$, the slots have the same resonant frequency as the cavity, and the two passbands become "confluent". This is the kind of thing that Dunn was doing when he used loop coupling. The main advantage in this case is that it has a practically linear phase characteristic at π-mode, so that we have the advantage of π-mode operation with the wide tolerances usually associated with $\pi/2$ mode operation. The main disadvantage is that we are now critically concerned with the dimensions of the slots, because they're now resonant, and therefore, voltage breakdown might occur in the slots themselves. This was a major disadvantage of the loop coupled structure: that the breakdown qualities of that structure were likely to be poor. When one has $R > 1$, where there is some point of the fundamental passband at which the slots become resonant, we obviously can see that the slots become capacitative instead of inductive. This has the effect of pushing down the π-mode resonant frequency, and hence, of reducing the passband.

There are many possible variations to the geometry of the Cloverleaf structure. For example, one can change the dimensions of the coupling slots, beam aperture, and so on. Figure 4 shows the effect on bandwidth of changing the slot length. Because it's the unperturbed mode, the various structures have the same π-mode frequency to within a few Mc/sec. As the slot length is increased, the resonant frequency of the 0-mode is pushed down, while at the same time the bandwidth increases. As can be seen, the ω-β curve gets steeper and straighter in the region of the π-mode. Ultimately, slots of sufficient length become resonant at π, and we would then have a straight ω-β curve across the π-mode region itself. Figure 5 shows the effect of varying the slot width which is much smaller. The thing which really determines slot width is now the voltage breakdown characteristic; the wider the slots, the lower the probability of breakdown. Figure 6 shows the variation of bandwidth as a function of periodic length. In both cases the π-mode has the same frequency. Now, in all the structures shown in Figs. 4, 5 and 6, we have used a coupling hole of the order of 1/2 in., and this will certainly be large enough when scaled up to 800 Mc/sec. The hole size itself has little effect on the passband of the structure, but variation of the size of the hole will modify slightly the π-mode frequency. Figure 7 is a geometric mesh showing the effect on frequency and phase velocity due to variations in the coupling hole and periodic length. The geometric mesh indicates a way by which phase velocity in the structure can be adjusted. There is clearly going to be some value of coupling hole size, where the D = const. curve is going to be parallel to the β-axis. From the point of view of manufacture this is very convenient, because it means that one

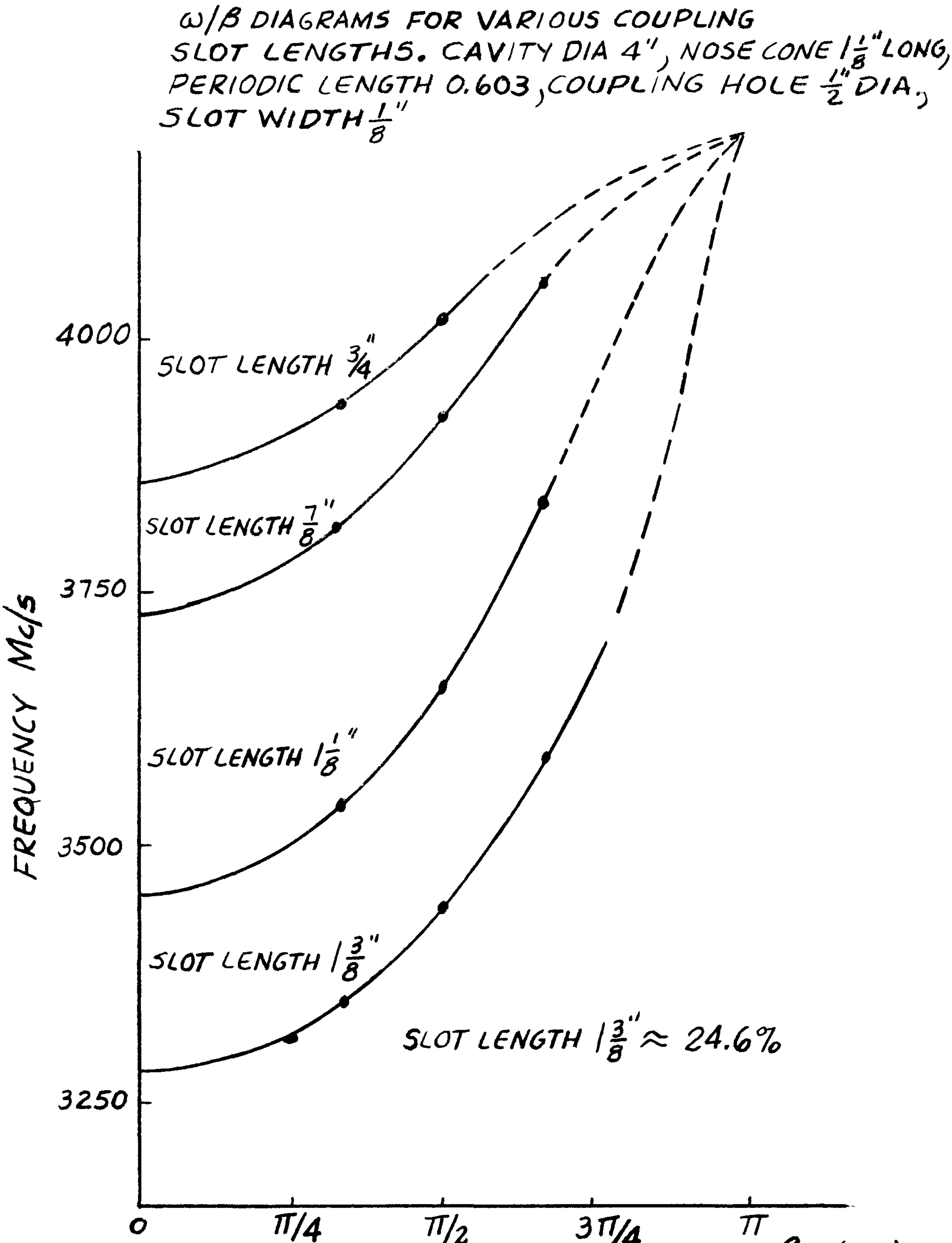
ω/β DIAGRAMS FOR VARIOUS COUPLING SLOT LENGTHS. CAVITY DIA 4", NOSE CONE 1 1/8" LONG, PERIODIC LENGTH 0.603, COUPLING HOLE 1/2" DIA., SLOT WIDTH 1/8"
FREQUENCY Mc/s
4000
3750
3500
3250
SLOT LENGTH 3/4"
SLOT LENGTH 7/8"
SLOT LENGTH 1 1/8"
SLOT LENGTH 1 3/8"
SLOT LENGTH 1 3/8" ≈ 24.6%
0
π/4
π/2
3π/4
π
βL (RAD)

FIG. 4

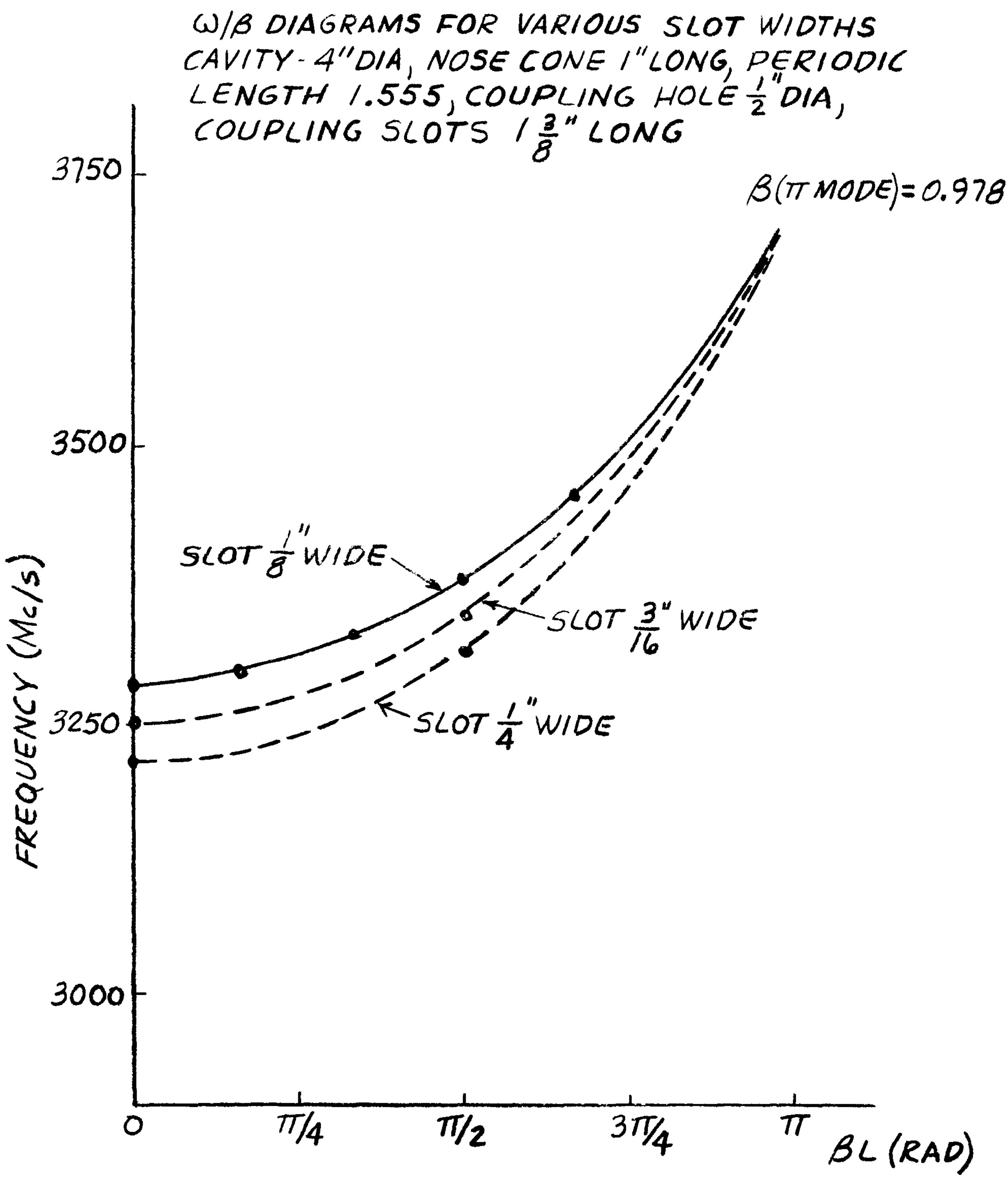
ω/β DIAGRAMS FOR VARIOUS SLOT WIDTHS
CAVITY - 4" DIA, NOSE CONE 1" LONG, PERIODIC LENGTH 1.555, COUPLING HOLE 1/2" DIA, COUPLING SLOTS 1 3/8" LONG
3750
3500
3250
3000
FREQUENCY (Mc/s)
β(π MODE) = 0.978
SLOT 1/8" WIDE
SLOT 3/16" WIDE
SLOT 1/4" WIDE
0
π/4
π/2
3π/4
π
βL (RAD)

FIG. 5

ω/β DIAGRAMS FOR VARIOUS PERIODIC LENGTHS
CAVITY DIA 4", NOSE CONE 1" LONG, COUPLING
HOLE DIA $\frac{1}{2}$", COUPLING SLOTS $1\frac{3}{8}$" × $\frac{1}{8}$"

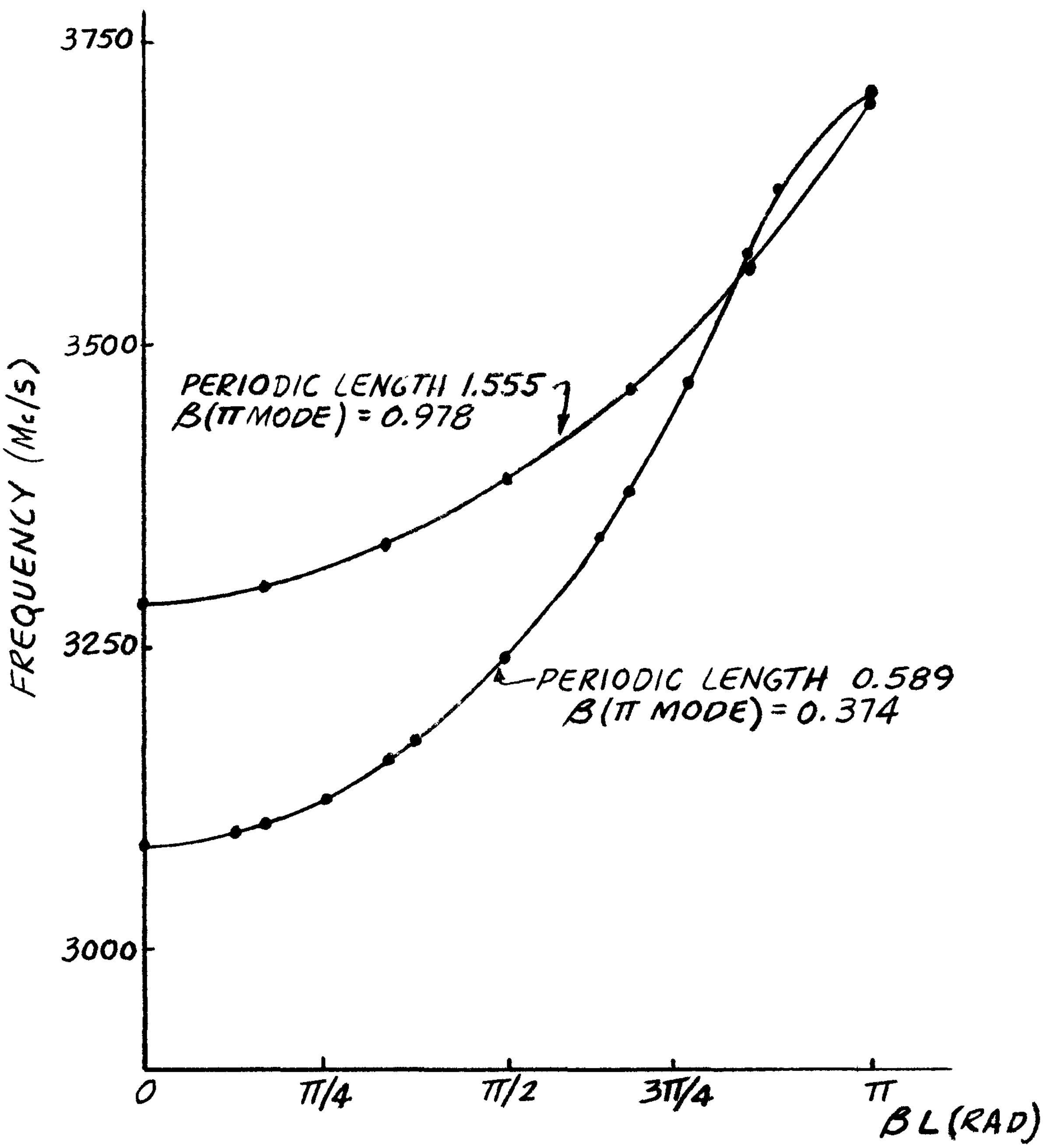

FIG. 6

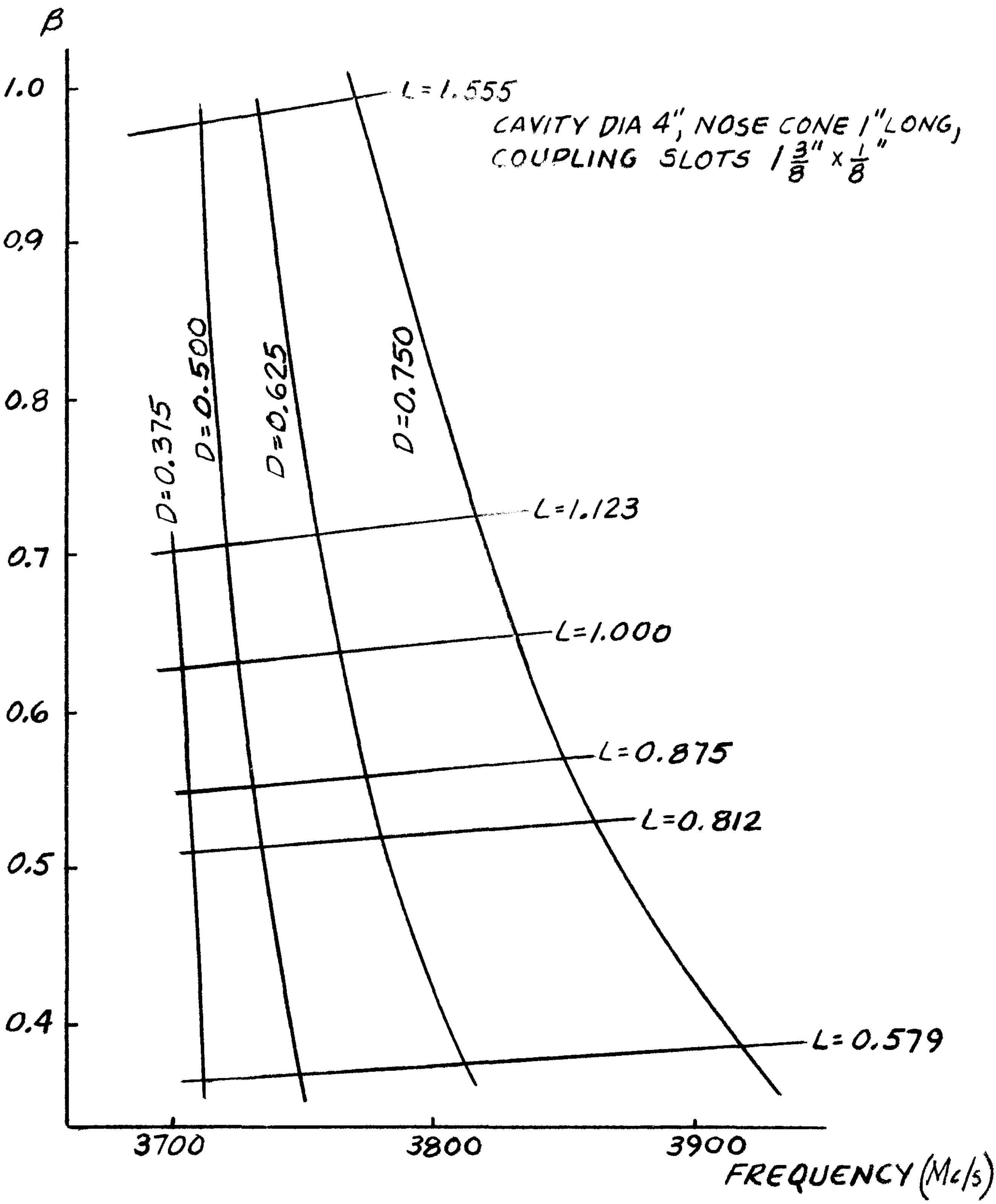
β
1.0
0.9
0.8
0.7
0.6
0.5
0.4
3700
3800
3900
FREQUENCY (Mc/s)
L = 1.555
CAVITY DIA 4", NOSE CONE 1" LONG,
COUPLING SLOTS 1 3/8" x 1/8"
D=0.375
D=0.500
D=0.625
D=0.750
L=1.123
L=1.000
L=0.875
L=0.812
L=0.579

FIG. 7

can change phase velocity by simply changing the periodic length of the structure, and the geometry of the coupling planes is unchanged. I think this is a feasible method of construction. At 800 Mc/sec, where the structure is about 14 in. in diameter, one could probably extrude the nose cones of aluminum, and copper plate them. The coupling plates could be stamped out from copper sheet. The sections could then be clamped together to complete the structure. With the geometry as given, we find that at $\beta \simeq 0.5$ at 400 Mc/sec, the shunt impedance is 14.6 MΩ/m, Q is 23,000 and the bandwidth is 16.5%. At $\beta \simeq 1$ for 400 Mc/sec, the shunt impedance is 24 MΩ/m, Q = 26,000 and the bandwidth is 12%. The bandwidth was found to be roughly linear with the phase velocity.

The other structure we have been looking at is the Crossbar, where again there is a possibility of having a very wide bandwidth. The Crossbar structure is a circular waveguide with drift tubes and bars set alternately at right angles, as shown in Fig. 8a. The actual field patterns inside the structure at π-mode are such that the magnetic field lines are grouped around alternate ("horizontal") bars and, in this case, the vertical bars carry virtually no current, but are just "sky hooks" to hold the drift tubes.

I have a simple description of the build-up of the Crossbar structure that is probably worth giving. We start by assuming a parallel plane waveguide, with parallel bars. In the 0-mode, the electric and magnetic fields are distributed as in Fig. 9a. In the π-mode, the fields are shown in Fig. 9b where the magnetic field is in loops. Now we

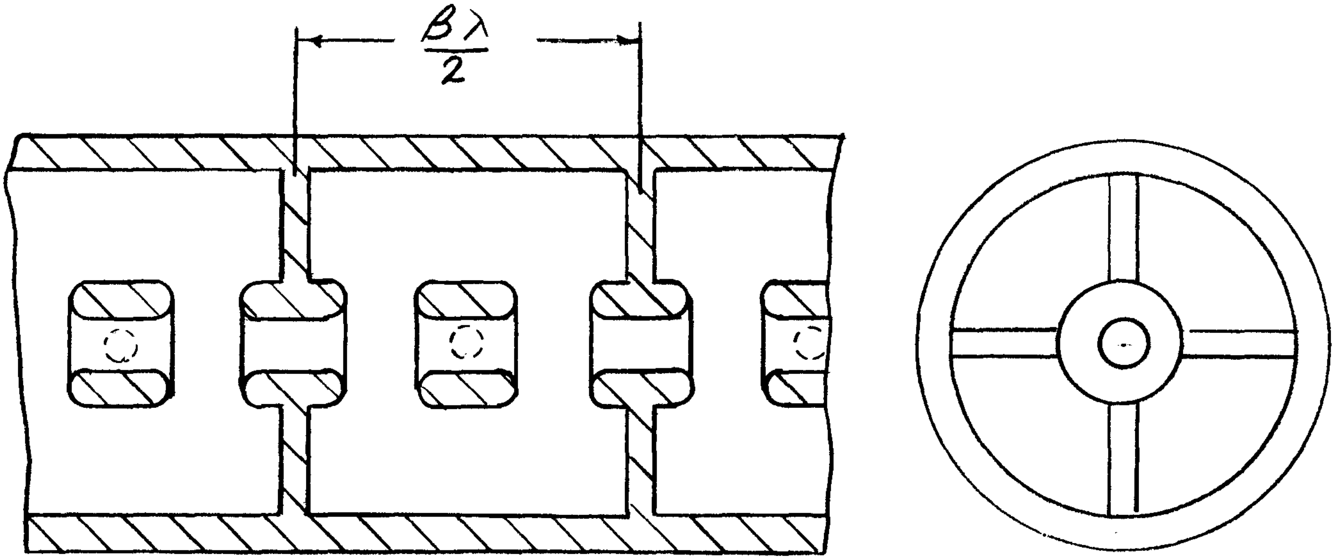

FIG. 8A

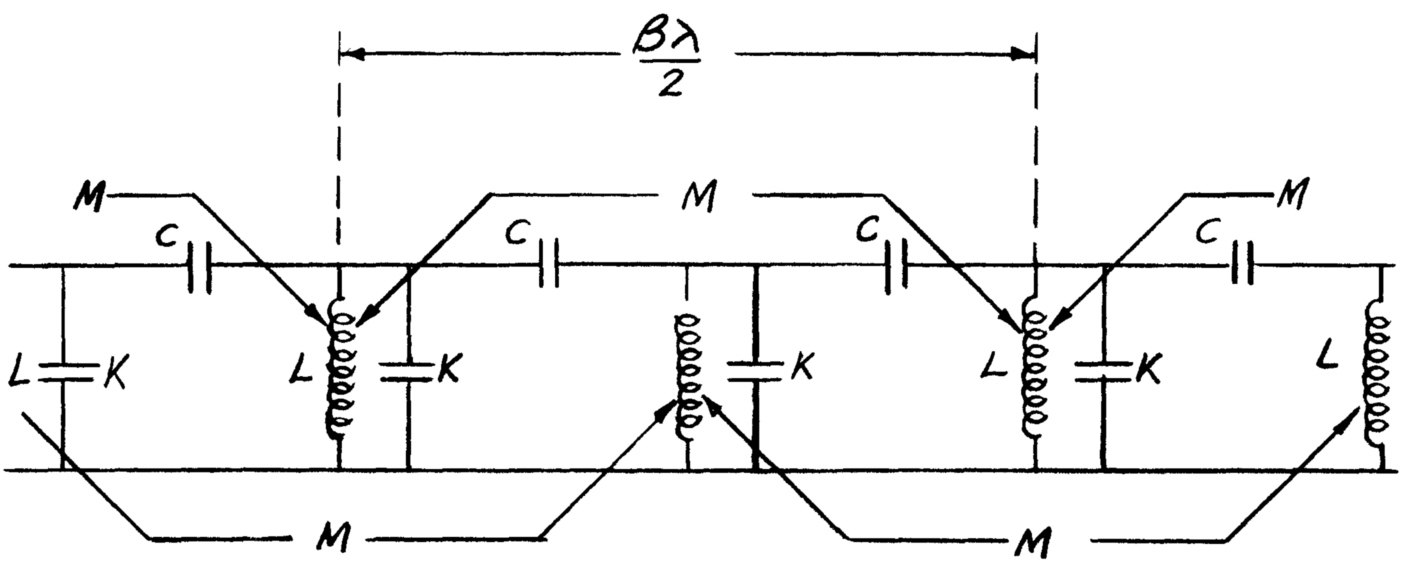

FIG. 8B

can find the 0- and π-mode resonances by inserting planes in mid-gaps at right angles to the paper: these are imaginary in the case of 0-mode and real, conducting planes in π-mode. In either case, the wavelength at resonance is going to be of the order of twice the length of the bars, consequently in the first instance, one does not expect to find a passband (see Fig. 10a). Now if we chop the corners off this rectangular waveguide to make a circular guide, as in Fig. 9c, the inductive effect is going to be greater in 0-mode than in π-mode because it is going to be filled much more. The passband will now have the appearance shown in Fig. 10b. If we put in drift tubes, we capacitatively load the π-mode much more than the 0-mode. Now the structure has a passband as sketched in Fig. 10c. With additional drift tubes and bars put in the mid-planes at right angles to the original bars, the inductive loading due to the new bars will be quite small in the π-mode, but the capacitative loading will lower the π-mode frequency even more. The passband becomes even wider, and we eventually get the passband of the order of 60% that we have found. Only the set of horizontal bars is really carrying large currents.

Figure 8b shows the equivalent circuit which was taken from an original report on the structure called "Jungle Gym" which consisted of meshes of pairs of wires at right angles to each other. In this particular representation that we call the π-mode, there is a $\pi/2$ mode for the equivalent circuit. This raises the possibility of actually taking the structure beyond the π-mode (in that notation).

The structure we have tested is a 400 Mc/sec model of

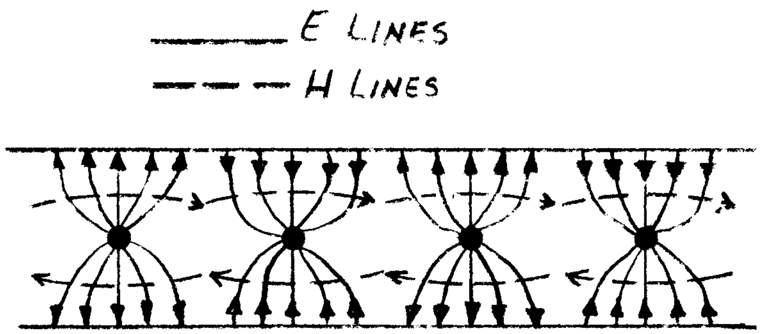

FIG. 9A- "O" MODE

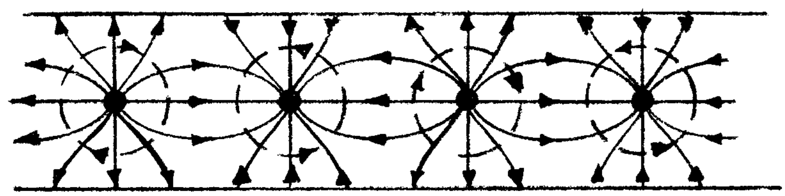

FIG. 9B π MODE

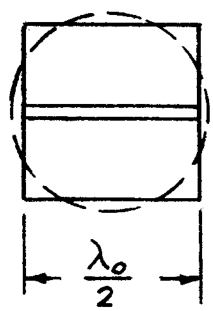

FIG 9C

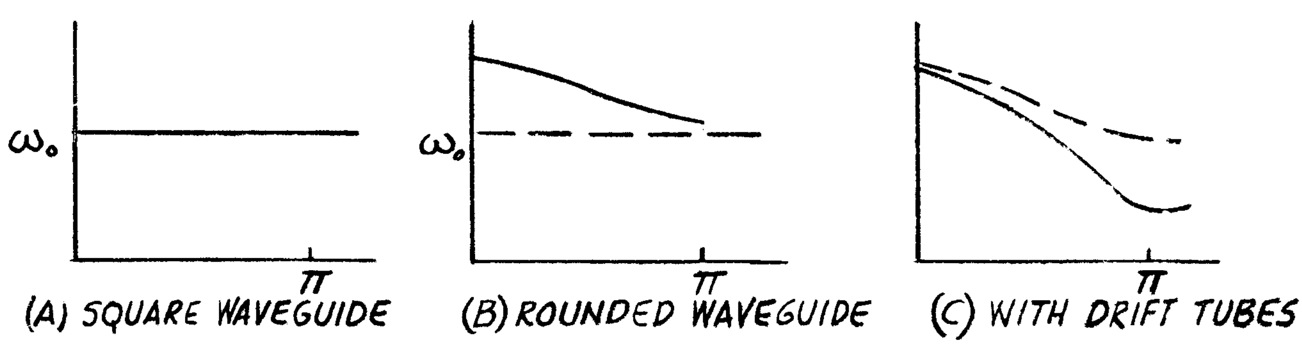

FIG. 10

the Crossbar, about 12 in. in diameter, giving a π-mode frequency near 400 Mc/sec. We chose the drift tube profiles to give a reasonable field breakdown characteristic, and we hope to be able to maintain fields of the order of 2 to 3 MV/m if necessary. The radii of curvature were taken from the Alvarez design of an early proposed Harwell accelerator. The beam hole diameter is set sufficiently large to permit a beam to drift through a tank of the order of 5 or 6 m long and also to allow for possible small misalignments of the quadrupole doublets between tanks (of the order of about 0.3 mm). We think the present drift tube bore is probably a little too small, and we want to increase this.

Figure 11 shows a velocity-frequency mesh, with dimensions. We have taken measurements on this structure denoted by "A" in the figure, with a gap of the order of about 1 in. and periodic length, L, about 7 in. (at 400 Mc/sec). We found a bandwidth of about 58%, which eases tolerance problems in the structure. At 400 Mc/sec we get a shunt impedance of 34 MΩ/m.

One of the interesting things about the Crossbar structure is that the fundamental harmonic amplitude is quite large, giving a good shunt impedance, but so is the first harmonic, which makes this structure rather inefficient from this point of view.

Figure 12 shows the ω-β diagram for the Crossbar structure for which the π-mode phase velocity β is roughly 0.5, and where we have a bandwidth of about 58%. It is interesting that we can actually get beyond π-mode in this structure, when every bar acts as its own resonator. The

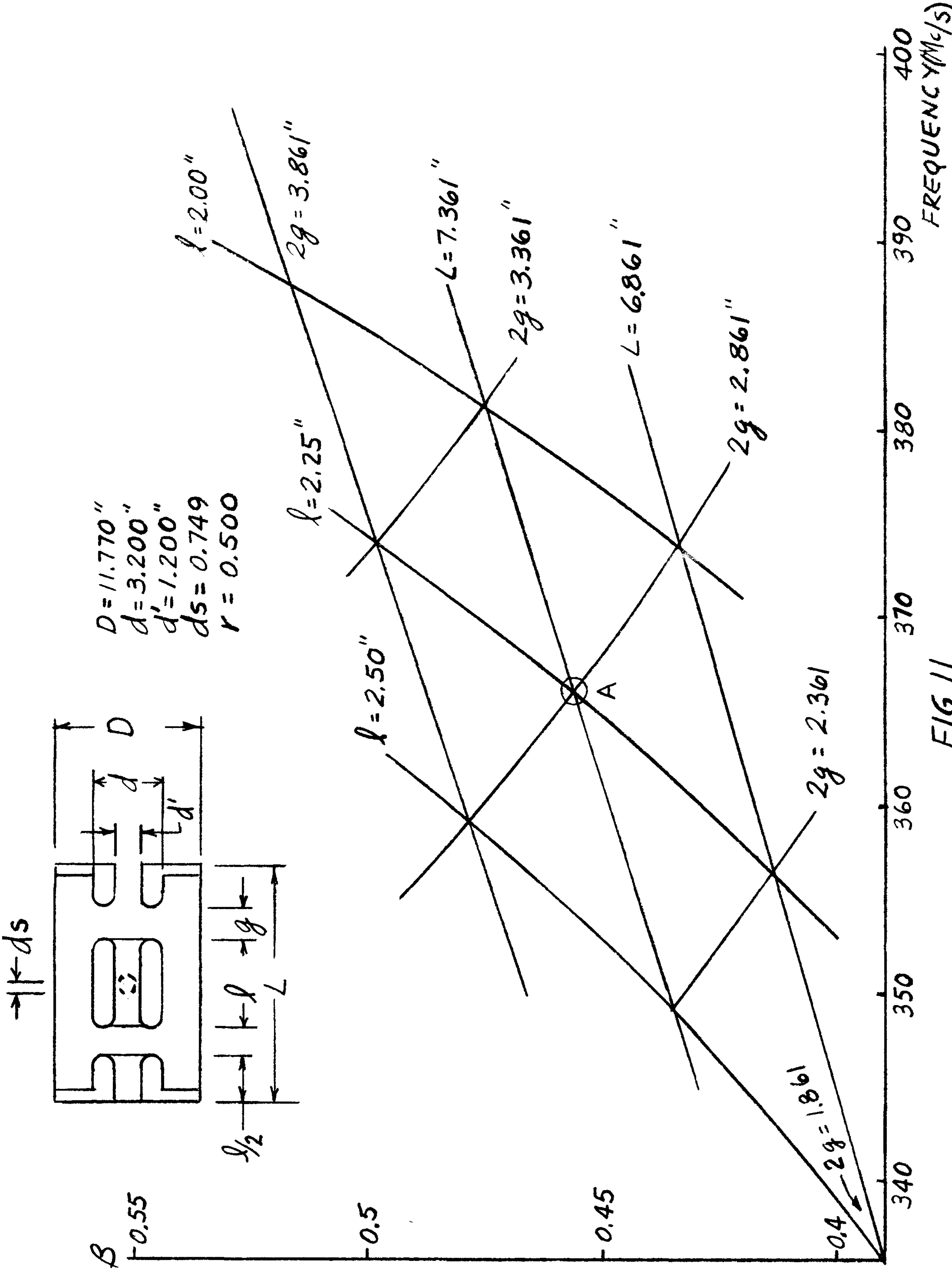
D = 11.770"
d = 3.200"
d' = 1.200"
ds = 0.749
r = 0.500
ℓ = 2.00"
ℓ = 2.25"
ℓ = 2.50"
2g = 3.861"
2g = 3.361"
2g = 2.861"
2g = 2.361
2g = 1.861
L = 7.361"
L = 6.861"
A
β
0.55
0.5
0.45
0.4
340
350
360
370
380
390
400
FREQUENCY (Mc/s)
ds
D
d
d'
ℓ/2
ℓ
g
L

FIG.11

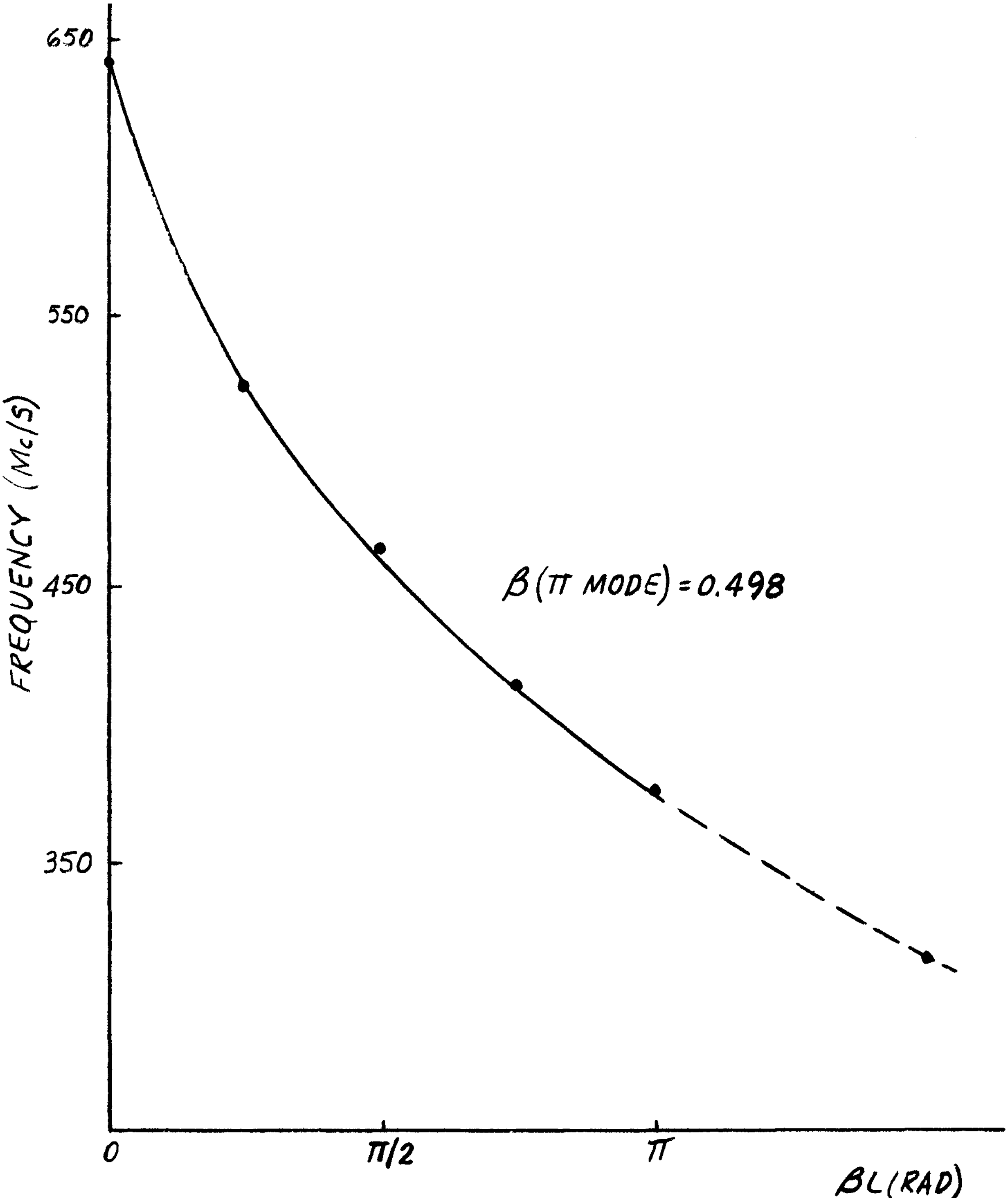

FIG. 12

scale model should be able to get up to the 2 π-mode, providing the terminations that we have permit it. However, our present terminations are not suitable so we have not observed the 2 π-mode yet.

By changing the periodic length of the structure, and the length of the drift tubes, to maintain the same resonant frequency, we increased the phase velocity of the structure to v = c to find the shunt impedance. It turned out to be disappointingly low, of the order of 9 MΩ/m at 400 Mc/sec as seen (scaled) in Fig. 1. We think we can improve this by increasing the diameter of the support bars, for the reasons to be given below.

If we refer to the structure of Fig. 9, we can show that there is an optimum value of shunt impedance when the ratio of stem diameter to pitch is equal to about 0.3. The use of drift tubes will modify this ratio to some small degree. By improving the transit time factor, the drift tubes will effect an increase in shunt impedance. On this fairly simple model, we can show that the shunt impedance of this kind of structure is certainly better than the original Jungle Gym. It was this kind of argument that led Walkinshaw to make the original suggestion for the Crossbar. The stem diameters in our model of the Crossbar for $\beta \sim 0.5$ at 400 Mc/sec, were chosen from breakdown considerations. It is difficult to say how near this is to the optimum ratio. When we increased the periodic length of the structure, roughly by a factor of 2, to increase β toward unity we did not change the diameter of the stems. The shunt impedance was seen to be low. We have a scheme in mind now to increase the diameter of the stems in order to improve the ratio, and by doing this, we think we can improve the shunt impedance.

There is also another way of improving shunt impedance, which is by making the structure assymetrical - that is, by having alternate drift tubes short and long. In the one case we have examined so far, by reducing alternate drift tubes to lengths equal to the stem diameter, and increasing the lengths of the other drift tubes to maintain resonant frequency, we can get an improvement of shunt impedance of about 10%. There may be a possibility that this will cause the π-mode to break up. The shunt impedance of the Crossbar structure is shown in Fig. 1, scaled to 2856 Mc/sec. We think we can increase the shunt impedance at β = 1.0 by a factor of the order of 2. On this present scale the Crossbar structure is better than the other structures up to nearly β = 0.8, which is roughly 600 MeV.

HUBBARD: Is the Alvarez structure shunt impedance referred to 2856 Mc/sec, in Fig. 1?

CARNE: Yes. This is just for comparison. An interesting possibility is the Crossbar at low β and we are looking at the Crossbar as an alternative to the Alvarez structure in the range 100 to 200 MeV. We're likely to have many problems, for example, focussing. It may not be too difficult to fit quadrupoles in drift tubes of this size if we're thinking in terms of about 200 Mc/sec. In fact, we may try this for the CERN injector design.

I should have mentioned that on the Cloverleaf, there are many possible nose cone shapes. We tried to make these very long indeed, so that they came close to being like hyperbolas. The idea was to put quadrupoles inside the nose cones and thus fulfil two functions at once. Very useful in principle, but unfortunately it doesn't work because the magnetic field breaks up into separate loops.

COMMENT: There is current flowing between the irises and the nose cone, so you must have an excellent electrical connection between them.

CARNE: Yes, that's true. We saw this very readily in the improvement in Q-value when we soldered the structure together.

QUESTION: Did you do this with the end plates? I noticed that the end plates were just fitted over the end.

CARNE: This introduces a certain amount of error. But the point in measuring the Q-value is that we have two structures - 1 plus 2 halves, and then just 2 halves; between the two we can eliminate the end plate loss. There is one other interesting thing in the Crossbar structure. We had experienced difficulty in coupling into the structure through an end plate because the Crossbar has a coaxial field distribution rather than a circumferential magnetic field and there is little magnetic field near the end plates. One can overcome this difficulty by coupling directly to a "horizontal" stem from a coaxial feed stub. If the stub of, say 50 Ω, is half a wavelength long, with a short circuit at one end, the boundary conditions at the Crossbar stem are completely satisfied. The rf feed now comes into the 50 Ω point along the coaxial stub.

BLEWETT: I don't see exactly what useful function is served in the Crossbar structure by the bars at 90° that couldn't be served by just lengthening the drift tubes. By putting in the second set you've just introduced another mode rotated 90°, haven't you?

CARNE: You could introduce another mode at 90°, but in fact, running it as we did, we had magnetic field around the horizontal bars, but didn't see magnetic fields around the other bars. We put the extra drift tubes in to increase capacitative loading, and so increase the passband.

BLEWETT: But couldn't this be done simply by lengthening the original drift tubes?

CARNE: You may be able to do this. We didn't try it.

HUBBARD: What are the possibilities of using a drift tube with the Cloverleaf structure?

CARNE: You could try it but we haven't as yet.

HUBBARD: Do you think you could get the field to go around the way you want to rather than breaking up the way it did in the first model?

CARNE: I don't think so. I think the important thing is the shape of the magnetic field one gets in the region of the slots. If you put drift tubes in the center, I don't think they will have much effect on the outside magnetic field. By putting in drift tubes you may cut down the transit time factor a little.

GLUCKSTERN: If I understand the Crossbar structure correctly, the alternate posts and drift tubes don't really contribute to the losses, but are there to increase the matching. That means that the losses can be viewed as coming primarily from the posts, and the drift tubes perform the function of loading to improve the transit time factor. If you look at it that way, then the next step is to spread the posts out into wider posts, so that you get less current density, and you eventually wind up with something like the disk-loaded structure. What you think you've done in these steps is to improve the efficiency, but you wind up with a disk-loaded structure which you know to be inefficient. Am I missing a point?

CARNE: This is a fairly old question. I think it comes back to the way you describe the field pattern. This is why I briefly went over to the original description of a parallel-plate waveguide with just bars across. If you look at this structure you can turn round into rectangular bars and then make them into wide ones, and then come back eventually to the kind of solid wall structure that you originally had. This is something that Walkinshaw thought about a long time ago, but he found that the best values of shunt impedance were with the Crossbar structure. There was little difference between having square crossbars and circular ones. And in fact, at about $\beta \cong 0.5$ it was much better than the pillbox guide, although worse than the pillbox at $\beta \simeq 1.0$.

GLUCKSTERN: I did a calculation on just that structure with the bars and came to the conclusion that shunt impedance went up as β went up, and was poorest at $\beta \simeq 0.5$.

LEISS: I'd like to go back to Blewett's question. In the Crossbar structure you essentially have two sets: vertical bars, and horizontal bars. I would expect that unless you can get enormously good tolerances, these two separate structures could produce stop bands, perhaps in very unfortunate places, because of tolerances.

CARNE: We've not actually seen magnetic fields around both sets of bars inside our structure.

LEISS: There's no reason why you shouldn't, everything is symmetrical.

CARNE: This is what I meant when I said that we may be letting ourselves in for trouble if we start varying alternate drift tubes or changing the dimensions of alternate bars.

GIORDANO: In an Alvarez structure, in order to support the 0-mode at the boundaries of each cell, the radial currents on the walls of the adjacent cavities are flowing in opposite directions. Therefore, it is possible to remove the walls between the cells, since the boundary will be satisfied by the field of the adjacent cavities. The result of removing these boundaries is to decrease the losses.

For a π-mode structure, it is required that a current sheet be placed between the adjacent cavities to support a π-mode. Since this current must be proportional to the electric field on the axis, then the geometry of the boundary between cells which must carry this current is very important in relation to the losses on this boundary. By reducing the area of this boundary, and by forcing the current to bunch up, since the losses go on the current squared, it would appear that the losses would be very great when stems are used to support the π-mode electrically, compared to irises.

CARNE: You rather expect that the greater the metal area, the lower the losses are going to be. But this does not take into account all the factors. You have a rather different distribution to start with and the results are different.