R.F. Note #127
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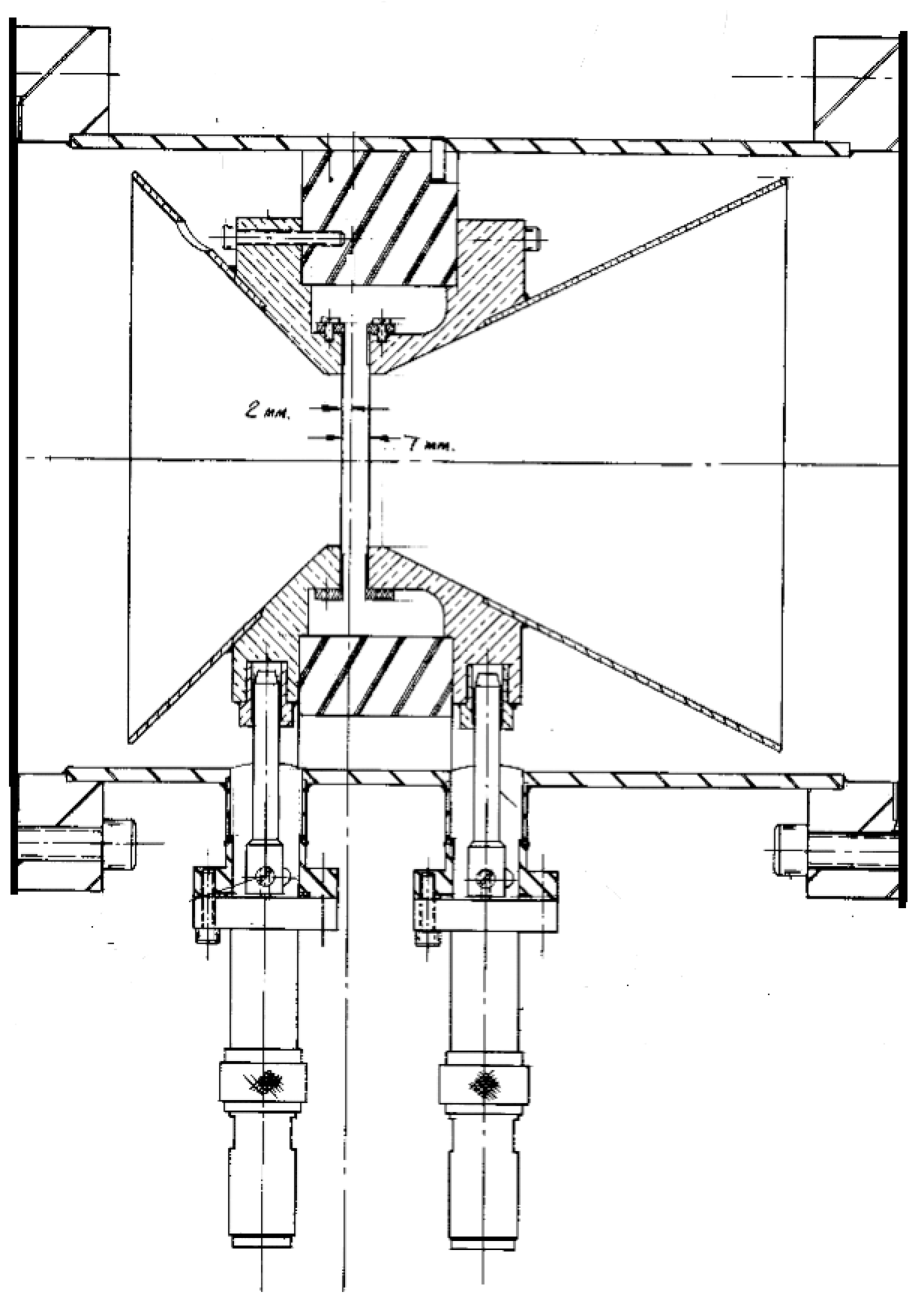
Beam Buncher Upgrade

Introduction

The existing beam buncher resonator only supports a single harmonic although the buncher gap assembly shown below is designed to support two quasi-independent harmonics. The large, small cones are to be driven by the first, second harmonic respectively. The buncher resonator (not shown) connects to the ports shown. We shall replace the existing buncher resonator with a version that supports both harmonics. This note documents the design of the new system.



Electrode Measurements

Input capacitance measurements were previously made to the buncher electrode structure to both ports with the alternate port both open and short circuited. Port #1 is the first harmonic port and port 2 is the second harmonic port. The results were:

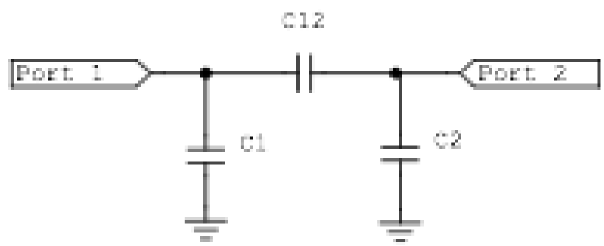
Cin1o = 52.1 pF: input capacitance of port 1 with port 2 open.

Cin1s = 55.7 pF: input capacitance of port 1 with port 2 shorted.

Cin2o = 45.4 pF: input capacitance of port 2 with port 1 open.

Cin2s = 47.1 pFL input capacitance of port 2 with port 1 open.

The following pie circuit topology is a first logical choice to describe the circuit.



The following formula were derived to obtain the above circuit element values from the measurements.

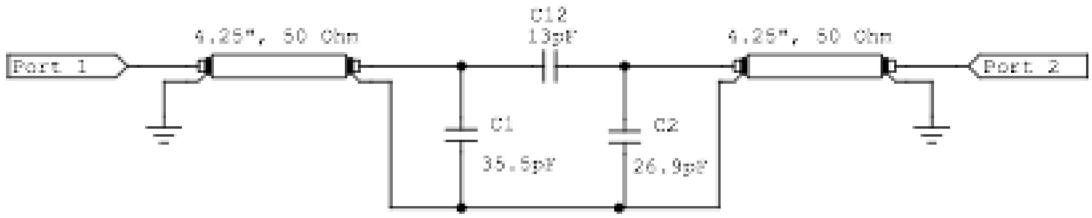
$$C_{12} = \sqrt{C_{in2s}\left(C_{in1s} - C_{in1o}\right)} = 13pF$$

$$C_1 = C_{in1s} - C_{12} = 42.7pF$$

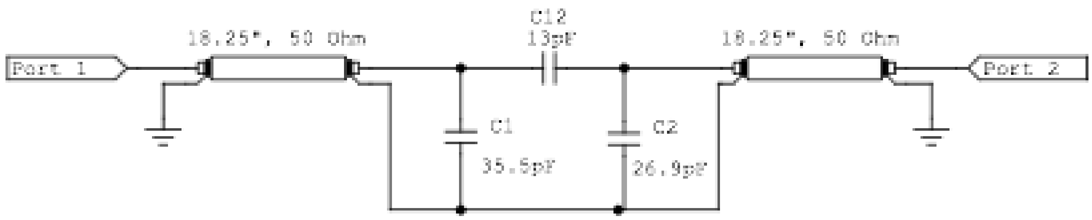
$$C_2 = C_{in2s} - C_{12} = 34.1pF$$

Advanced Model

From the illustration of the buncher electrode structure, notice that the actual buncher electrodes are some distance from the ports where the measurements were made. These distances are modeled as 4.25” long 50 Ohm transmission lines. Subtracting the capacitance of these lines from the original pie circuit leaves the following equivalent circuit for the buncher electrode assembly.



Fourteen inch long RG11AU flexible transmission lines are used to connect the buncher electrode assembly to the buncher resonator leading to the following circuit as seen from the ports of the resonator.



First Order Resonator Design

The first step in this process is to separate the first and second harmonic structures shown above into quasi-independent resonators. The central capacitance π circuit will be separated into two circuits by assuming the input capacitance is the average of the input capacitance measured at each port with the other port open and shorted.

$$C_{in1s} = C_1 + C_{12} = 48.5\text{pF}$$

$$C_{in2s} = C_2 + C_{12} = 39.9\text{pF}$$

$$C_{in1o} = C_1 + \frac{C_{12}C_2}{C_{12} + C_2} = 44.3\text{pF}$$

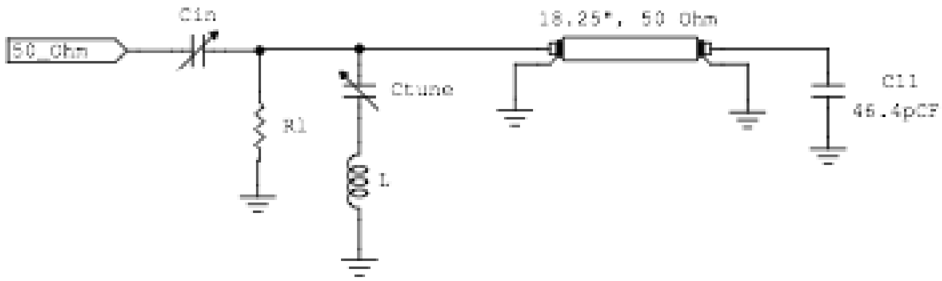
$$C_{in2o} = C_2 + \frac{C_{12}C_1}{C_{12} + C_1} = 36.4\text{pF}$$

$$C_{11} = \frac{C_{in1o} + C_{in1s}}{2} = 46.4\text{pF}$$

$$C_{22} = \frac{C_{in2o} + C_{in2s}}{2} = 38.2\text{pF}$$

The following circuit is now assumed to be the sought after design for the first harmonic resonator. Design goals are established to determine values for Ctune, R1, and Cin.

For now, R1 includes the inherent circuit losses plus any additional resistance added to lower the Q and broaden the coupling range.



Frequency Range:	9 - 27 MHz
Peak Buncher Voltage:	750 Volts
Input Impedance:	50 Ohms
Power:	<= 25 Watts

The first step is to determine the input impedance looking into the buncher transmission line across the desired frequency range. The values obtained are used to determine the range of inductance to ground needed at this port to resonate out the reactive component of the impedance. The combination of Ctune and L will be designed to form the "effective inductance" required.

The input impedance looking into the transmission line port feeding the buncher first harmonic from the resonator location is:

$$Z_{in} = -jZ_o \left[\frac{\frac{1}{\omega C_{11}} - Z_o \tan \beta l}{Z_o + \frac{1}{\omega C_{11}} \tan \beta l} \right] - jX_c$$

Zo: transmission line characteristic impedance
l: transmission line length
v: transmission line group velocity
β: radians per meter = ω/v

F (MHz)	Xc11 (Ohms)	Xc22 (Ohms)	tanBl	Zin1 (Ohms)	Zin2 (Ohms)
9	381.1	462.9	0.10	211.6	235.6
11	311.8	378.8	0.12	171.9	191.5
13	263.9	320.5	0.15	144.1	160.8

F (MHz)	Xc11 (Ohms)	Xc22 (Ohms)	tanBl	Zin1 (Ohms)	Zin2 (Ohms)
15	228.7	277.8	0.17	123.6	138.1
17	201.8	245.1	0.19	107.7	120.6
19	180.5	219.3	0.22	95.0	106.6
21	163.3	198.4	0.24	84.6	95.1
23	149.1	181.1	0.27	75.8	85.6
25	137.2	166.7	0.29	68.3	77.4
27	127.0	154.3	0.31	61.9	70.3

The resulting values of capacitive reactance's for the two electrodes are tabulated above. Inductances must be established to resonant out the reactance's tabulated as Zin1 and Zin2 above.

The “effective inductance” of the series combination of Ctune and L is:

$$L_e = L - \frac{1}{\omega^2 C_{tune}}$$

To resonant out the reactance requires the effective inductance reactance to be equal to the capacitive reactance:

$$\omega L_e = X_c$$

Solving for Ctune yields:

$$C_{tune} = \frac{1}{\omega(\omega L - X_c)}$$

The following table lists the values of the tuning capacitor for the first (1) and second (2) harmonic circuits. The capacitor values are computed based on a 4.05uH fixed inductor for the first harmonic and a 4.5uH inductor for the second harmonic. The actual inductor values used will be field engineered by setting the tuning capacitors to their minimum values and then trimming the choke until the circuit is resonant at 27.1MHz for the first harmonic and 54.2MHz for the second harmonic. The adjustment range will then be whatever results from this engineering step.

F (MHz)	Ctune (1)	Ctune (2)
9	1.02E-09	9.36E-10
11	1.34E-10	1.21E-10
13	6.56E-11	5.92E-11
15	4.11E-11	3.71E-11
17	2.88E-11	2.60E-11
19	2.16E-11	1.95E-11
21	1.68E-11	1.52E-11
23	1.36E-11	1.23E-11
25	1.12E-11	1.01E-11
27	9.43E-12	8.51E-12