DESIGN, TEST AND COMMISSIONING OF A DUAL FREQUENCY CHOPPER FOR THE TRIUMF ISAC FACILITY

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Abstract

The medium energy beam transport (MEBT) line for the ISAC radioactive beam facility at TRIUMF requires a dual frequency chopper at 5.89 MHz and 11.78 MHz operating in cw mode. Each chopper has two pairs of parallel plates separated from each other by a copper ground plate with an aperture for the beam. The bottom plates are mounted on ceramic bi-pass capacitors where dc bias voltages are applied. The top plates are connected directly to the inner conductor of the rf feedthroughs. Two separate rf amplifiers power the chopper and a combination of dc and rf voltages are employed to produce an 86 ns or a 172 ns time separation between pulses. An aluminum box houses the inductive coils, fine frequency tuners and rf coupling loops for each resonant circuit. The resonant frequencies are determined by these inductive coils in parallel with the capacitances of the rf feedhroughs and the parallel plates. A commercial ceramic feedthrough has been modified to withstand the nominal operating voltage of 7.5 kV. The chopper has been tested and commissioned to full rated voltages and is routinely operated with beam.

1 INTRODUCTION

The prebunched beam at 11.78 MHz of the ISAC radioactive facility [1,2] goes through the 36 MHz RFQ without being chopped. The dual frequency chopper is installed down stream from 106 MHz bunch rotator in the medium energy beam transport line of ISAC . Dual mode operation of the chopper provides an 86 ns or a 172 ns time separation between pulses and combination of dc and rf voltages on the parallel plates of the chopper minimizes the emittance growth of the beam [3]. The basic parameters of the chopper is given in Table 1 where plates 1A and 1B are upper and lower plates for the 11.78 MHz chopper where as plates 2A and 2B belong to 5.89 MHz chopper. The maximum required effective voltages for the low frequency and high frequency choppers are 7.4 kV and 5.5 kV respectively. The chopper has been commissioned and has been operational since May 2001.

Table 1: Basic parameters of the Chopper

Parameter	Mode A	Mode B
Δt (ns)	86	172
Mode	Cosine-wave	Cosine-wave
Frequency	11.78 MHz	5.89 MHz
Plate 1A (upper)	7.4 kV rf	5.5 kV rf
Plate 1B (lower)	-6.8 kV dc	-5.1 kV dc
Plate 2A (upper)	0 kV	5.5 kV rf
Plate 2B (lower)	0 kV	-5.1 kV dc
$\Delta V/V$	$\leq 2\%$	$\leq 2\%$
$\Delta\phi$	$\leq 2^0$	$\leq 2^0$

2 DESIGN OF THE CHOPPER

The choppers employ lumped circuit components to obtain the desired resonant frequencies of 5.89 MHz and 11.78 MHz. Each parallel plate resonant circuit consists of a water cooled inductive coil, the capacitance of the chopper plates and the capacitance of the feedthrough assembly. The inductive coils, made from hollow ¼" o.d copper tubes, are housed in an aluminum box (36"X12"X12") and are connected to the rf feedthrough via a rigid coaxial transmission line. The coaxial line is designed to support the coil box above the other beam line components. Water cooling is provided to the ceramic rf feedthrough via the inductive coils. The coupling loops and motor controlled fine frequency tuners are also housed in the same box. The chopper plates, which are 3"

Figure 1: Photograph of dual mode chopper.

square with a thickness of 1/8", are located in the vacuum box. The upper plates are supported by rf feedthroughs and the lower plates are supported by ceramic bi-pass capacitors to allow dc bias voltages to be applied. The bi-pass capacitors are 1500 pF and are rated at 15 kV dc. The two pairs of chopper plates are separated by a vertical copper plate with a 32 mm diameter hole for the passage of the beam and also to provide adequate isolation between the two resonant modes. Figure 1 is a photograph of the dual frequency chopper installed in the ISAC beam line. The resonant frequency of the left hand side of the box is 5.89 MHz and the right hand side is 11.78 MHz.

2.1 Prototype and circuit model

Prototype test and circuit models were done to design the coils and the enclosing box. The coils are designed as helical resonators [4] where the coil, as an inner conductor, is connected at one end to the box which acts as a shield (outer conductor). The maximum theoretical value of unloaded Q of such a shielded coil below its self resonance is given by

$$Q = 50Df^{1/2} \qquad (1)$$

where D is diameter of coil in inches and f is in MHz.

Investigations were made to optimize the resonators for highest shunt impedances which leads to lowest rf drive power. Measurement and calculations are also done to understand and minimize coupling from one resonator to the other. The main coupling is due to the stray capacitance between the two top plates of each circuit through the hole in the vertical shielding plate. This capacitance is measured to be 0.05 pF. Circuit model as shown in figure 2 is analyzed using Pspice. The shunt impedance has been assumed to be 270 KΩ for each resonator. L and C values for the resonators are shown in the schematic. Simulation result is shown in Figure 3 as the frequency is swept from 2 MHz to 20 MHz. To avoid parasitic reactions in the control systems for each of the resonant circuits, the specified isolation is –34 dB. The difference in voltage coupling, which is a measure of isolation between the two circuits, as shown in Table 2, is less than this specified value.

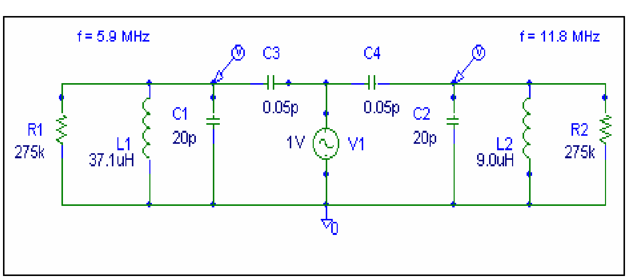

Figure 2: Pspice model of the two resonators.

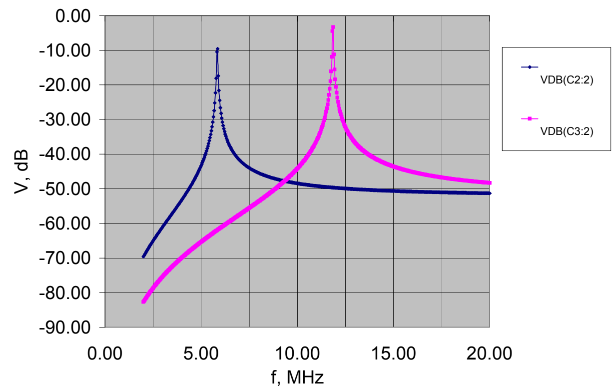

Figure 3. Pspice simulation result

Table 2: Isolation between two resonators obtained from Pspice simulation of figure 3

Voltage coupled computed		Value
from	to	
11.8 MHz	5.9 MHz	-46 dB
5.9 MHz	11.8 MHz	-52 dB

2.2 RF Feedthrough

The critical component of the chopper is the rf ceramic feedthroughs which should withstand the design voltage of 7.4 kV. Also, the feedthrough forms the inner conductor of the rigid coaxial transmission line which connect to the inductive coil. This restricts the size of the feedthroughs that can be used. Commercial feedthroughs, which broke down along the ceramic surface at 5 kV rf voltage with 10% duty cycle and 800 Hz repetition rate, were modified to withstand twice the maximum operating

Figure 4: Modified feedthrough with shield

voltage at the operating frequencies in cw mode. The overall length of the feedthrough is 6" and the outer diameter of the inner hollow conductor is 3/4" with a wall thickness of 1/32". Figure 4 is a photograph of the modified feedthrough mounted inside the coaxial line. A shield has been silver soldered to the feedthrough flange which is at ground potential and the space between the shield and the ceramic has been filled with silicone jell and cured for 24 hours at room temperature.

2.3 Assembly of the chopper

The vacuum box uses a 8" cubic stainless steel frame structure where copper and stainless steel plates are attached. The top, bottom and one of the side plates, where the turbo pump is mounted, are made of copper where as the two end plates and the diagnostic plate, opposite to the turbo pump, are made of stainless steel. Beam flanges are mounted on the stainless steel end plates in the beam axis and vacuum gauges and rf monitor probes are installed on the diagnostic plate. This enabled pre installation of rf feedthroughs on the top plate for aligning the chopper top plates to the requisite height of 0.79" from beam axis. Aligning the bottom chopper plates on the ceramic bi-pass capacitors was difficult since the capacitors did not have a true flat surface. Both the chopper plates were aligned within ± 0.5% of beam aperture. Figure 5 shows the mounting of the chopper plates inside the vacuum box. The rf feedthrough can be seen inside the coaxial line. The dc bias is applied to the bottom of the ceramic bi-pass capacitor via a rf choke.

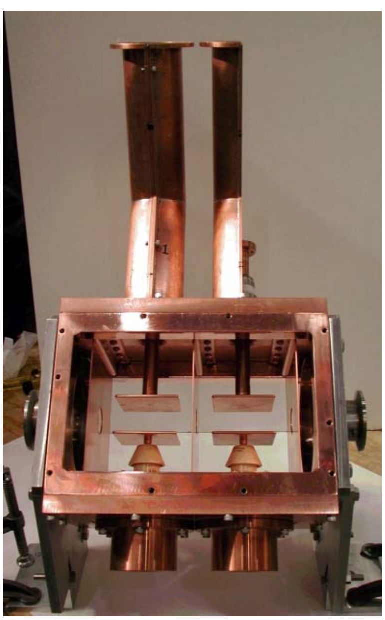

Figure 5: Chopper plates mounted inside vacuum box.

3 MEASURED RF PARAMETERS

The theoretical maximum Q and measured Q of the coils are 1630 and 1130 for 11.78 MHz and 1140 and 1060 for 5.89 MHz respectively. The shunt impedances are measured with a 50 ohm probe and are shown in Table 3. Two solid state amplifiers, built in-house, are used to drive the chopper at the two specified frequencies. Coupling loops are installed in the coil box near the short circuit end of the coils and are matched for 50 Ω to the amplifier. Voltage probes mounted in the vacuum box and in the coil box, are used for monitoring and rf feedback control.

Table 3: RF Parameters of the chopper

Parameters	Mode A	Mode B
Frequency (MHz)	11.78	5.89
Qo	1130	1060
Rshunt, KΩ	306	430
P required for nominal rf voltage, Watts	100	36
Amplifier Power Output rating, cw, Watts	300	150
Coil diameter, inches	9.5	9.5
No. of turns	15	61/2
Water flow liters/minute	3	1
Tuner , δf	+ 30KHz, -100 KHz	+22 KHz, -52 KHz

4 CONCLUSIONS

The chopper was installed in May 2001 and has been operating without any major problem since then. Beam commissioning of the ISAC dual frequency chopper is discussed in detail in reference [5]

5 REFERENCES

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[4] Reference Data for Radio Engineers, Howard W. Sams & Co. Inc, pp24-28

[5] R.E. Laxdal, M. Pasini, L. Root, "Beam Dynamics Study and Beam Commissioning of the ISAC Two Frequency Chopper", this conference