Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Engineering Division

MASTER

Presented at the 1985 Particle Accelerator Conference, Vancouver, B.C., Canada, May 13-16, 1985; and to be published in Transactions on Nuclear Science, NS-32, No. 4

STOCHASTIC BEAM COOLING AMPLIFIER SYSTEM FRONT END COMPONENTS PERFORMANCE CHARACTERISTICS

C.C. Lo

May 1985

LEGAL NOTICE

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Lawrence Berkeley Laboratory, University of California
Berkeley, California 94720

Abstract

The stochastic beam cooling amplifier front end consists of 180° hybrids, cables, directional couplers, power dividers/combiners and low noise preamplifiers. Most front ends will be operating at near liquid nitrogen (LN) temperature. Components used in the front ends should be able to operate at this temperature satisfactorily. Since the noise performance of the front end is of utmost importance to the beam cooling process, the insertion losses of cables, 180° hybrids, directional couplers and power combiners have been measured at room temperature and near liquid nitrogen temperature. The purpose of this report is to describe and present some measurements and data on the components mentioned, with the exception of the 1-2 and 2-4 GHz preamplifiers, which have been described elsewhere.^{1,2}

Introduction

The bunched particles in a high energy accelerator tend to spread with time. Systems for reducing this spreading, known as cooling systems, have been developed.^{3,4} The anti-proton source (which consists of a debuncher ring and an accumulator ring) of the Fermi National Laboratory will employ a stochastic beam cooling system to reduce the emittance and spreading of the particle beam. This beam "cooling" system includes pick-up electrodes coupled to very low-noise preamplifiers through a component system that is discussed in this report. The feedback system picks up signals from the beam bunches with pick-up electrodes, amplifies them and feeds them back to the beam through kicker electrodes with proper amplitude, phase and propagation delay to keep the particle beam "cooled".

Figure 1 shows a typical front end of the amplifier systems; there will be three to four variations of this configuration in the anti-proton source. Most front ends will be operating near liquid nitrogen temperature. The preamplifiers used in those front ends will be those described in References 1 and 2. They will be operating at about 80 K with noise figures in the 0.2-0.6 dB range. Since the hybrids, directional couplers, power combiners, and interconnecting cables are mostly situated ahead of the preamplifiers, any insertion loss due to these components degrades the signal to noise ratio of the whole system. Therefore it is imperative that such losses be kept at minimum. In some front ends, where the output signals from the pick-up electrodes are higher, no liquid nitrogen cooling is necessary. In such cases, commercially available preamplifiers with noise figures in the range 1.5-2 dB are used. Those front ends will be operating at room temperature.

The pick-up electrode consists of arrays of 32 pairs of electrodes.⁷ The signal picked up by each electrode is combined by a primary combiner whose outputs are in turn combined by a secondary combiner which has a single output port. Both the upper and lower pick-up electrodes are configured in the same way. The signals picked up by this array of 32 pairs of electrodes was calculated to be approximately equal to 1.4 pW in the stack tail system. By combining

four such arrays the signal power will double, yielding a signal to noise ratio of better than one at 80 K. The average loss of a combiner is approximately 0.6 dB at 80 K. The output signals from the upper and lower secondary combiners either go into the two input ports of a 180° hybrid or into a power combiner depending on which system the front end is located. The output of the delta and/or the sum port of the 180° hybrid or the power combiner, as the case may be, is connected to a bidirectional coupler whose two coupling ports are used for monitoring purposes. When one of these two ports is being used for signal injection, the other unused port must be terminated with a high quality 50-ohm termination. The output of the direction coupler is then connected to the low noise preamplifier which has a gain of ~ 30 dB. The output of this preamplifier then goes through the portion of the amplifier system which contains filters, drivers, phase shifters, power amplifiers and power splitters. Finally, the amplified signals with the correct phase, delay and amplitude are used for cooling the particle beam by means of the kicker electrodes.

Components Characteristics Measurements

All insertion loss measurements were made with the HP 8409 network analyzer using HP's 12-term calibration procedure. Accuracy of the measurement system was estimated to be $\pm .03$ dB, but it became worse when measurements were made on components installed inside a liquid nitrogen-cooled chamber. In such cases the losses of the interconnecting cables must be subtracted to obtain the losses of the cooled devices. As a result, the accuracy of the 80 K data was estimated to be ± 0.06 dB. The loss in the semi-rigid cables which were part of the input system operating at 80 K was measured by using a 5 foot piece of cable immersed in liquid nitrogen. Two stainless steel buffer cables were used between the test ports of the network analyzer and the cable under test to minimize heat loss. The decrease in loss of the stainless steel cables at low temperature was taken into account in the final semi-rigid cable loss data. Low temperature insertion loss measurements of all other components were made by using a liquid nitrogen-cooled copper plate which was installed in a vacuum chamber. Heatsink compound was used between the copper plate and the components to obtain good thermally-conductivity. The lowest temperature obtained by this cold plate was approximately 90-95 K.

Since a large number of measurements have to be made other than the insertion loss measurement on the 180° hybrids, directional couplers, power combiners and 50-ohm terminations, it was not practical to make all these measurements using the liquid nitrogen-cooled plate inside the vacuum chamber. The cool-down and warm-up cycle of the LN-cooled plate took ~ 8 hours and a large amount of LN had to be used for each cycle. As a result, components were instead lowered into an LN bath very slowly for cool-down, with the measuring cables connected to the device through 90° swept right angle assemblies which were also included in the calibration procedures. The LN bath enabled components

to cool down a lot faster, although it also subjected components to a much higher stress than they will encounter in the intended application.

Results of Insertion Loss Measurements

Table 1 shows the losses of all components measured at room temperature and at 90-95 K in the 1-2 GHz and the 2-4 GHz band. Since the uncertainty of the low temperature data was ± 0.06 dB, numbers below 0.1 dB should be regarded as typical rather than absolute.

Table 2 shows the total loss of different front ends between the output of the secondary combiner and the input of the preamplifier. At 3 GHz the front end loss (without combiner losses) with 180° hybrid was 0.99 dB at room temperature and 0.6 dB at 90 K for a system using 141 semi-rigid cables. At 1.5 GHz, the front end loss with the 180° hybrid and 141 semi-rigid cables was 0.68 dB at room temperature and 0.49 dB at 90K. Insertion losses of other front ends can be obtained from Tables 1 and 2.

Results of 50 Ohm Termination Measurements

A few 50-ohm terminations were tested. The return loss of one of the terminations is shown in Fig. 2 at room and LN temperature. 50-ohm terminations similar to these units should be used in the front ends. It is helpful to point out that the mechanical stress put on the terminations by ordinary wrenches could cause the device to fail; hence it is advisable to use a torque wrench when tightening the connections.

Results of 180° Hybrid Measurements

Figure 3 shows the 1-2 GHz hybrid's delta port to output port 1 and port 2 response at room temperature, and Fig. 4 shows the same response at LN temperature. Figures 5 and 6 give the same response of the 2-4 GHz hybrid at room temperature and at LN temperature, respectively. The voltage output of the delta port of the 1-2 GHz hybrid, as a function of the difference of two voltages of the same frequency and phase but different amplitude feeding into ports 1 and 2, is presented in Fig. 7 while Fig. 8 shows the response of the 2-4 GHz hybrid under the same testing procedures. The deviation from linear phase was within ± 12 degrees for both 180° hybrids. The isolation between the sum and the difference ports was better than 24dB for both units across their frequency bands of operation.

Hybrid Problems and Solutions

When the hybrids were cooled down to LN temperature, one out of sixteen connections opened in the 1-2 GHz hybrid and three out of sixteen connections opened in the 2-4 GHz hybrid. Such failure was not acceptable for this application. The opening of the connections was due to the shrinkage of the aluminum case and the circuit boards. Various attempts to solve the problem, including shimming and adding screws to increase the loading on the tab and circuit, were carried out. One solution was found which involved taking the hybrids apart, exposing the connector tabs and the hybrid circuits on both sides of the board. A very tiny amount of gallium-indium-tin alloy² was then very carefully painted on the exposed tabs and the portion of the circuit where the tabs make contact. The hybrid was then put back together exactly the same as before. It is advisable to mark the hybrid case for delta and sum port and note the circuit orientation right after the top half

of the hybrid has been removed. This will help the reassembly of the hybrid in the proper way. Figure 9 is the modification illustration drawing of the 1-2 GHz. A similar procedure should be applied to the 2-4 GHz hybrids. As a result of the application of the alloy, additional screws or shimming were not needed. After a hybrid has been modified it should be immersed in an LN bath and cooled down thoroughly. The hybrid should then be pulled out of the bath and all existing screws should be tightened to take up the shrinkage of the hybrid case. The gallium-indium-tin alloy attacks aluminum; hence care should be exercised not to use excessive amount of the alloy to avoid its being squeezed out of the contact areas, causing short circuits or corrosion problems.

Results of Directional Coupler Measurements

The 1-2 GHz and the 2-4 GHz directional couplers are both bidirectional couplers. Figures 10 and 11 show the coupling response of the 1-2 GHz and the 2-4 GHz directional coupler at room and LN temperature. The directivity of both directional couplers were in the order of 50 dB or better at room and LN temperature. The coupling responses in the other direction on both devices were similar to those shown in Figs. 10 and 11.

Results of Power Combiner Measurements

The 1-2 GHz in-phase two-way power combiner is internally isolated with two resistors which limit the maximum operating power level to 6 W at room temperature. Figure 12 shows the response of one of the two output ports at room and LN temperature and Fig. 13 shows the same response of the other port at room and LN temperature.

Conclusion

During measurements some analyzer calibration drift was experienced. The error was minimized by doing calibration checks before, after, and in between data taking. Recalibrations were done whenever necessary.

Putting a minute amount of gallium-indium-tin alloy on the connecting surfaces of the circuits and the connector tabs provides a good cure for problem joints and an insurance for performing joints for the 180° hybrids. The failure rate of connections after this treatment was zero with 10 cycles of rigorous LN testing.

At liquid nitrogen temperature the center conductor and the teflon dielectric recede from the cold ends of the 141 semi-rigid cables. The amount of shrinkage in some cases may be enough to open up connections. With the very short length of cable used in the front ends, this may not cause any problem provided the center conductor, which also serves as the pin for the connector, is not marginally short to start with. In all amplifier front end assemblies SMA couplers and SMA swept right angle assemblies will be used to interconnect components. The VSWR of a swept right angle assembly is in the order of 1.01-1.05 across the 1-4 GHz band. Short pieces of 141 semi-rigid cables will also be used.

Acknowledgment

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

References

1. C.C. Lo, B. Leskovar, "Cryogenically Cooled Broad-Band GaAs Field-Effect Transistor Preamplifier", IEEE Trans. Nucl. Science, NS-31, No. 1, February 1984. LBL-15983.
2. H.G. Jackson, T.T. Shimizu, "A Low-Noise 2-4 GHz Preamplifier", to be published in Nuclear Instruments and Methods. LBL-17811.
3. G. Lambertson, et al., "Experiments on Stochastic Cooling of 200 MeV Protons", IEEE Trans. Nucl. Sci., NS-28, No. 3, 1981, 12471-2473.
4. B. Leskovar, C.C. Lo, "Low-Noise Wide-Band Amplifier System for Stochastic Beam Cooling Experiments", IEEE Trans. Nucl. Sci., NS-27, No. 1, 1980, 292-301.
5. C.C. Lo, "Stochastic Cooling of Amplifier System Front End Components Insertion Loss Measurements", BECON 44. LBID 873.
6. C.C. Lo, "Stochastic Cooling Amplifier System Front End Components Performance Characteristics", BECON 47. LBID 922.
7. F. Voelker, Private Communication, 1984.
8. T. Henderson, Private Communication, 1984.

TABLE 1: DEVICE INSERTION LOSS AT 80-90 K

[No. in () at room temperature]

DEVICE	1 GHz	1.5 GHz	2 GHz	3 GHz	4 GHz	5 GHz
1/4" cable	(.06 dB)	(.11 dB)	(.13 dB)	(.16 dB)	(.18 dB)	(.22 dB)
40 CM	.03 dB	.05 dB	.06 dB	.08 dB	.09 dB	.13 dB
141 cable	(.15 dB)	(.18 dB)	(.23 dB)	(.29 dB)	(.35 dB)	(.39 dB)
40 CM	.065 dB	.09 dB	.1 dB	.13 dB	.16 dB	.175 dB
180° HYBRID			(.35 dB)	(.45 dB)	(.52 dB)	
2-4 GHz			.32 dB	.35 dB	.38 dB	
DIR. COUPLER			(.15 dB)	(.18 dB)	(.3 dB)	
2-4 GHz			.1 dB	.13 dB	.16 dB	
POWER COMBINER			(.15 dB)	(.22 dB)	(.29 dB)	
2-4 GHz			.13 dB	.2 dB	.25 dB	
180° HYBRID	(.2 dB)	(.31 dB)	(.42 dB)			
1-2 GHz	.13 dB	.25 dB	.34 dB			
DIR. COUPLER	(.08 dB)	(.1 dB)	(.13 dB)			
1-2 GHz	.07 dB	.1 dB	.12 dB			
POWER COMBINER	(.11 dB)	(.13 dB)	(.2 dB)			
1-2 GHz	.07 dB	.08 dB	.13 dB			

ESTIMATED RESULT ACCURACY $\pm .06$ dB

TABLE 2: FRONT END INSERTION LOSS

[Total Loss Between S.C. Output & Preamplifier Input Number in () w/ 141 Cable; All Others w/ 1/4" Cable]

OPERATING TEMPERATURE	1 GHz	1.5 GHz	2 GHz	3 GHz	4 GHz	REMARKS
Room Temperature			(.76 dB)	(.99 dB)	(1.27 dB)	w/180° Hybrid
			.61 dB	.8 dB	1.02 dB	
90°K			(.5 dB)	(.6 dB)	(.74 dB)	w/180° Hybrid
			.44 dB	.54 dB	.64 dB	
Room Temperature	(.5 dB)	(.66 dB)	(.89 dB)			w/180° Hybrid
	.37 dB	.57 dB	.75 dB			
Room Temperature	(.4 dB)	(.5 dB)	(.67 dB)			w/Power Combiner
	.18 dB	.4 dB	.52 dB			
90°K	(.29 dB)	(.49 dB)	(.61 dB)			w/180° Hybrid
	.245 dB	.42 dB	.55 dB			
90°K	(.24 dB)	(.32 dB)	(.4 dB)			w/Power Combiner
	.19 dB	.25 dB	.34 dB

Fig. 1 Block diagram of a typical front end

2B 648-1011

Fig. 2 Return loss of a 50 ohm termination.

KBL 648-3417

Fig. 3 1-2 GHz hybrid delta port - port 1 and port 2 response at room temperature

XBL 848-3418

Fig. 4 1-2 GHz hybrid delta port - port 1 and port 2 response at LN temperature

XBL 848-3419

Fig. 5 2-4 GHz hybrid delta port - port 1 and port 2 response at room temperature

XBL 848-3420

Fig. 6 2-4 GHz hybrid delta port - port 1 and port 2 response at LN temperature

XBL 848-3421

1-2 GHz
180° HYBRID

Fig. 7 1-2 GHz hybrid delta port output as a function of input voltages

XBL 848-3' 2

2-4 GHz
180° HYBRID

Fig. 8 2-4 GHz hybrid delta port output as a function of input voltages

XBL 848-3423

**MODIFICATION ILLUSTRATION
1-2 GHz 180° HYBRID**

NOTE:

AFTER THE HYBRID HAS BEEN MODIFIED AS SHOWN, CONNECT SHORTS TO THE TWO 3dB PORTS AND MONITOR THE 2 AND 4 PORTS RESISTANCE WITH A DVM. IMMERSE THE HYBRID INTO A LN BATH WHILE MONITORING THE NEAR ZERO RESISTANCE. LET THE HYBRID COOL DOWN THOROUGHLY THEN PULL UNIT OUT OF THE LN BATH TIGHTEN ALL THE SCREWS IMMEDIATELY.

XBL 848-3943

Fig. 9 Modification illustration diagram for the 1-2 GHz 180° hybrid

XBL 848-3424

Fig. 10 Coupling between the input port and the coupled port of the 1-2 GHz directional coupler at room and LN temperature

XBL 848-3425

Fig. 11 Coupling between the input port and the coupled port of the 2-4 GHz directional coupler at room and LN temperature

Fig. 12 Response of one of the two output ports of the 1-2 GHz power divider at room and LN temperature

XBL 848-3426

Fig. 13 Response of the second output port of the 1-2 GHz power divider at room and LN temperature

XBL 848-3427

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.