STOCHASTIC BEAM COOLING AMPLIFIER SYSTEM FRONT END
COMPONENTS PERFORMANCE CHARACTERISTICS

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Abstract

The stochastic beam cooling amplifier front end
consists of 180° hybrids, cables, directional cou-
plers, power dividers/combiners and low noise pre-
amplifiers. 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 excep-
tion 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 devel-
oped.[3,4] The anti-proton source (which consists of
a debuncher ring and an accumulator ring) of the Fer-
mi 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 dis-
cussed 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 ampli-
fier 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 fig-
ures in the 0.2-0.6 dB range. Since the hybrids,
directional couplers, power combiners, and intercon-
necting cables are mostly situated ahead of the pre-
amplifiers, any insertion loss due to these components
degrades the signal to noise ratio of the whole sys-
tem. 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,
commerically available preamplifiers with noise fig-
ures 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.[6] The signal picked up by each
electrode is combined by a primary combiner whose out-
puts 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 aproximately 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 con-
nected 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 direc-
tion coupler is then connected to the low noise pre-
amplifier 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 cali-
bration procedure. Accuracy of the measurement system
was estimated to be ± .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 de-
vices. 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 op-
erating 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 cop-
per plate and the components to obtain good thermo-
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 cy-
cle. 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.

The total loss of different front ends between the output of the secondary combiner and the input of the preamplifier can be calculated from Table 1. 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.

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.

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 LN temperature. Figure 4 gives the same response of the 2-4 GHz hybrid at LN temperature. 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. 5 while Fig. 6 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 alloy[7] 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 7 is the modification illustration drawing of the 1-2 GHz hybrid. 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 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 8 and 9 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. 8 and 9.

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 10 shows the response of one of the two output ports at room and LN temperature.

Conclusion

Putting a minute amount of gallium-indium-tin alloy in 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. 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

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, 198, 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 Amplifier System Front End Components Performance Characteristics BECON 47. LBID   .

[6] F. Voelker, Private Communication, 1984.

[7] 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 40 CM	(.06 dB) .03 dB	(.11 dB) .05 dB	(.13 dB) .06 dB	(.16 dB) .08 dB	(.18 dB) .09 dB	(.22 dB) .13 dB
.141 cable 40 CM	(.15 dB) .065 dB	(.18 dB) .09 dB	(.23 dB) .1 dB	(.29 dB) .13 dB	(.35 dB) .16 dB	(.39 dB) 1.75 dB
180° HYBRID 2-4 GHz			(.35 dB) .32 dB	(.45 dB) .35 dB	(.52 dB) .38 dB	
DIR. COUPLER 2-4 GHz			(.15 dB) .1 dB	(.15 dB) .13 dB	(.3 dB) .16 dB	
POWER COMBINER 2-4 GHz			(.15 dB) .13 dB	(.22 dB) .2 dB	(.29 dB) .25 dB	
180° HYBRID 1-2 GHz	(.2 dB) .13 dB	(.31 dB) .25 dB	(.42 dB) .34 dB			
DIR. COUPLER 1-2 GHz	(.08 dB) .07 dB	(.1 dB) .1 dB	(.13 dB) .12 dB			
POWER COMBINER 1-2 GHz	(.11 dB) .07 dB	(.13 dB) .08 dB	(.2 dB) .13 dB			

ESTIMATED RESULT ACCURACY ≈ ± .06 dB

Fig. 1   Block diagram of a typical front end
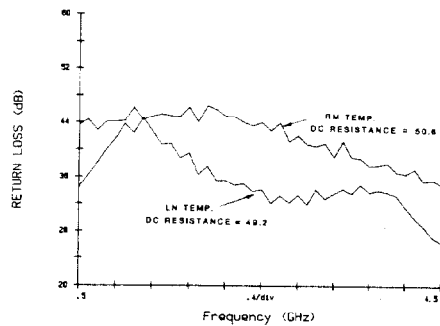
Fig. 2   Return loss of a 50 ohm termination
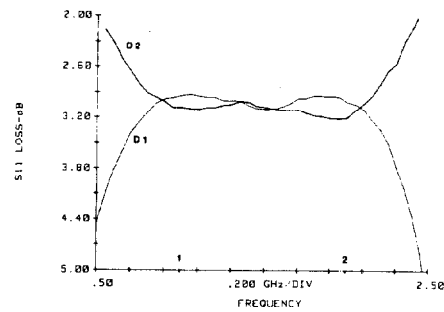
Fig. 3   1-2 GHz hybrid delta port - port 1 and port 2 response at LN temperature
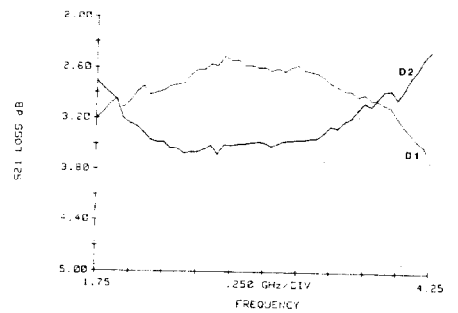
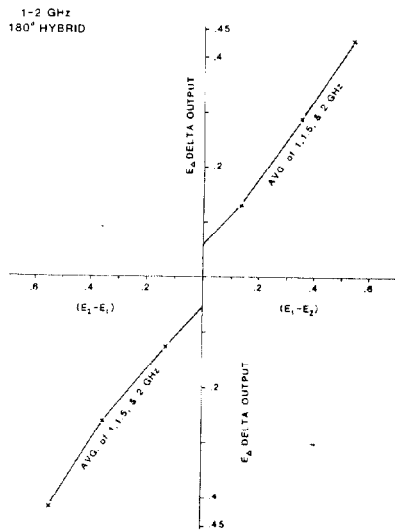Fig. 4   2-4 GHz hybrid delta port - port 1 and port 2 response at LN temperature

Fig. 5   1-2 GHz hybrid delta port output as a function of input voltages
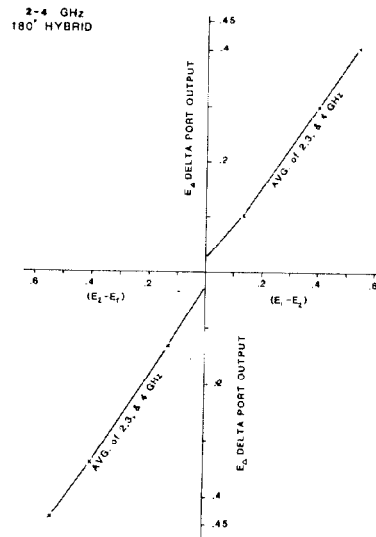

Fig. 6   2-4 GHz hybrid delta port output as a function of input voltages

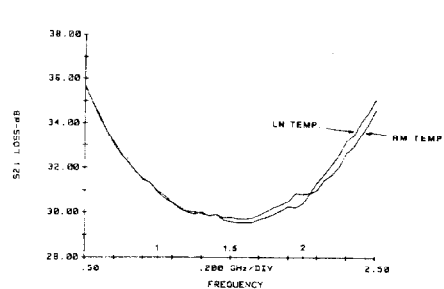Fig. 7   Modification illustration on a section for the 1-2 GHz 180° hybrid

Fig. 8   Coupling between the input port and the coupled port of the 1-2 GHz directional coupler at room and LN temperature
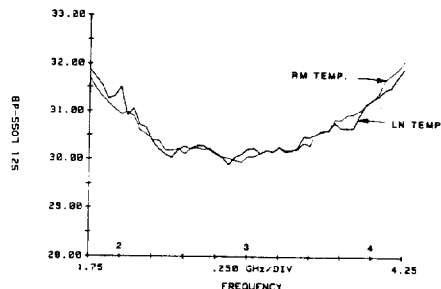

Fig. 9   Coupling between the input port and the coupled port of the 2-4 GHz directional coupler at room and LN temperature
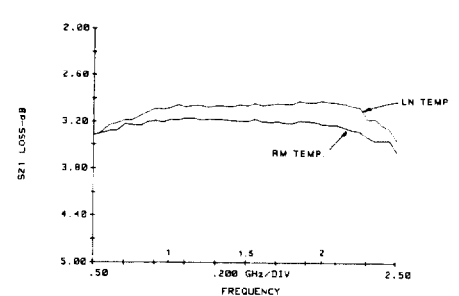

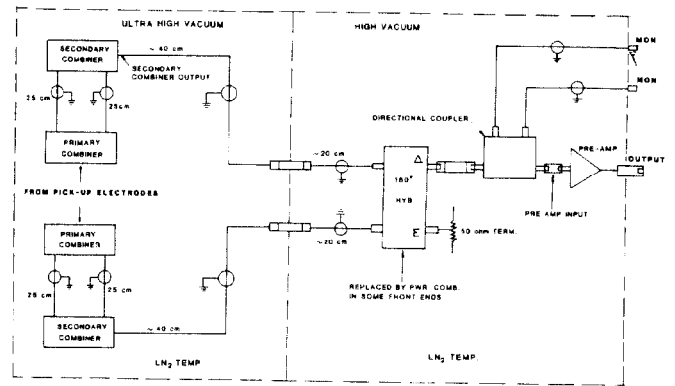Fig. 10   Response of one of the two output ports of the 1-2 GHz power divider at room and LN temperature