Booster Longitudinal Dampers
Module Settings and Functional Checks.

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Introduction
This is a working document, meaning that not only is it in perpetual DRAFT state waiting for input from others, but will be added to as time permits.

This document contains three sections. The first simply list references discussing why and how the Booster Longitudinal Dampers operate and some history on what has been tried in the past and why the damping methods have changed.

References:
[1] C.M. Ankenbrandt, J.E.Griffin, R.P. Johnson, J. Lackey and K. Meisner, "Longitudinal Motion of the Beam in the Fermilab Booster," IEEE Trans. Nucl. Sci. NS-24 1449 (1977).

[2] D. Wildman and K. H ar kay, " HOM R F Cavity Dampers for Suppressing Coupled Bunch Instabilities in the Fermilab Booster," 1993 PAC Proc. Washington, DC., p.3528A.

[3] K. Cecelia Harkay "A Study of longitudinal Instabilities and Emittance Growth in the Fermilab Booster Synchrotron." FERMILAB-THESIS-1993-65 (Dec 1993) 211p.

[4] J.P. Shaw, D. McGinnis, and R. Tomlin, "Reducing the Coupled-Bunch Oscillation in the Fermilab Booster by Optimizing RF Voltage," 1993 PAC Proc. Washington, DC. ,p.3787

[5] J.M. Steimel and D. McGinnis, "Damping in The Fermilab Booster," 1993 PAC Proc. Washington, DC., p. 2100

[6] D.A. Herrup, D. McGinnis, J. Steimel, and R. Tomlin, "Analog Dampers in the Fermilab Booster," 1995 PAC Proc. Dallas, Texas, p.3010.

[7] W.A. Pellico, D.W. Wildman, "Booster's Coupled Bunch Damper Upgrade," 2003 PAC Proc. Portland, OR, p.3177.

Other References

Fermi Accelerator Division Operations, “Booster Rookie Book,” p.39, http://www-bdnew.fnal.gov/operations/rookie_books/Booster_V4.1.pdf

D.K. Weaver, “A Third Method of Generation and Detection of Single-Sideband Signals,” Proc. of the IRE, vol. 44 issue 12, p.1703

System Drawings

Booster Longitudinal Damper Block Diagram, 0323.00 - ED - 282391, W. Pellico, C. Drennan 2/19/2014

Booster Front End Damper Module, 0323.00 - EC - 282390, W. Pellico, C. Drennan 2/19/2014

Tracking Narrow Band Filter, 0323.00 - ED - 282392, D. McGinnis, G. Golinski 8/1996

Appendix A: Compute the DIP Switch Settings for the DDS on the "Tracking Narrow Band Filter" Modules.

There are two configurations for the Longitudinal Damper systems. One provides a DDS clock at 8x the LLRF reference frequency and takes the Beam signal directly, and the second provides a DDS clock at 2x the LLRF reference frequency and downconverts the mode frequencies on the beam signal before sending to the Tracking Narrow Band Filter modules.

The input to the DDS, besides the clock, is a digital word that represents the desired frequency of its sinewave output. The input bits can be considered as bits (30 ... 1) of a 32-bit frequency setting, FW(31 ... 0).

$$FW(31..0) = 2^{32} \cdot \frac{F_{OUT}}{F_{CLK}}$$

System Using the x8 Clock.

For the first damper system we will use a DDS reference clock, F_{CLK}, that will be 8 times higher than the LLRF Reference Frequency, f_o. The DDS output frequency, F_{OUT}, is to be the frequency of the mode we wish to damp f_{mode}.

$$f_{mode} = f_0 + f_0 \cdot \frac{m}{84}, for\ m = 1 \cdots 83$$

Therefore we can determine the frequency setting as

$$FW = 2^{32} \cdot \frac{\left(1 + \frac{m}{84}\right) \cdot f_o}{8 \cdot f_o} = 2^{32} \cdot \frac{\left(1 + \frac{m}{84}\right)}{8}$$

Example 1:

Setup DDS for the Mode 1 Damper, (m=1).

$$FW = 2^{32} \cdot \frac{\left(1 + \frac{1}{84}\right)}{8} = 2^{32} \cdot 0.126488 = 543{,}262{,}232$$

The 32-bit binary version of this number is

$$FW(31..0) = 0010\ 0000\ 0110\ 0001\ 1000\ 0110\ 0001\ 1100$$

The DDS Input bits are bits (30 .. 1)

$$Switch\ Settings\ (30..1) = 010\ 0000\ 0110\ 0001\ 1000\ 0110\ 0001\ 110$$

Example 2:

Setup DDS for the Mode 50 Damper, (m=50).

$$FW = 2^{32} \cdot \frac{\left(1 + \frac{50}{84}\right)}{8} = 2^{32} \cdot 0.199405 = 856{,}436{,}931$$

The 32-bit binary version of this number is

$$FW(31\,..\,0) = 0011\ 0011\ 0000\ 1100\ 0011\ 0000\ 1100\ 0011$$

The DDS Input bits are bits (30 .. 1)

$$Switch\ Settings\ (30\,..\,1) = 011\ 0011\ 0000\ 1100\ 0011\ 0000\ 1100\ 001$$

System Using the Front End Damper Module and the x2 Clock.

For the second damper system we will use a DDS reference clock, F_{CLK}, that will be 2 times higher than the LLRF Reference Frequency, f_o, and we will downconvert the mode frequencies in the beam pickup signal using this $2 \cdot f_o$clock. The DDS output frequency, F_{OUT}, is to be the downconverted mode frequency of the mode we wish to damp $f_{mode}{}^{*}$.

$$f_{mode}{}^{*} = 2 \cdot f_o - f_{mode} = 2 \cdot f_o - \left(f_0 + f_0 \cdot \frac{m}{84}\right) = f_0 - f_0 \cdot \frac{m}{84}\ , for\ m = 1 \cdots 83$$

Therefore we can determine the frequency setting as

$$FW = 2^{32} \cdot \frac{\left(1 - \frac{m}{84}\right) \cdot f_o}{2 \cdot f_o} = 2^{32} \cdot \frac{\left(1 - \frac{m}{84}\right)}{2}$$

Example 3:

Setup DDS for the Mode 47 Damper, (m=47).

$$FW = 2^{32} \cdot \frac{\left(1 - \frac{47}{84}\right)}{2} = 2^{31} \cdot 0.440476 = 945{,}915{,}416$$

The 32-bit binary version of this number is

$$FW(31\,..\,0) = 0011\ 1000\ 0110\ 0001\ 1000\ 0110\ 0001\ 1000$$

The DDS Input bits are bits (30 .. 1)

$$Switch\ Settings\ (30\,..\,1) = 011\ 1000\ 0110\ 0001\ 1000\ 0110\ 0001\ 100$$

For the modes currently damped using this configuration we have the following switch settings.

Mode 47 : $Switch\ Settings\ (30\ ..\ 1) = 011\ 1000\ 0110\ 0001\ 1000\ 0110\ 0001\ 100$

Mode 51 : $Switch\ Settings\ (30\ ..\ 1) = 011\ 0010\ 0100\ 1001\ 0010\ 0100\ 1001\ 001$

Mode 52 : $Switch\ Settings\ (30\ ..\ 1) = 011\ 0000\ 1100\ 0011\ 0000\ 1100\ 0011\ 000$

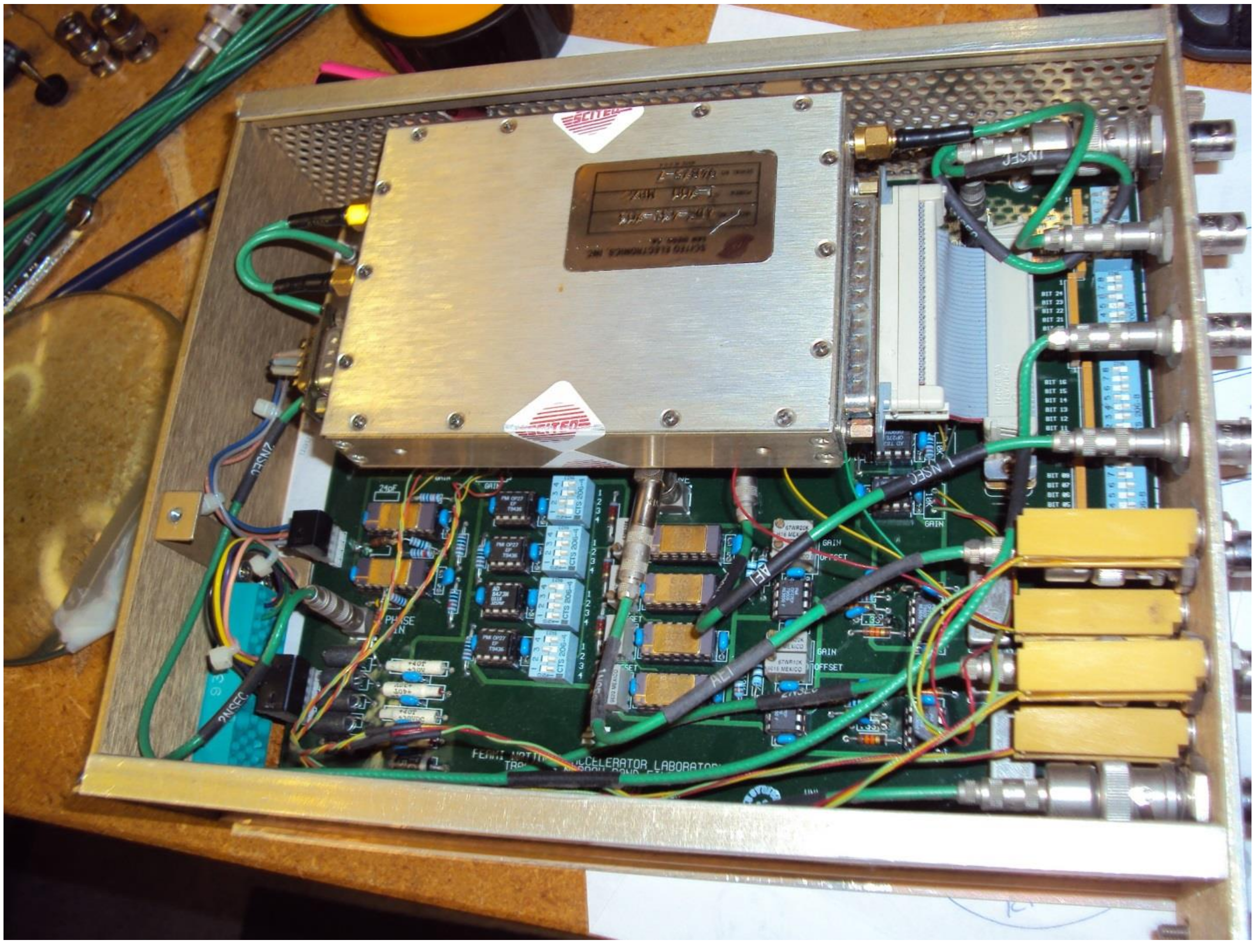


Figure A.1 Tracking Narrowband Filter Module.

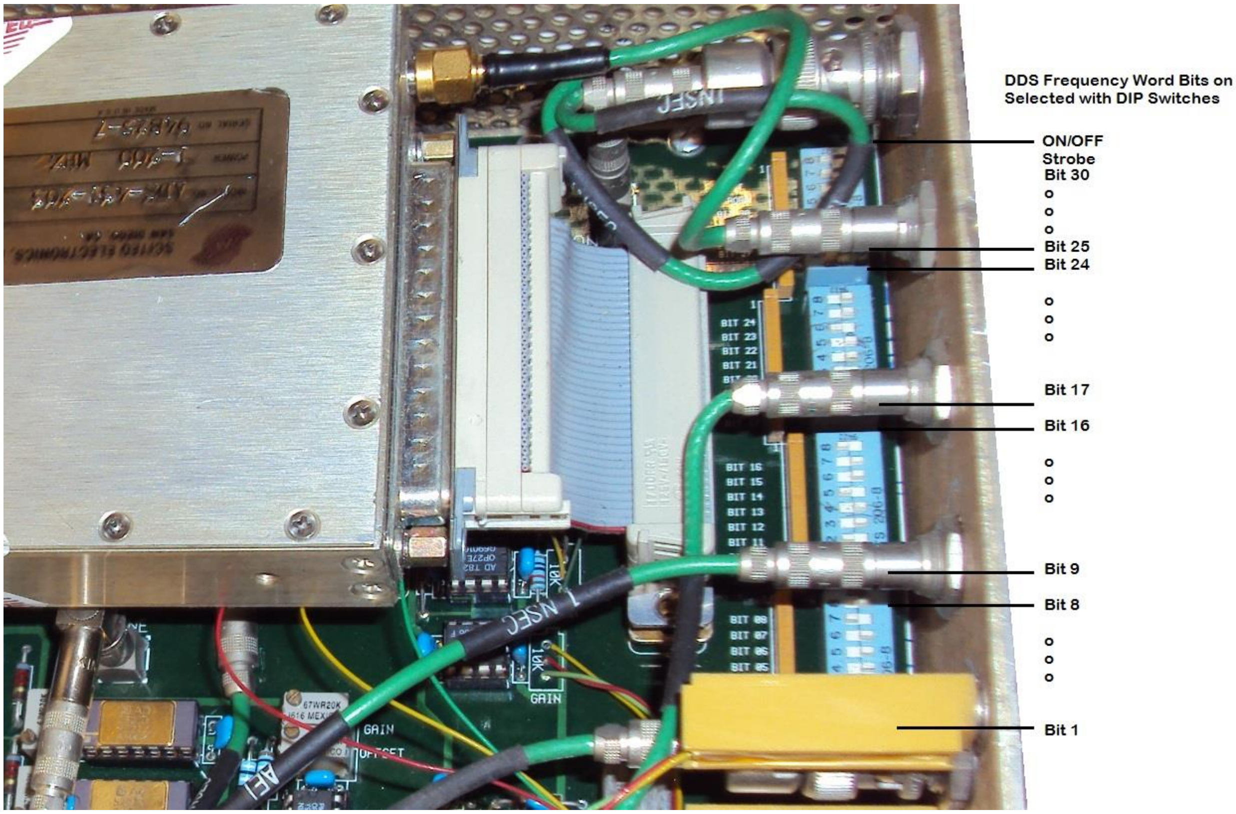


Figure A.2 Location of the DDS Frequency Word selection DIP switches.

Appendix B: Tracking Narrow Band Filter Functional Checks

The following test is meant to test the basic function of the mode dampers. There are two versions of the damper modules. One is provided a DDS clock at 8x the LLRF reference frequency and takes the beam pickup signal directly, and the second provides a DDS clock at 2x the LLRF reference frequency and downconverts the mode frequencies on the beam pickup signal before sending to the Tracking Narrow Band Filter modules.

Table B.1 lists the frequencies of the currently damped modes given points through the Booster LLRF reference frequency sweep.

Table B.1 Input Beam Frequencies of Interest, MHz

	Mode							
Fllrf	1	2	47	48	49	50	51	52
37	37.440	37.881	57.702	58.143	58.583	59.024	59.464	59.905
38	38.452	38.905	59.262	59.714	60.167	60.619	61.071	61.524
39	39.464	39.929	60.821	61.286	61.750	62.214	62.679	63.143
40	40.476	40.952	62.381	62.857	63.333	63.810	64.286	64.762
41	41.488	41.976	63.940	64.429	64.917	65.405	65.893	66.381
42	42.500	43.000	65.500	66.000	66.500	67.000	67.500	68.000
43	43.512	44.024	67.060	67.571	68.083	68.595	69.107	69.619
44	44.524	45.048	68.619	69.143	69.667	70.190	70.714	71.238
45	45.536	46.071	70.179	70.714	71.250	71.786	72.321	72.857
46	46.548	47.095	71.738	72.286	72.833	73.381	73.929	74.476
47	47.560	48.119	73.298	73.857	74.417	74.976	75.536	76.095
48	48.571	49.143	74.857	75.429	76.000	76.571	77.143	77.714
49	49.583	50.167	76.417	77.000	77.583	78.167	78.750	79.333
50	50.595	51.190	77.976	78.571	79.167	79.762	80.357	80.952
51	51.607	52.214	79.536	80.143	80.750	81.357	81.964	82.571
52	52.619	53.238	81.095	81.714	82.333	82.952	83.571	84.190
53	53.631	54.262	82.655	83.286	83.917	84.548	85.179	85.810

F mode = F llrf + mode*(Fllrf/84)

Table B.2 lists the downconverted mode frequencies used in the x2 Clock version of the damper modules.

Table B.2 Downconverted Mode Frequencies, MHz

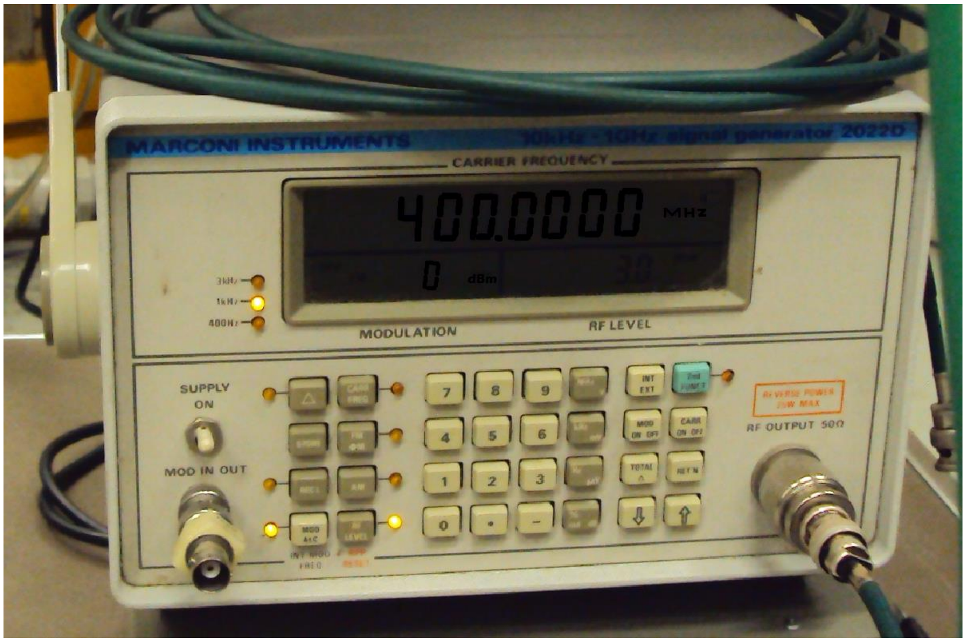
Front End Damper Module Output

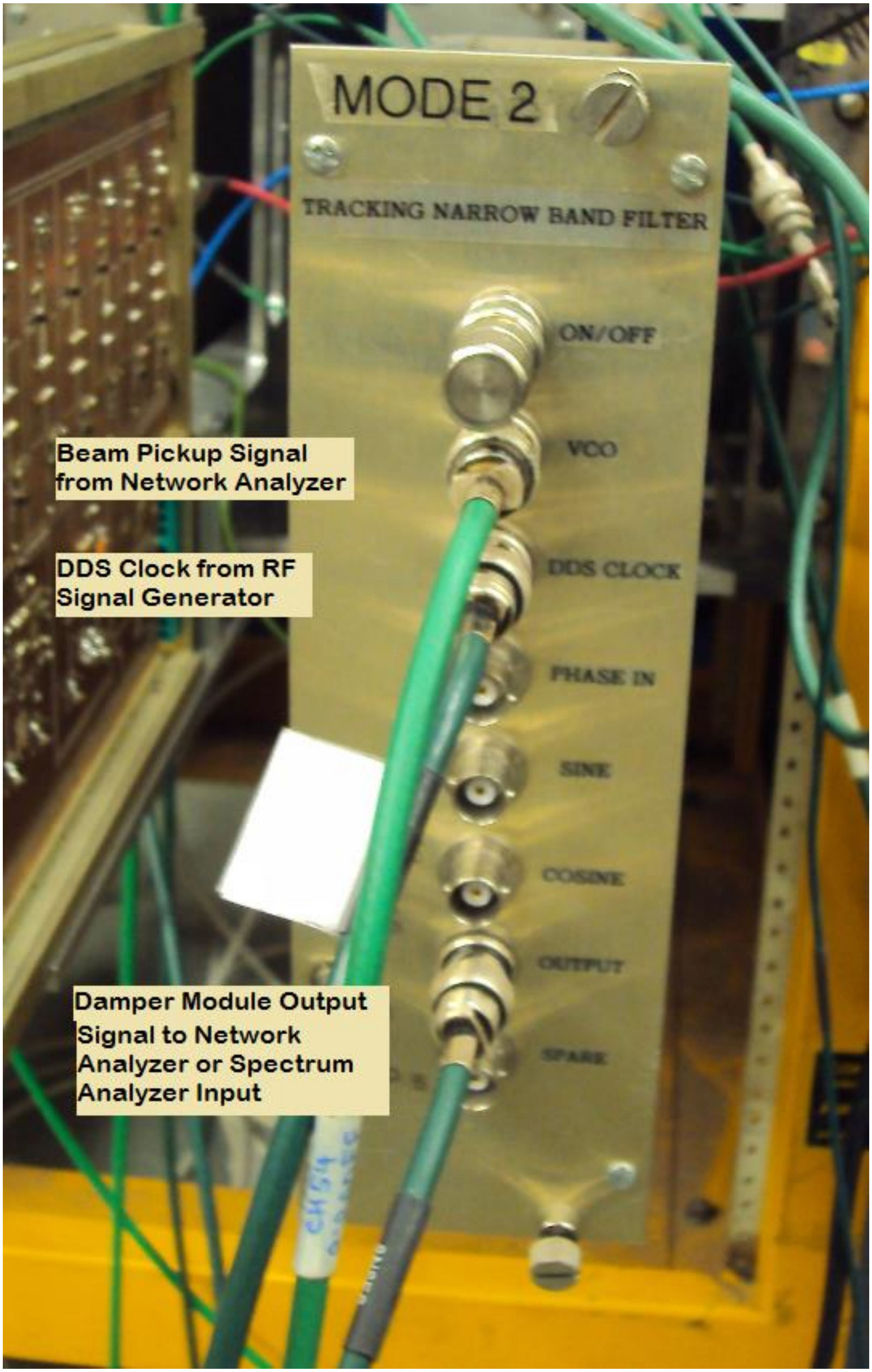
Fllrf	Fclk = 2 x F llrf	F mixer out Fclk - F llrf	Down Converted Mode 1	2	47	48	49	50	51	52
37	74.000	37.000	36.560	36.119	16.298	15.857	15.417	14.976	14.536	14.095
38	76.000	38.000	37.548	37.095	16.738	16.286	15.833	15.381	14.929	14.476
39	78.000	39.000	38.536	38.071	17.179	16.714	16.250	15.786	15.321	14.857
40	80.000	40.000	39.524	39.048	17.619	17.143	16.667	16.190	15.714	15.238
41	82.000	41.000	40.512	40.024	18.060	17.571	17.083	16.595	16.107	15.619
42	84.000	42.000	41.500	41.000	18.500	18.000	17.500	17.000	16.500	16.000
43	86.000	43.000	42.488	41.976	18.940	18.429	17.917	17.405	16.893	16.381
44	88.000	44.000	43.476	42.952	19.381	18.857	18.333	17.810	17.286	16.762
45	90.000	45.000	44.464	43.929	19.821	19.286	18.750	18.214	17.679	17.143
46	92.000	46.000	45.452	44.905	20.262	19.714	19.167	18.619	18.071	17.524
47	94.000	47.000	46.440	45.881	20.702	20.143	19.583	19.024	18.464	17.905
48	96.000	48.000	47.429	46.857	21.143	20.571	20.000	19.429	18.857	18.286
49	98.000	49.000	48.417	47.833	21.583	21.000	20.417	19.833	19.250	18.667
50	100.000	50.000	49.405	48.810	22.024	21.429	20.833	20.238	19.643	19.048
51	102.000	51.000	50.393	49.786	22.464	21.857	21.250	20.643	20.036	19.429
52	104.000	52.000	51.381	50.762	22.905	22.286	21.667	21.048	20.429	19.810
53	106.000	53.000	52.369	51.738	23.345	22.714	22.083	21.452	20.821	20.190

Mode Frequencies Passed by the Output Filter

Checkout Procedure

1. An RF sinewave signal source is setup for 400 MHz, 0 dBm. This is approximately 8x the final Booster LLRF Frequency (50.0 MHz). This signal is connected to the DDS Clock input of the device under test (DUT).




MODE 2
TRACKING NARROW BAND FILTER
ON/OFF
VCO
DDS CLOCK
PHASE IN
SINE
COSINE
OUTPUT
SPARE
Beam Pickup Signal from Network Analyzer
DDS Clock from RF Signal Generator
Damper Module Output Signal to Network Analyzer or Spectrum Analyzer Input

2. A Network Analyzer is setup to produce the Beam Pickup signal. This network analyzer output is connected to the Beam In or VCO input connection on the Damper Module.

   x8 Clock Version: The network analyzer frequency is set to sweep through the mode frequency at which the module has been setup to damp.
   If it is not apparent which mode the module has been setup for, recall the method for determining the DIP switch settings in Appendix A and work back through the equations

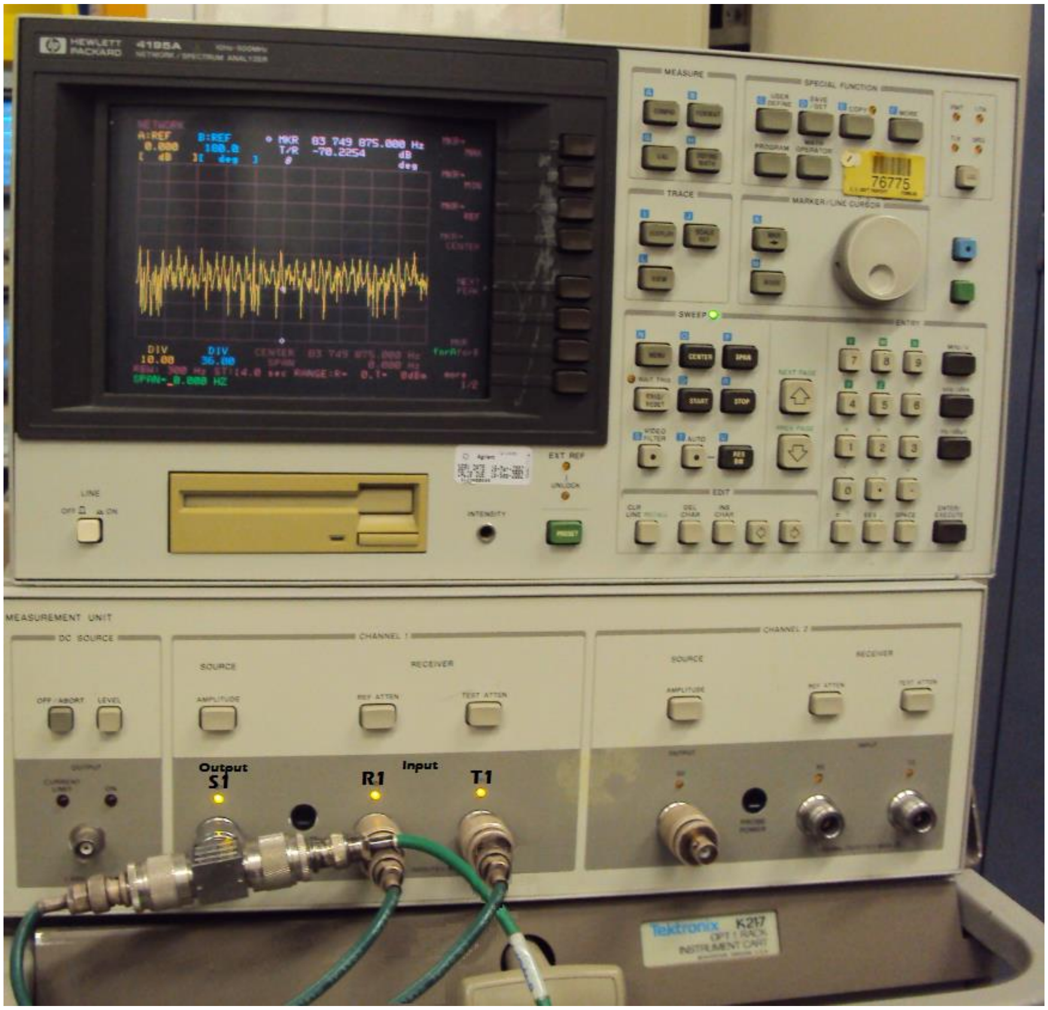
$$\left(FW \cdot \frac{8}{2^{32}} - 1\right) \cdot 84 = mode$$

   Recall that the 32-bit frequency word is the Switch Settings(31 .. 1) with zero's attached at either end for bit 32 and bit 0.

   X2 Clock Version: The network analyzer frequency is set to sweep through the downconverted mode frequency at which the module has been setup to damp. Refer to Table B.2 for this frequency.
   Again, to determine the mode the module is setup for work back using the appropriate method in Appendix A.

$$\left(1 - FW \cdot \frac{2}{2^{32}}\right) \cdot 84 = mode$$

   Recall that the 32-bit frequency word is the Switch Settings(31 .. 1) with zero's attached at either end for bit 32 and bit 0.



3. The network analyzer should show a peak near the mode frequency (or downconverted mode frequency). By centering the display on this peak and reducing the frequency "Scan" width to approximately 20 kHz, we hope to see a display similar to that in Figure B.1 below.

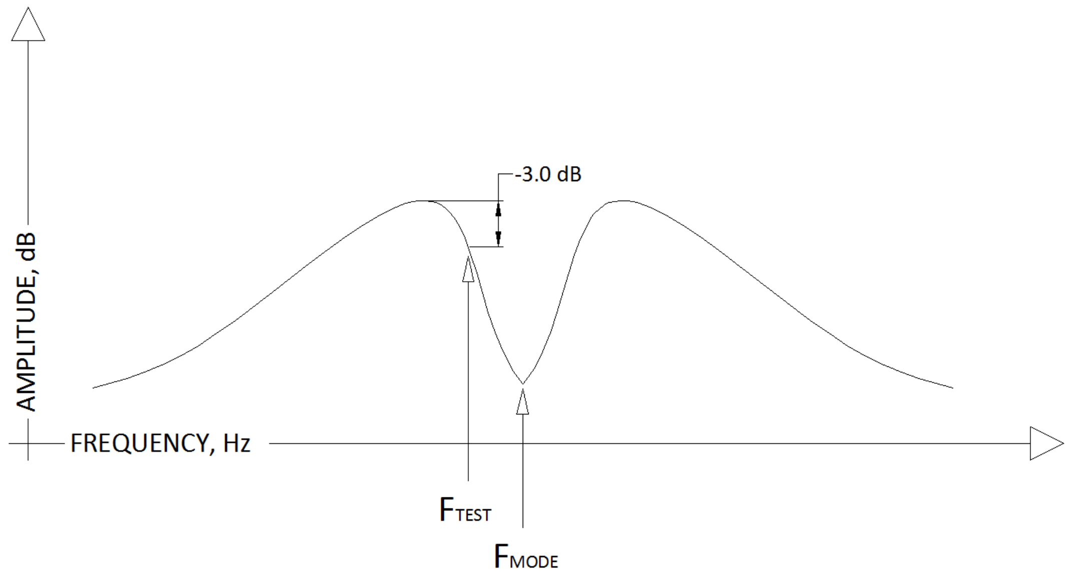


Figure B.1 Network Analyzer Display.

4. Determine the frequency of F_{TEST} as indicated in Figure B.1. Center the network analyzer at this frequency then set the frequency span to 0 Hz. This will drive a constant frequency (CW) signal into the damper module.
5. Remove the output of the damper module from the T1 input of the network analyzer and connect to a spectrum analyzer.
6. Adjust the spectrum analyzer to find and display something similar to Figure B.2. Note the expected location of F_{TEST} .

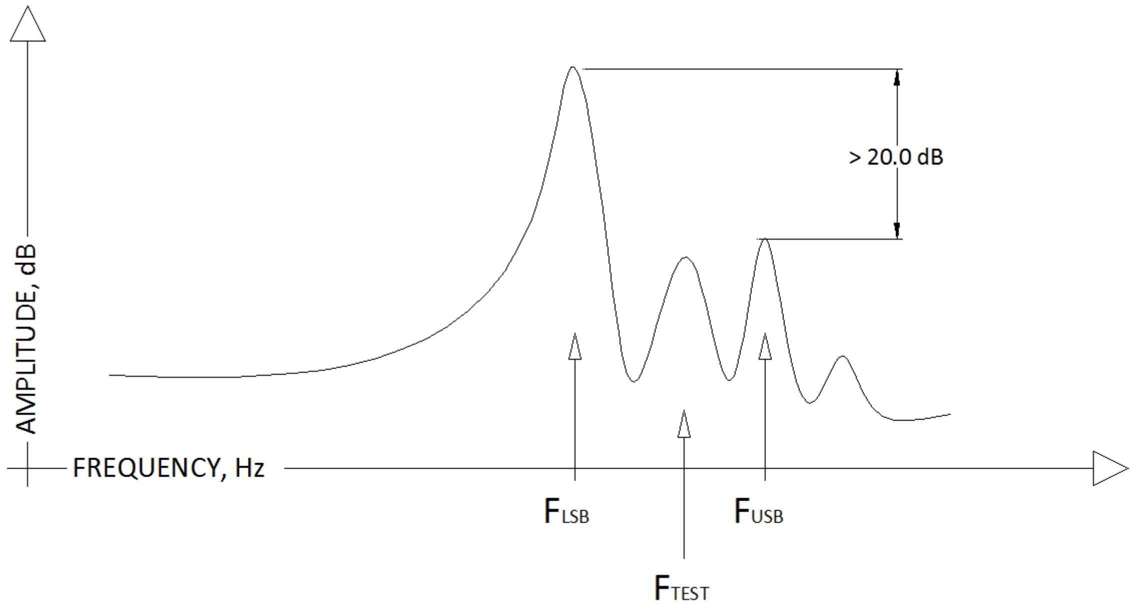


Figure B.2 Spectrum Analyzer Display

7. Under normal operation the mode frequency will be modulated by the oscillations we wish to damp. This modulation would appear as sidebands on either side of the fundamental mode frequency. The damper module is designed to select the lower side band (F_{LSB}) to produce the feedback to damp the oscillation.

   In this test, higher order mixer products generated by the downconversion stage in the damper module are used to examine the adjustment of the circuit and probe the filtering in place of the modulation sidebands.

   The lower side band amplitude should be 20 dB greater than the upper side band at F_{USB}.