Electronic Systems for Proposed Anti-Proton Source Accumulator Core Betatron Systems

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Abstract: *New waveguide pickups and kickers have been proposed for the accumulator core betatron systems. With new waveguide components, the electronics of the system have to be redesigned. The waveguide components have new frequency bands and power concerns that have to be addressed. This paper discusses the calculations used to design the new electronic system, and it also discusses the practical concerns of the electronic hardware.*

Waveguide pickups

The proposed accumulator betatron system consists of three frequency bands. The frequency bands are shown in Table 1. Each band has a trunk that goes across the ring from the pickup to the kicker. This leads to a total of six trunks, and six of each electronic component. Three for the horizontal system, and three for the vertical system.

Band 1	4.35 – 5.65 GHz
Band 2	5.35 – 6.65 GHz
Band 3	6.35 – 7.65 GHz

Table 1. Frequency bands of waveguide pickups.

Electronic Gain of the System

The electronic gain of the proposed system is approximated using calculations shown in appendix A. These calculations include the electronic gain for the proposed bands 1, 2, 3, and it also contains calculations for the electronic gain of the existing system. The calculated electronic gain of the existing system is compared to the actual measured electronic gain of the existing system to verify that the calculations can be used to design the new proposed system.

Measurement of the Existing System

The measurement of the existing system was measured using a network analyzer and a power meter. The operational bandwidth of the existing system is about 3.8–5 GHz. The measurement of electronic gain was made at one frequency point of 4.5 GHz. The network analyzer in the AP 10 control room was used to generate the 4.5 GHz signal. The signal from the network analyzer was sent to the input of the electronic system at the 20 dB coupler following the 180 Hybrid at the pickup. A power meter was used to measure the total signal power going into the system. The signal power that should be used at the input of the existing system is determined using the calculations shown in appendix A and appendix B. From the calculations, the power should be about –67.7 dBm. The actual measured power going into the system was –69.8 dBm. A diagram of the measurement is shown in fig 1. With the system turned on, the power at the output of the system was measured to be 42.2 dBm. This results in a total gain for the existing electronic system of 112 dB. The calculated electronic gain from appendix A is 98 dB. This shows that the calculations need to be adjusted by 14 dB. The design of the new proposed system will take into account the 14 dB difference and adjust any calculations from appendix A.

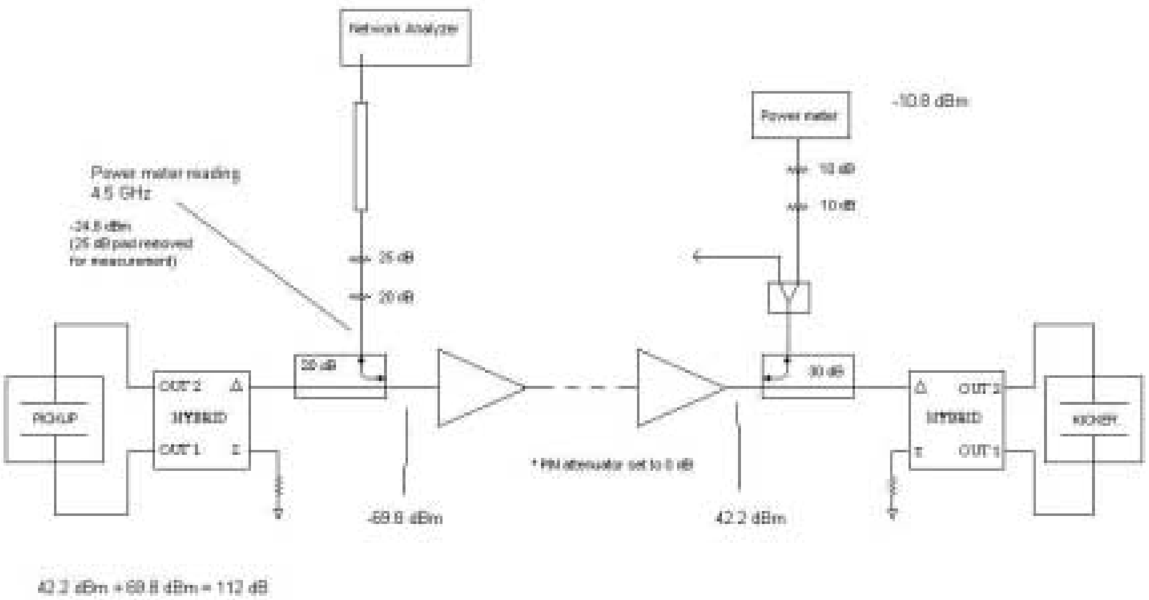


Fig. 1. Diagram of measurement of electronic gain of the existing system

Power Amplifier at the Kicker

From appendix A, the calculated total power at the kicker is 65 mW with 120 mA of beam current. This is about 18 dBm of signal power at the kicker. Using the measured results of the existing system, 14 dB should be added to this number to get a better approximation of the actual power needed at the kicker. This adds up to 32 dBm, which is a little less than 2 Watts. To be safe, and to have extra power at the kicker, an 8 Watt power amplifier was chosen to supply power to the kicker. The amplifier is a Microwave Power Inc, model #L0408-40-S302. The amplifier has a single tone 1 dB compression point of 8 Watts, but the amplifier has a 1 dB compression point at about 5 Watts when broadband noise is applied at the input. The broadband noise 1 dB compression test is a better specification for this application because the amplifier will be under similar conditions while in operation. Using the broadband 1 dB compression test, about 5 Watts is assumed as the practical limit of this amplifier. More watts can be achieved, but the non-linearity of the amplifier above 5 watts would hinder the performance of the system. A typical set of measurements for one the amplifier's is shown in appendix D.

System Electronics from Pickup to Kicker

The system electronics are divided up into three sub systems. There is the low level electronics, medium level electronics, and high level electronics. The classification of sub systems is related to the power levels. The low level electronics are right at the pickup and amplify the small signal with minimal noise. The medium level electronics amplifies the signal sufficiently enough for it to be sent across the ring in the trunks. The high level electronics amplifies the signal to supply several watts of power to the kicker.

The components that make up the low level electronics are shown in fig 2. At the pickup, a 180 hybrid is needed at the output of the waveguide pickup to take the difference signal. A trombone is placed between the pickup and the hybrid so that the common mode rejection can be maximized. The trombone is a 125 ps range Narda 29784, and the 180 hybrid is a Fermi made Petter hybrid. After the hybrid, a 20 dB coupler is used for injecting a test signal into the system. The coupler is a Narda 4014C-20. A low noise amplifier follows the 20 dB coupler. The low noise amplifier is a Miteq #AFS4-04000800-08-10P-4. The amplifier has a gain of 42 dB, and a noise figure of 0.8. Next is a DBS #DB97-1787 low level amplifier with a gain of 31 dB. The power level at the output of this amplifier is approximately +6 dB, with a beam current of 120 mA.

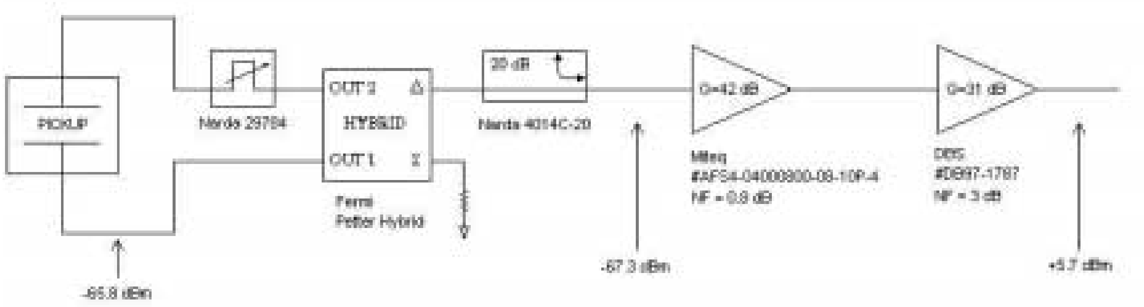


Fig. 2. Low level electronics

The components that make up the medium level electronics and are shown in fig 3. A trombone to adjust the time delay between the pickup and the kicker is the first component of the medium level electronics. The trombone is a 500 ps Narda 27223. After the trombone, a bandpass filter is needed to eliminate side lobes outside the band. Fermi made bandpass filters are used for this. These filters are coupled line filters and have high reflections outside the passband, so 3 dB pads are placed on the input and output of the filters to suppress reflections. Next in the system is a Narda 4014C-20 20 dB coupler for extracting a test signal. A transfer switch follows the 20 dB coupler. The transfer switch is used to make measurements of the total transfer function of the system.

The transfer switch is model DMT T4-413E291 B. After the transfer switch, a pin attenuator is used to adjust the total gain of the system. The pin attenuator has an insertion loss of 6 dB, and a total of 31.75 dB of attenuation can be added to the system. The pin attenuator is a GT Microwave model A3P-58N-ODF. After the pin attenuator is a pin diode switch, to turn the system ON or OFF. The pin switch is a Miteq #N136 ANM1. Next is a DBS #DB97-1788 1 Watt amplifier. This is the last amplifier before the trunk. The last component before the trunk is a power splitter. A power sensing diode is placed on one output of the splitter to measure the power level, and the other output of the splitter goes to the trunk. The trunk is ½ inch helix cable, with approximately 28 dB of loss at 7 GHz (Band 3).

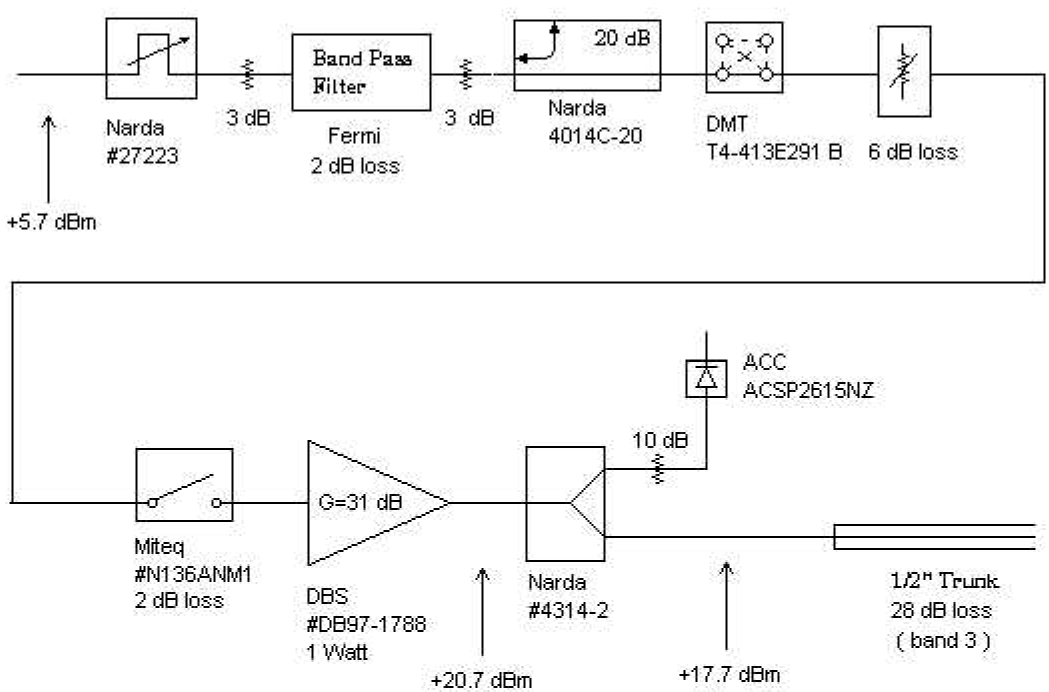


Fig. 3. Medium level electronics.

The high level electronics are shown in fig 4. After the trunk, a 6 dB pad is used to adjust the power level. Different values of attenuation are used for each band because the electronic gain is different for each band, and the losses in the trunk are different for each band. The 8 watt amplifier is used as the last stage of amplification before the kicker. The 8 Watt amplifier has about 55 dB of gain. A 20 dB coupler is placed at the output of the 8 Watt amplifier for signal testing. After the 20 dB coupler, a Fermi made Petter 180 hybrid connects directly to the kicker. The complete electronics system is shown in appendix D.

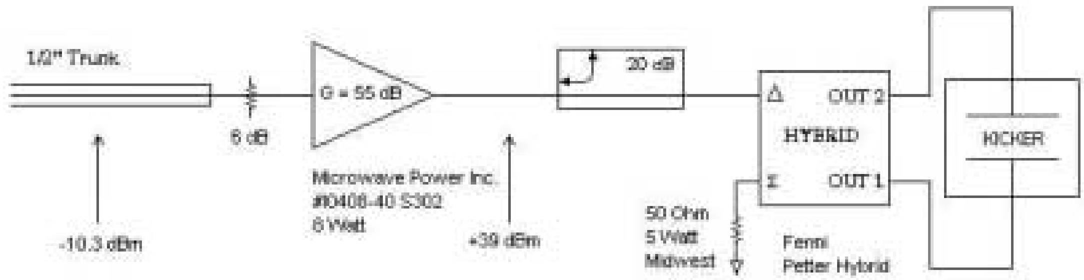


Fig. 4. High level electronics

System Gain and Power

The system is capable of about 105 dB of gain and 8 Watts of power at the kicker. As mentioned earlier, pushing the amplifier to 8 Watts would introduce non-linearity into the system, but the option to increase power is available. The pin attenuator in the medium level electronics can add up to 31 dB of attenuation, giving the system an electronic gain range between 74 to 105 dB. The attenuator in the high level electronics can also be used to further adjust the range of the electronic gain.

Noise Figure

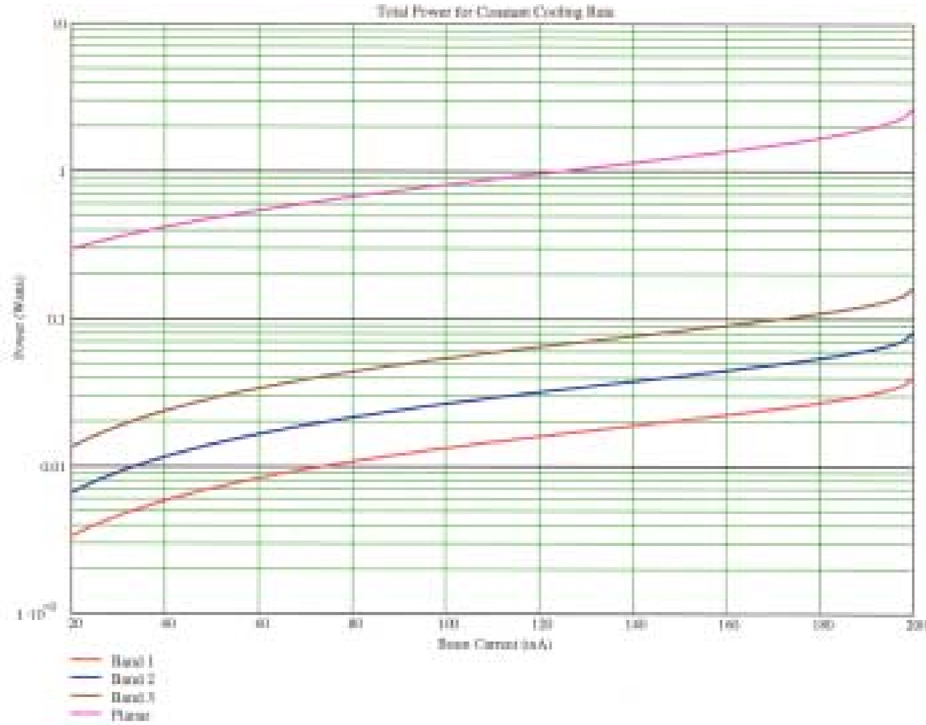
The noise figure of the system is calculated to be 2.376 dB. The noise figure of the system is largely due to the losses directly at the pickup, and the noise figure of the first amplifier. This is the reason for low noise amplifier at the input with a noise figure of 0.8 dB. The losses directly at the pickup are from the cables, trombone, and 180 hybrid. The equation for noise figure is

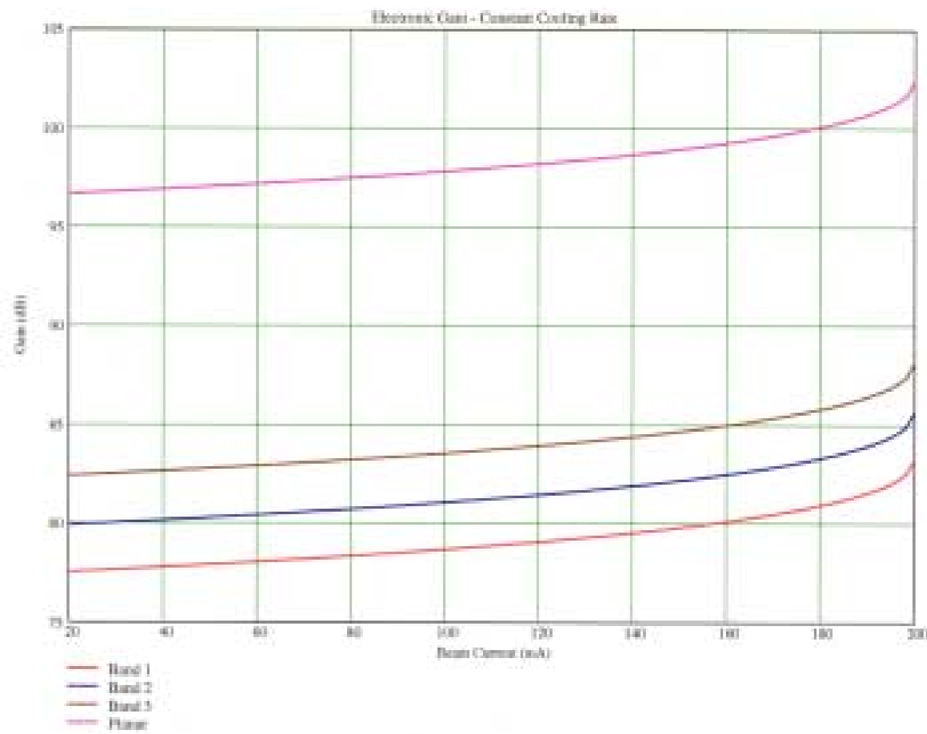
$$F := F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \,..$$

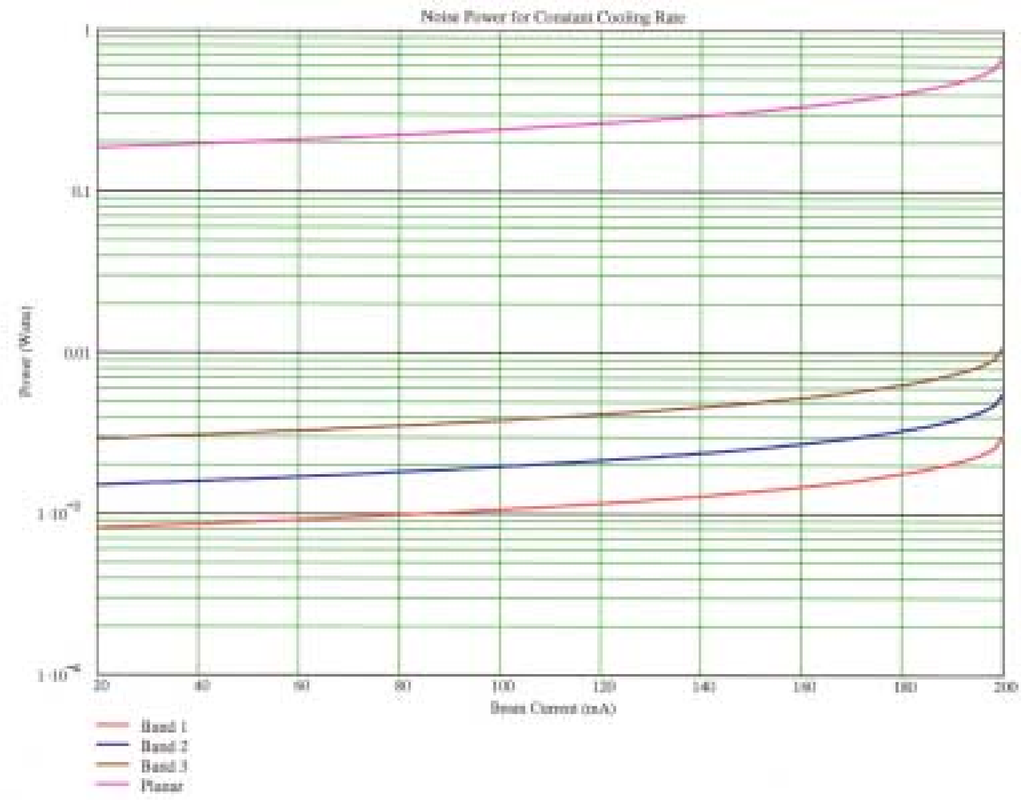
From the equation above, it is clear that the first two terms contribute the most to the noise figure. For this system, F1 is from the cables, trombone, and hybrid, and F2 is from the noise figure of the low noise amplifier. G1 is the loss in the cables, trombone, and hybrid, and G2 is the gain of the low noise amplifier. The noise calculations can be seen in appendix B.

Appendix A

Constant cooling power and gain plots (Courtesy Dave McGinnis)






Noise Power for Constant Cooling Rate
Power (Watts)
1
0.1
0.01
$1\cdot10^{-3}$
$1\cdot10^{-4}$
20
40
60
80
100
120
140
160
180
200
Beam Current (mA)
Band 1
Band 2
Band 3
Planar

Appendix B

Electronic System Calculations for Core Betatron Electronics Ed Cullerton 3/11/02

Calculated Signal Power Power at Pickup of the Existing System

$SE_o := 980 \quad mW$ From data in Appendix A - Total power at 120 mA

$SE_{o\_dBm} := 10 \cdot \log(SE_o) \qquad SE_{o\_dBm} = 29.912 \ dBm$

$NE_o := 270 \ mW$ From data in Appendix A - Noise Power at 120 mA

$NE_{o\_dBm} := 10 \cdot \log(NE_o) \qquad NE_{o\_dBm} = 24.314 \ dBm$

$SE_{i\_dBm} := SE_{o\_dBm} - 98 \qquad SE_{i\_dBm} = -68.088 \ dBm$

$SE_i := 10^{\frac{SE_{i\_dBm}}{10}} \qquad SE_i = 1.553 \cdot 10^{-7} \quad mW$

$SNE_o := \frac{SE_o}{NE_o} \qquad SNE_i := 3 \cdot SNE_o$ A Noise figure of 3 dB was used in the noise calculations shown in Appendix A

$SNE_o = 3.63 \qquad SNE_i = 10.889$

$NE_i := \frac{SE_i}{SNE_i} \qquad NE_i = 1.426 \cdot 10^{-8} \ mW \quad NE_{i\_dBm} := 10 \cdot \log(NE_i) \qquad NE_{i\_dBm} = -78.458 \quad dBm$

$PE_i := SE_i + NE_i \qquad PE_i = 1.696 \cdot 10^{-7} \quad mW$

$PE_{i\_dBm} := 10 \cdot \log(PE_i) \qquad PE_{i\_dBm} = -67.706 \ dBm$

Noise and Gain Calculations for Proposed System

* All calculations are made for Band 3 of the proposed system

$T_{tun} := 311 \qquad T_0 := 290$

G1, F1 = Losses: trombone, hybrid, coupler
1.5 dB

$$G_1 := \frac{1}{10^{\frac{1.5}{10}}} \qquad F_1 := 1 + \left(\frac{1}{G_1} - 1\right)\cdot\frac{T_{tun}}{T_0}$$

G2, F2 = LNA Miteq AFS4-04000800-08-10p-4
F=0.8 dB (max)
G=42 dB (typ)

$$G_2 := 10^{\frac{42}{10}} \qquad F_2 := 10^{\frac{0.8}{10}}$$

G3, F3 = Amplifier DBS #DB97-1787
F=3 dB (max)
G=31 dB (typ)

$$G_3 := 10^{\frac{31}{10}} \qquad F_3 := 10^{\frac{3}{10}}$$

G4, F4 = Losses:

trombone	0.2	dB
BPF filter	8	dB
coupler	0.2	dB
transfer switch	0.4	dB
total	8.8	dB

$$G_4 := \frac{1}{10^{\frac{8.8}{10}}} \qquad F_4 := 1 + \left(\frac{1}{G_4} - 1\right)\cdot\frac{T_{tun}}{T_0}$$

G5, F5 = Losses:

variable attenuator	6	dB
Pin diode switch	2	dB
total	8	dB

$$G_5 := \frac{1}{10^{\frac{8}{10}}} \qquad F_5 := 1 + \left(\frac{1}{G_5} - 1\right)\cdot\frac{T_{tun}}{T_0}$$

G6, F6 = Amplifier DBS #DB97-1788
F=6 dB
G=31 dB

$$G_6 := 10^{\frac{31}{10}} \qquad F_6 := 10^{\frac{6}{10}}$$

G7, F7 = Losses: splitter, trunk
31 dB

$$G_7 := \frac{1}{10^{\frac{31}{10}}} \qquad F_7 := 1 + \left(\frac{1}{G_7} - 1\right)\cdot\frac{T_{tun}}{T_0}$$

G8, F8 = Amplifier Micowave Power, inc.
#l0408-40-s302
F=10 dB
G=45

$$G_8 := 10^{\frac{55}{10}} \qquad F_8 := 10^{\frac{10}{10}}$$

$F_1 = 1.442 \qquad F_2 = 1.202 \qquad F_3 = 1.995 \qquad F_4 = 8.063 \qquad F_5 = 6.694$

$F_6 = 3.981 \qquad F_7 = 1.35\cdot 10^3 \qquad F_8 = 10$

Proposed System Noise Figure

$$F := F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \frac{F_5 - 1}{G_1 \cdot G_2 \cdot G_3 \cdot G_4} + \frac{F_6 - 1}{G_1 \cdot G_2 \cdot G_3 \cdot G_4 \cdot G_5} + \frac{F_7 - 1}{G_1 \cdot G_2 \cdot G_3 \cdot G_4 \cdot G_5 \cdot G_6} + \frac{F_8 - 1}{G_1 \cdot G_2 \cdot G_3 \cdot G_4 \cdot G_5 \cdot G_6 \cdot G_7}$$

$F = 1.728$ $\quad F_{dB} := 10 \cdot \log(F)$

$F_{dB} = 2.376$

Propsed System Gain

$G := G_1 \cdot G_2 \cdot G_3 \cdot G_4 \cdot G_5 \cdot G_6 \cdot G_7 \cdot G_8$

$G = 9.333 \cdot 10^{10}$ $\quad G_{dB} := 10 \cdot \log(G)$

$G_{dB} = 109.7$ dB

Calculated Signal Power Power at Pickup of the Propsed System

$S_o := 65$ mW From data in Appendix A - Total power at 120 mA

$S_{o\_dBm} := 10 \cdot \log(S_o)$ $\quad S_{o\_dBm} = 18.129$ dBm

$N_o := 4$ mW From data in Appendix A - Noise Power at 120 mA

$N_{o\_dBm} := 10 \cdot \log(N_o)$ $\quad N_{o\_dBm} = 6.021$ dBm

$S_{i\_dBm} := S_{o\_dBm} - 84$ $\quad S_{i\_dBm} = -65.871$ dBm

$S_i := 10^{\frac{S_{i\_dBm}}{10}}$ $\quad S_i = 2.588 \cdot 10^{-7}$ mW

$SN_o := \frac{S_o}{N_o}$ $\quad SN_i := 3 \cdot SN_o$ A Noise figure of 3 dB was used in the noise calculations shown in Appendix A

$SN_o = 16.25$ $\quad SN_i = 48.75$

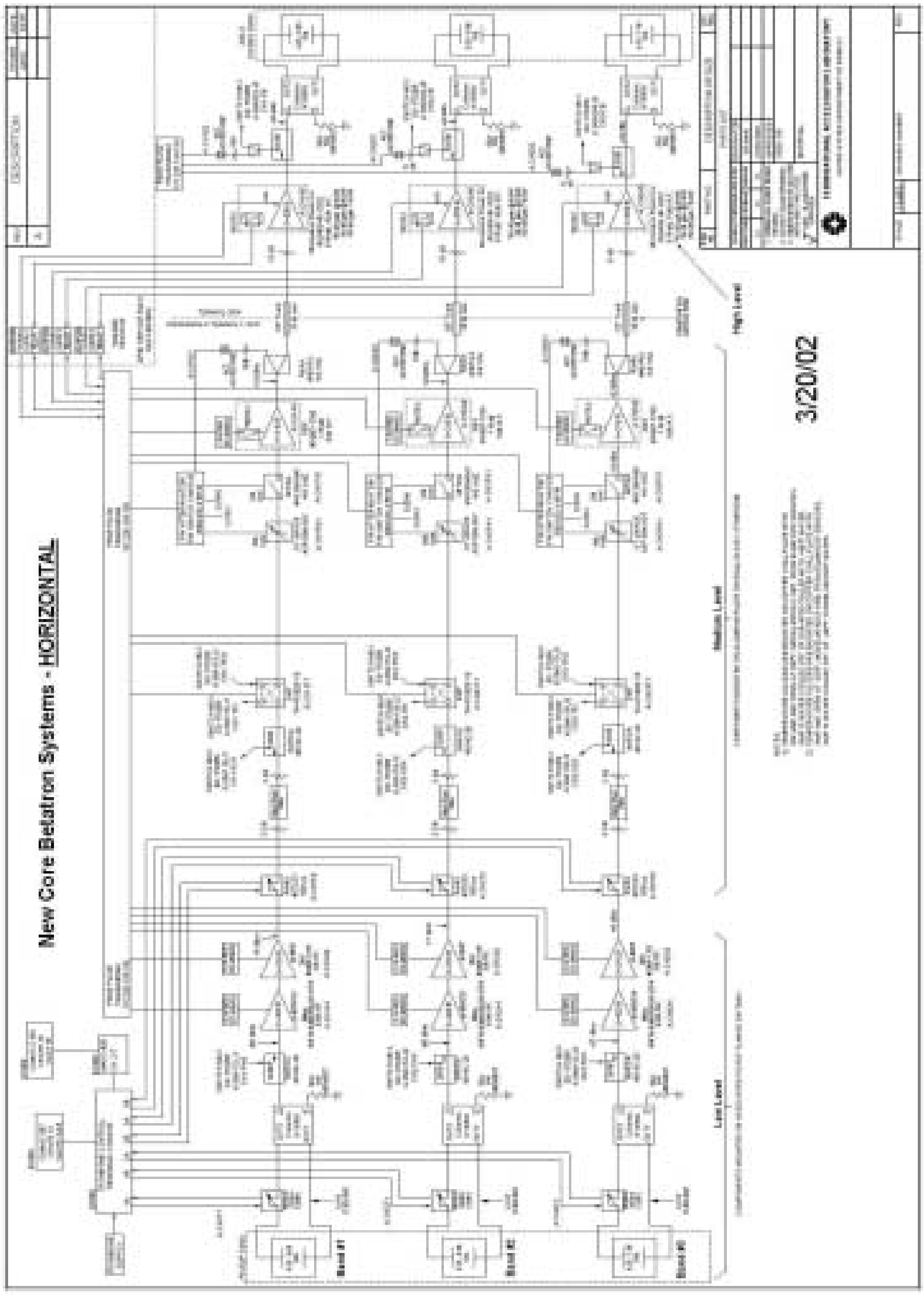
$N_i := \frac{S_i}{SN_i}$ $\quad N_i = 5.308 \cdot 10^{-9}$ mW $\quad N_{i\_dBm} := 10 \cdot \log(N_i)$ $\quad N_{i\_dBm} = -82.751$ dBm

$P_i := S_i + N_i$ $\quad P_i = 2.641 \cdot 10^{-7}$ mW

$P_{i\_dBm} := 10 \cdot \log(P_i)$ $\quad P_{i\_dBm} = -65.783$ dBm

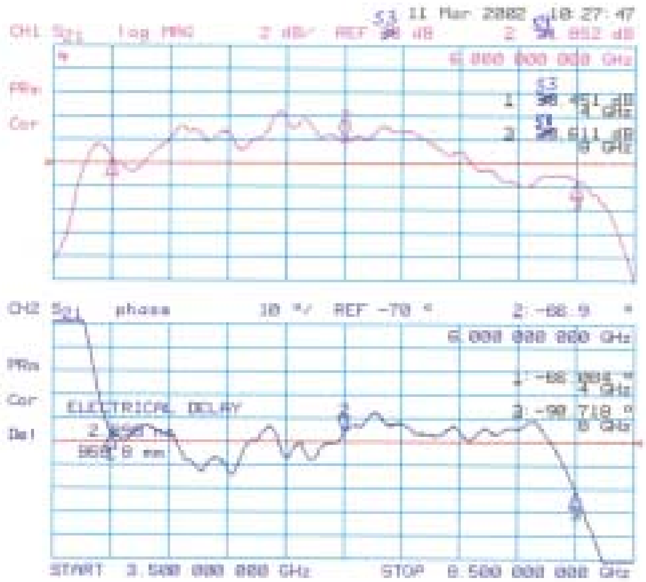
Appendix C

Proposed New Core Betatron Systems
(Courtesy Pete Seifrid and Wes Mueller)

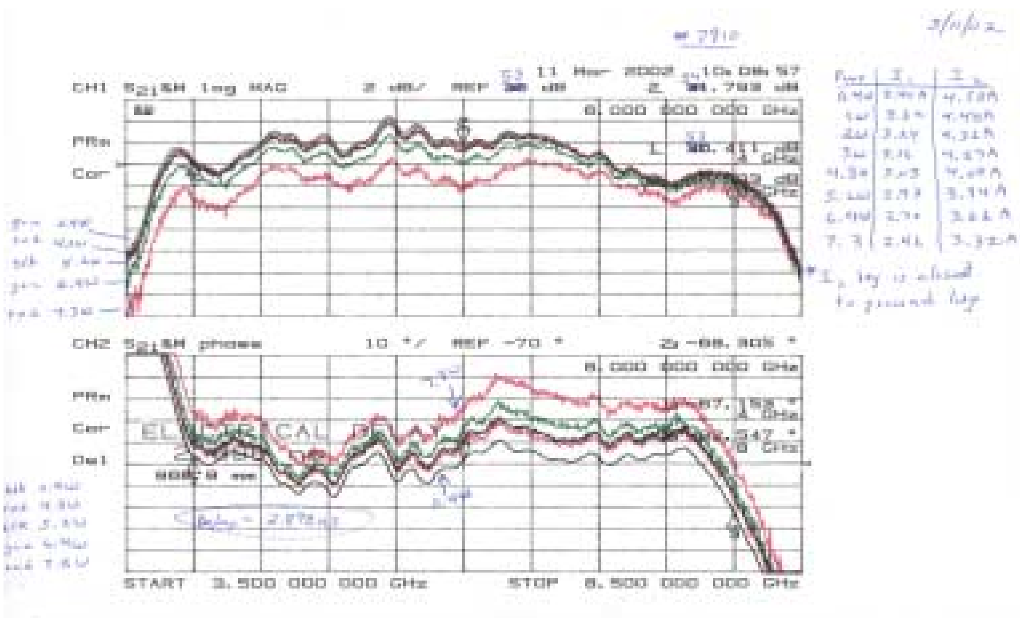


Appendix D

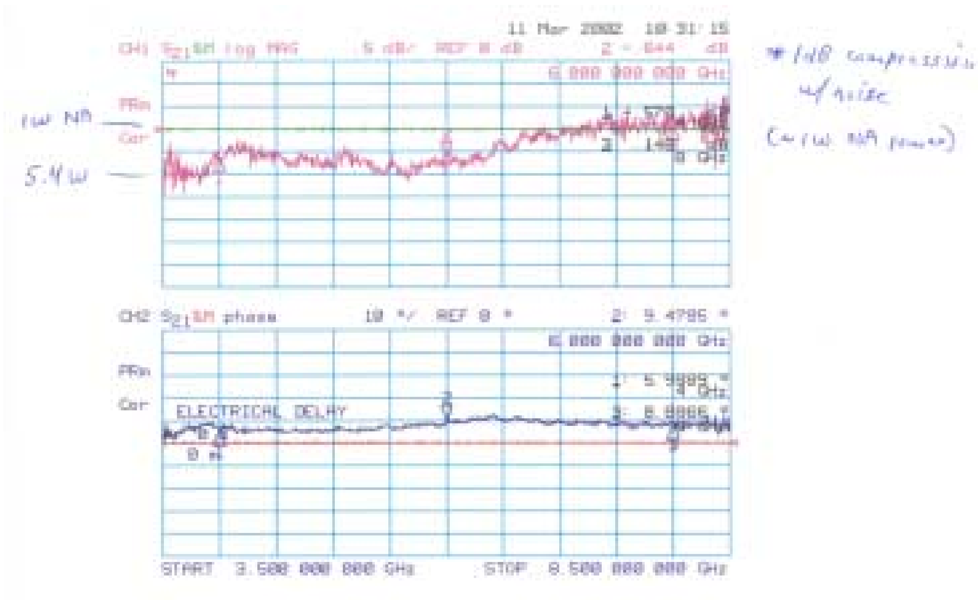
Typical Measurements of the Microwave Power Inc. Model #L0408-40-S302
(Courtesy Wes Mueller)



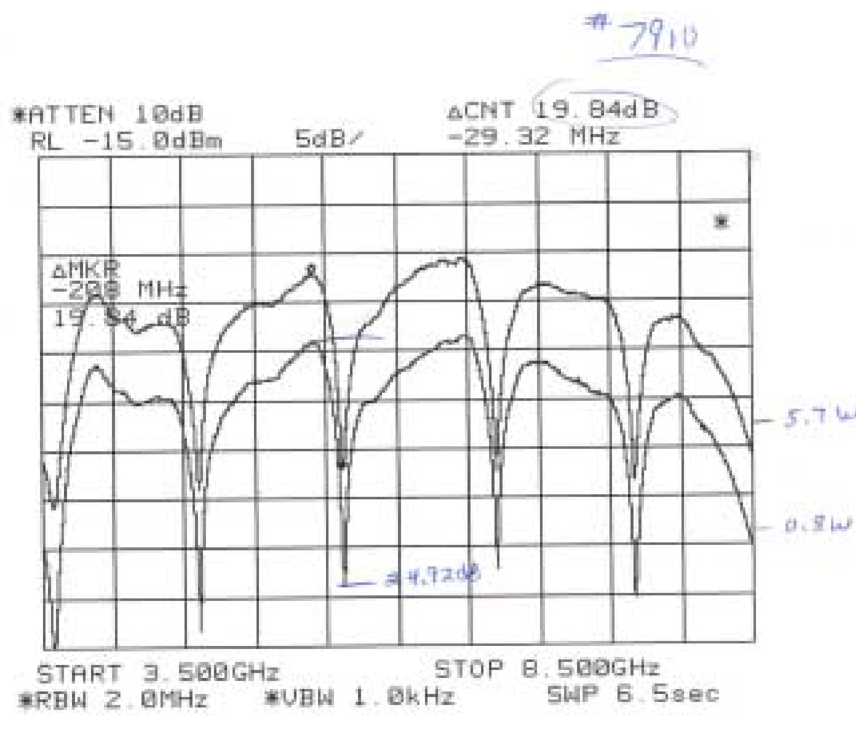
Small Signal Amplifier Gain



Amplifier Gain at Several Power Levels



1 dB Compression Point with Broadband Noise



Notch Test

For the notch test, an open circuit stub is placed at the input of the amplifier to create the notches. Broadband noise is applied at the input and the power levels are increased. The amount that the notches fill in as power increases is directly related to the non-linearity of the amplifier. The measurement above shows very little filling in of the notches, thus good linear performance.