Fermilab

$\bar{p}$ Note #408

RF Harmonic Power in Stochastic Cooling Pickup

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BPM NOTE
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There is some concern that harmonics of the 53 MHz beam modulation frequency will be sufficient to overdrive or damage the stochastic cooling preamplifiers during injection or extraction operations. The signal power picked up by the electrodes is analyzed for the following cases

1. Injection into the Debuncher. Every two seconds approximately 7×10^7 $\bar{p}$'s are injected into the Debuncher. The $\bar{p}$'s are accompanied by about 7×10^{10} π^-'s and e^-'s. The decay length of the π's is about 500 m (1.6 μsec) and the e's are lost due to synchrotron radiation in about 10 turns. The particles are very tightly bunched (rms bunch width about 150 psec) so there are many harmonics of 53 MHz present. The Debuncher pickups are 2-4 GHz in the difference mode configuration for betatron cooling. The pickups are in zero dispersion regions so the beam is directly under the electrodes. Only coherent betatron oscillations will produce a signal at the preamplifier as the sum mode ideally is cancelled.

2. During extraction from the Accumulator. A moving h=2 bucket (frequency about 1.25 MHz) moves a 200 nsec wide bunch of $\bar{p}$'s (about 10^{11}) from the core orbit to the extraction orbit. It is then recaptured in about 11-13 h=84 buckets (53 MHz) and then extracted to the Main Ring

Each bunch will have roughly 1×10^{10} $\bar{p}$'s and an rms bunch width of about 1 nsec. These bunched $\bar{p}$'s will be directly under the 2-4 GHz betatron pickups in the A10 straight section. The betatron oscillations (coherent) are not expected to be large, however. In the A60 region, the pickups most likely to be sensitive to RF modulated bunches are the 1-2 GHz stack tail momentum pickups. The beam will be displaced about 5 cm from the electrode center line so the sensitivity is reduced.

The rms output voltage of a stripline pickup is given by [BPM Design Note #9, R. Shafer, 8/17/82]

$$V_m = \sqrt{2}\, Z_0 F \langle I_b \rangle \sin\left(\frac{m\omega_0 l}{c}\right) \exp\left[\frac{-m^2\omega_0^2\sigma^2}{2}\right]$$

for Gaussian shape bunches of rms width σ. the variables are:

Z_0 = characteristic impedance of pickup (ohms)

$\langle I_b \rangle$ = average beam current (amps)

m = harmonic of 53 MHz

F = fraction of charge seen by pickup electrode (azimuthal).

ω_0 = $2\pi \times 53$ MHz = 3.34×10^8 sec^{-1}

l = pickup electrode length (cm)

c = 3×10^{10} cm/sec

σ = rms bunch width (sec)

V_m = rms voltage in m^{th} harmonic of 53 MHz.

On the next page the specific values used for the two analyzed cases are presented.

Parameter	2-4 GHz Debuncher	1-2 GHz Accumulator
Z_0	100	100 ohms
F	0.33	0.02
$\langle I_b \rangle$	.007	.085 amps
ω_0	3.34×10^8	$3.34 \times 10^8 \, sec^{-1}$
ℓ	2.5 cm	5 cm
σ	1.5×10^{-10} sec	1×10^{-9} sec

Tables I and II show the power in the 1st 100 harmonics for each case. Remember, this is the power per electrode. This is to be compared to the thermal power per 53 MHz band:

$$kT\Delta B = 1.38 \times 10^{-23} \times 78^\circ \times 53 \times 10^6 = 5.7 \times 10^{-11} \, mW$$
$$\Rightarrow -102 \, dbm$$

In the case of the Debuncher 2-4 GHz pickups, 64 electrodes are combined to give a difference signal into the preamp. If the beam is displaced about ½ way to one side of the aperture, the power per harmonic should be increased by

$$10 \log_{10} 32 + 10 \log_{10} 1/4 = 15db - 6db = +9db$$

in the 2-4 GHz band. The combiner efficiency is somewhat lower at lower frequencies (Ferd Voelker to provide table).

In the case of the Accumulator 1-2 GHz pickups, 64 electrodes are

are summed into each preamp. In this case the power per harmonic at the preamp should be increased by

$$10 \log_{10} 64 = +18 db$$

Again, the combiner efficiency is somewhat lower below the 1-2 GHz band. Ferd Voelker will supply table.

In conclusion, in the Debuncher during the 1st turn of injection the maximum power per harmonic will be about 0 dbm into the preamp at about 1 GHz (assuming good efficiency in the combiner at this frequency; and in the Accumulator, the maximum power per harmonic will be about - 5 dbm into the preamp at 150 MHz, again assuming good combiner efficiency at this frequency.

1go

m	Freq (GHz)	dbm	Σ power (mW)
1.	.053	-30.8	.000824
2.	.106	-24.9	.004095
3.	.159	-21.4	.011353
4.	.212	-19.0	.024008
5.	.265	-17.1	.043295
6.	.318	-15.7	.070236
7.	.371	-14.5	.105608
8.	.424	-13.5	.149929
9.	.477	-12.7	.203443
10.	.530	-12.0	.266124
11.	.583	-11.5	.337681
12.	.636	-11.0	.417585
13.	.689	-10.6	.505085
14.	.742	-10.3	.599251
15.	.795	-10.0	.699001
16.	.848	-9.8	.803152
17.	.901	-9.7	.910450
18.	.954	-9.6	1.019618
19.	1.007	-9.6	1.129393
20.	1.060	-9.6	1.238557
21.	1.113	-9.7	1.345971
22.	1.166	-9.8	1.450601
23.	1.219	-10.0	1.551532
24.	1.272	-10.2	1.647989
25.	1.325	-10.4	1.739338
26.	1.378	-10.7	1.825091
27.	1.431	-11.0	1.904907
28.	1.484	-11.3	1.978578
29.	1.537	-11.7	2.046026
30.	1.590	-12.1	2.107284
31.	1.643	-12.6	2.162486
32.	1.696	-13.1	2.211849
33.	1.749	-13.6	2.255656
34.	1.802	-14.1	2.294245
35.	1.855	-14.7	2.327986
36.	1.908	-15.3	2.357274
37.	1.961	-16.0	2.382515
38.	2.014	-16.7	2.404114
39.	2.067	-17.4	2.422465
40.	2.120	-18.1	2.437949
41.	2.173	-18.9	2.450922
42.	2.226	-19.7	2.461718
43.	2.279	-20.5	2.470641
44.	2.332	-21.4	2.477965
45.	2.385	-22.2	2.483936
46.	2.438	-23.2	2.488772
47.	2.491	-24.1	2.492662
48.	2.544	-25.1	2.495770
49.	2.597	-26.1	2.498238
50.	2.650	-27.1	2.500183
51.	2.703	-28.2	2.501707
52.	2.756	-29.3	2.502893
53.	2.809	-30.4	2.503810
54.	2.862	-31.5	2.504514
55.	2.915	-32.7	2.505051
56.	2.968	-33.9	2.505458
57.	3.021	-35.1	2.505764

Table I
2-4 GHz Debuncher betatron pickups.
$\bar{P}$ injection conditions.
Table shows power per electrode.
Power into preamp/add 9db.

c, pu

```
      PROGRAM PU(INPUT,OUTPUT)
      IMPLICIT REAL(L-Z)
      Z=100  Z0
      F=.33  F̄
      AI=.007 <J0>
      W=3.34E8  ω0
      L=2.5  ℓ
      C=3E10  c
      SIG=1.5E-10  σ
      M=0  m
      SUM=0
      DO 10 I=1,100
      M=M+1.0
      SMWL=SIN(M*W*L/C)
      E=EXP(-(M*W*SIG)**2/2)
      VM=SQRT(2.)*Z*F*AI*SMWL*E
      PWR=1000.*VM**2/Z
      DB=10.*ALOG10(PWR)
      SUM=SUM+PWR
      FREQ=.053*M
      PRINT 200,M,FREQ,DB,SUM
200   FORMAT(5X,F4.0,F8.3,F8.1,3X,F8.6)
10    CONTINUE
      STOP
      END
```

Table I (continued).

60.	3.180	-39.0	2.506290
61.	3.233	-40.3	2.506382
62.	3.286	-41.7	2.506449
63.	3.339	-43.1	2.506498
64.	3.392	-44.6	2.506533
65.	3.445	-46.0	2.506558
66.	3.498	-47.5	2.506576
67.	3.551	-49.0	2.506588
68.	3.604	-50.6	2.506597
69.	3.657	-52.2	2.506603
70.	3.710	-53.8	2.506607
71.	3.763	-55.4	2.506610
72.	3.816	-57.1	2.506612
73.	3.869	-58.8	2.506614
74.	3.922	-60.5	2.506614
75.	3.975	-62.2	2.506615
76.	4.028	-64.0	2.506615
77.	4.081	-65.9	2.506616
78.	4.134	-67.7	2.506616
79.	4.187	-69.6	2.506616
80.	4.240	-71.5	2.506616
81.	4.293	-73.4	2.506616
82.	4.346	-75.4	2.506616
83.	4.399	-77.4	2.506616
84.	4.452	-79.5	2.506616
85.	4.505	-81.6	2.506616
86.	4.558	-83.7	2.506616
87.	4.611	-85.8	2.506616
88.	4.664	-88.0	2.506616
89.	4.717	-90.3	2.506616
90.	4.770	-92.5	2.506616
91.	4.823	-94.8	2.506616
92.	4.876	-97.2	2.506616
93.	4.929	-99.6	2.506616
94.	4.982	-102.0	2.506616
95.	5.035	-104.5	2.506616
96.	5.088	-107.1	2.506616
97.	5.141	-109.7	2.506616
98.	5.194	-112.3	2.506616
99.	5.247	-115.0	2.506616
100.	5.300	-117.8	2.506616

0.079 CP SECONDS EXECUTION TIME.

Table II.

1-2 GHz stack tail Δp pickups
Extraction conditions from Accum.
Table shows power per electrode.
Power into preamp / add 18db

m	Freq(GHz)	dbm	Σ power (mW)
1.	.053	-28.0	.001600
2.	.106	-23.4	.006167
3.	.159	-22.3	.012019
4.	.212	-23.3	.016749
5.	.265	-25.7	.019432
6.	.318	-29.5	.020551
7.	.371	-34.5	.020904
8.	.424	-40.7	.020989
9.	.477	-48.0	.021005
10.	.530	-56.4	.021007
11.	.583	-65.8	.021008
12.	.636	-76.3	.021008
13.	.689	-87.8	.021008
14.	.742	-100.4	.021008
15.	.795	-114.0	.021008
16.	.848	-128.6	.021008
17.	.901	-144.2	.021008
18.	.954	-160.8	.021008
19.	1.007	-178.5	.021008
20.	1.060	-197.1	.021008
21.	1.113	-216.8	.021008
22.	1.166	-237.4	.021008
23.	1.219	-259.0	.021008
24.	1.272	-281.7	.021008
25.	1.325	-305.3	.021008
26.	1.378	-330.0	.021008
27.	1.431	-355.6	.021008
28.	1.484	-382.2	.021008
29.	1.537	-409.8	.021008
30.	1.590	-438.5	.021008
31.	1.643	-468.1	.021008
32.	1.696	-498.7	.021008
33.	1.749	-530.3	.021008
34.	1.802	-562.9	.021008
35.	1.855	-596.5	.021008
36.	1.908	-631.1	.021008
37.	1.961	-666.7	.021008
38.	2.014	-703.3	.021008
39.	2.067	-740.9	.021008
40.	2.120	-779.6	.021008
41.	2.173	-819.2	.021008
42.	2.226	-859.9	.021008
43.	2.279	-901.5	.021008
44.	2.332	-944.2	.021008
45.	2.385	-988.0	.021008
46.	2.438	-1032.8	.021008
47.	2.491	-1078.6	.021008
48.	2.544	-1125.5	.021008
49.	2.597	-1173.5	.021008
50.	2.650	-1222.7	.021008
51.	2.703	-1273.0	.021008
52.	2.756	-1324.7	.021008
53.	2.809	-1377.7	.021008
54.	2.862	-1432.5	.021008
55.	2.915	-1489.9	.021008
56.	2.968	-1554.0	.021008
57.	3.021	-1624.5	.021008

```
c,pu
      PROGRAM PU(INPUT,OUTPUT)
      IMPLICIT REAL(L-Z)
      Z=100        Z0
      F=.02        F
      AI=.085      <Ib>
      W=3.34E8     ω0
      L=5.0        ℓ
      C=3E10       c
      SIG=1.0E-9   σ
      M=0          m
      SUM=0
      DO 10 I=1,100
      M=M+1.0
      SMWL=SIN(M*W*L/C)
      E=EXP(-(M*W*SIG)**2/2)
      VM=SQRT(2.)*Z*F*AI*SMWL*E
      PWR=1000.*VM**2/Z
      DB=10.*ALOG10(PWR)
      SUM=SUM+PWR
      FREQ=.053*M
      PRINT 200,M,FREQ,DB,SUM
200   FORMAT(5X,F4.0,F8.3,F8.1,3X,F8.6)
10    CONTINUE
      STOP
      END
```