TRANSVERSE SCHOTTKY DETECTOR FOR ANTIPROTON RECYCLE RING

P.J. Chou, Dec. 18, 1995

§ *Recycle Ring parameters* [1]

Table 1: Design parameters of antiproton recycle ring.

Parameter	Value
circumference [m]	3319.419
Main Injector rf harmonic number	588
injection momentum [GeV/*c*]	8.9
horizontal tune Q_H	26.425
vertical tune Q_V	25.415
transition gamma γ_T	21.8
injection momentum spread dp/p [%]	0.1
relative speed β (υ/c)	0.9944888
Lorentz factor γ	9.538082
slip factor $\eta = \gamma_T^{-2} - \gamma^{2}$ at injection	-0.0088878
rotation frequency at injection energy [Hz]	89816.993

§ *Design parameters of transverse Schottky detector*

The mechanical design of the Schottky detector is depicted in Fig. 1. The design is based on the present Main Ring Schottky detectors installed at A17 location.[2] The actual implementation of the Recycle Ring Schottky detector is depicted in Fig. 2. Parameters of the equivalent circuit for the Recycle Ring Schottky detector is given in Table 2. The block diagram of receiver design is depicted in Fig. 3. We need to order some crystal bandpass filters from Piezo Technology Inc. with customized design: center frequency= 79.263 MHz, 3 dB bandwidth ≥ 90 kHz, insertion loss ≤ 7 dB.

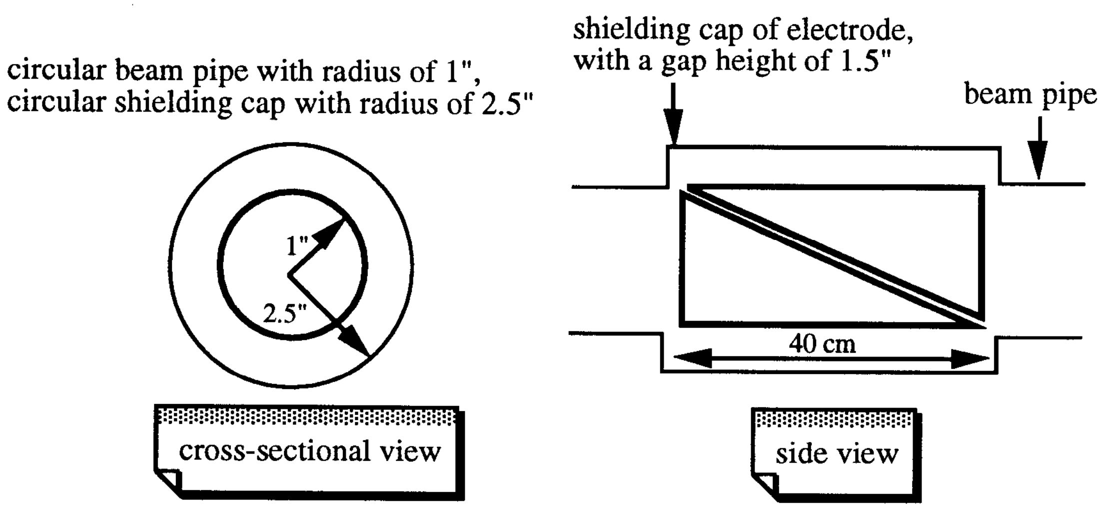

Fig. 1: The sketch of mechanical design for the transverse Schottky detector. A split-box capacitive BPM is chosen for its linear response to the beam displacement.

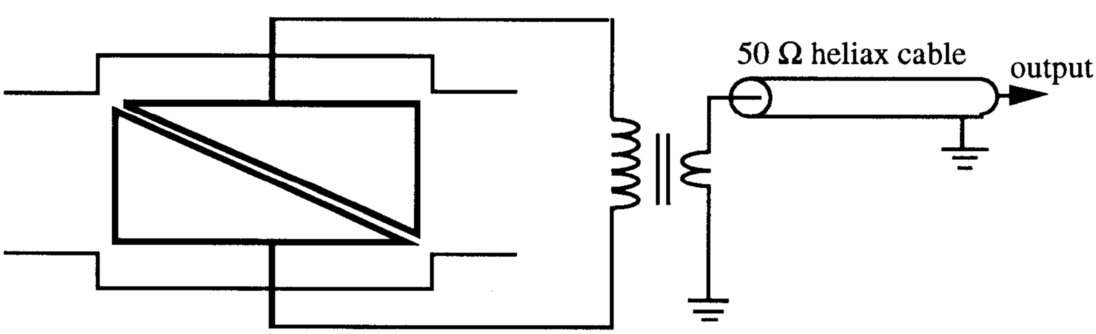

Fig. 2: The actual implementation of the Recycle Ring Schottky detector. The detector and the primary inductor form a resonant circuit. The secondary inductor will load the signal to the output cable.

Table 2: Parameters of the equivalent circuit for the Recycle Ring Schottky detector.

resonant frequency f_c= 79.263496 MHz, corresponding to the rotation harmonic number n= 882.5
3 dB bandwidth= 90 kHz
loaded quality factor Q_L= 880
frequency of local oscillator $f_{L.O.}$= 79.218587 MHz, corresponding to the rotation harmonic number n= 882 or (1.5 × 588).
pre-amplifier= Trontech ultra-low noise amplifier, L80A (70~90 MHz, min. gain 60 dB), minimum detectable signal~ -99 dBm.

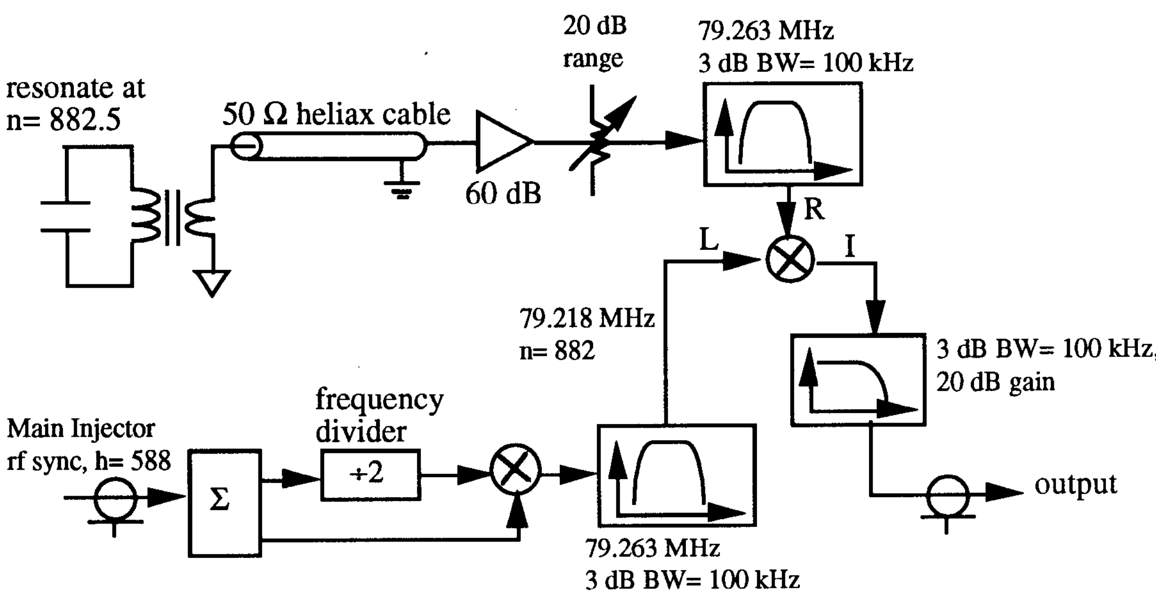

Fig. 3: The block diagram of receiver design for the Recycle Ring Schottky detector.

Locations of observed betatron sidebands, the output of local oscillator, the center frequency of crystal filter, and the resonant frequency of Schottky detector in the frequency domain are depicted in Fig. 4.

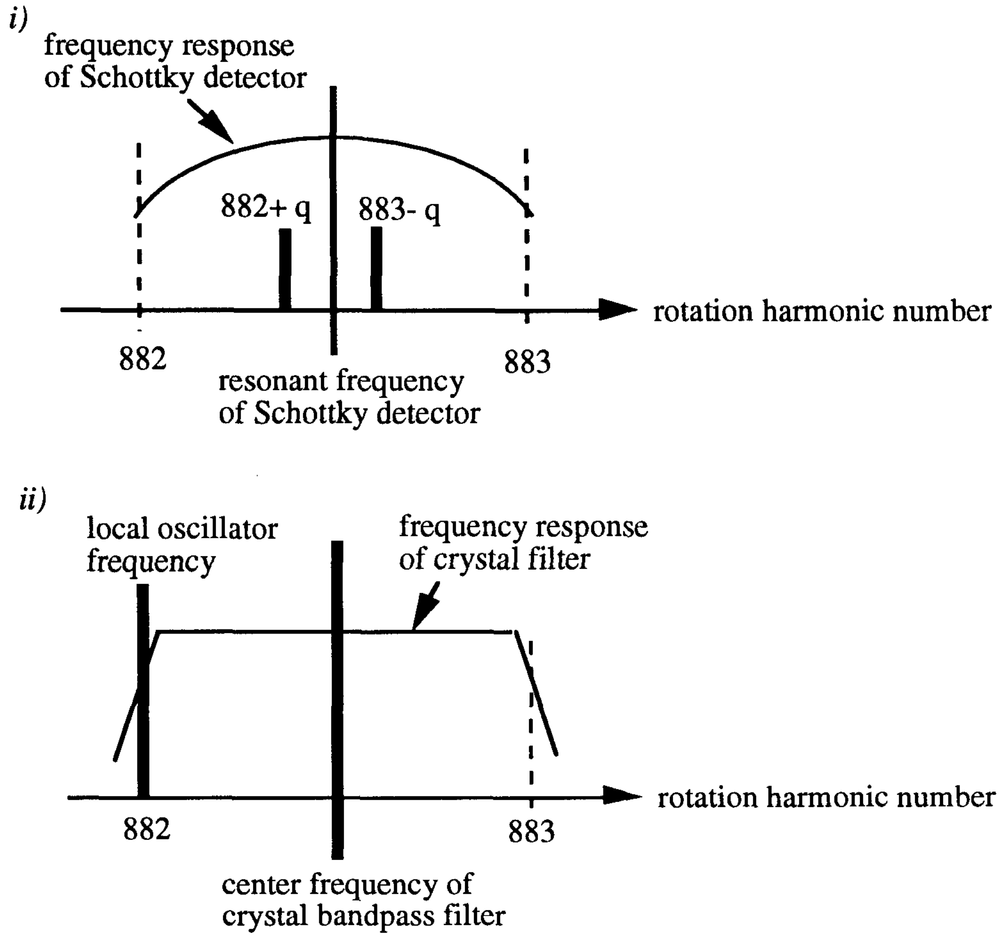

Fig. 4: Locations of spectral lines in the frequency domain *i)* betatron sides within the 3 dB bandwidth of the detector response *ii)* the local oscillator frequency within the 3 dB bandwidth of the crystal filter.

§ ***Estimate of the gap capacitance and primary inductance***

For a coaxial cable with circular cross section, the capacitance per unit length is given by the following formula:[2, 3]

$$C = \frac{0.2416\varepsilon_r}{\log_{10}(b/a)} \qquad (1)$$

where C= capacitance in units of [pF/cm], ε_r= dielectric constant relative to air, a= radius of the electrode, and b= radius of the shielding cap. Using the dimensions depicted in Fig. 1, we get the gap capacitance C_g= C/2= 12.14 [pF]. According to the past experience, the coupling capacitance C_p between two electrodes is about 18 [pF].[2] Therefore, the total capacitance (C_g /2 + C_p) of the equivalent circuit is about 24 [pF]. The circuit analysis is the same as the Main Ring Schottky detector, the results are quoted directly from Ref. [2]. The above results are summarized in Table 3.

Table 3: Summary of the estimated capacitance for the Recycle Ring Schottky detector.

gap capacitance between the electrode and the shielding cap C_g= 12.14 [pF]
coupling capacitance between two electrodes C_p= 18 [pF]
total capacitance C_t= 24 [pF]
radius of the shielding cap= 2.5"
radius of the electrode= 1"
length of the electrode ℓ= 40 [cm]
gap between the electrode and the shielding cap h= 1.5"

The required inductance L is given by $(\omega^2 C_t)^{-1}$. Using the following parameters: f_c= 79.264 [MHz], and C_t= 24 [pF], the required inductance L is given as 0.168 [μH]. Using the following formulas:[3]

$$L = Fn^2 d \qquad (2)$$

$$Q = Ad\sqrt{f} \qquad (3)$$

where d= diameter of the coil in inches, n= number of turns, A and F= form factors given in Ref. [3], and f= frequency in MHz. If we use the 3/8" hollow copper tube with the following parameters: 2" and 1.2" for the diameter and the length of the inductor coil respectively, and wind a coil of two turns, the calculated results are: A= 85, F= 0.02, L= 0.16 [μH], Q= 1513. The above results are summarized in Table 4.

Table 4: Summary of estimated parameters for the inductor coil made with 3/8" hollow copper tube.

turn number n= 2	length of inductor coil ℓ= 1.2"
diameter of inductor coil d= 2"	F= 0.02
A= 85	resonant frequency f= 79.264 MHz
estimated inductance L= 0.16 μH	estimated quality factor Q= 1513

§ ***Estimate of the detector sensitivity***

From Ref. [3], the detector sensitivity is given by the following formula:

$$S_{\perp} = \frac{\ell}{2bc}\sqrt{\frac{R_0\omega_c Q_0}{C_t}} \qquad (4)$$

where ℓ= length of the electrode [m], b= radius of the cross section of electrode [m], c= speed of light [m/s], R_0= load resistance 50 Ω, ω_c= angular resonant frequency [Hz], Q_0=

quality factor of the primary inductor coil, C_t= total capacitance [F], and $S_\perp$= detector sensitivity in units of [Ω/m]. We use 1" for the cross section of electrode. The estimated detector sensitivity $S_\perp$ is given by:

$$\begin{aligned} S_\perp &= \frac{0.4}{2(0.0254)(3\times10^8)}\sqrt{\frac{50\times2\pi\times79.264\times10^6\times1513}{24\times10^{-12}}} \\ &= 32885.299\ [\Omega/\mathrm{m}] \\ &= 32.885\ [\Omega/\mathrm{mm}] \end{aligned} \tag{5}$$

Compared with the value of Main Ring Schottky detector, 0.9 [Ω/mm], the Recycle Ring Schottky detector has a sensitivity 36 times higher. Note that the Tevatron Schottky detector has a detector sensitivity of 27 [Ω/mm].[4]

§ *Estimate of output signal level*

Using the following beam parameters given in Table 5, the estimated Schottky signal can be calculated with the following formula:[3]

$$V_{out} = \Delta e f_0 S_\perp \sqrt{N_p} \tag{6}$$

where e= charge of an electron in units of [C], f_0= revolution frequency of Recycle Ring in units of [Hz], N_p= the number of particles within the resolution bandwidth, Δ= rms beam size in units of [mm], and V_{out}= observed Schottky signal in units of [Volt]. Assuming a resolution bandwidth of 1 Hz for the spectrum analyzer, and the full width at half maximum of the betatron frequency spread is 100 Hz, then the number of particles N_p is given by the following expression for a Gaussian distribution:

$$
\begin{aligned}
N_p &= N_{total}\frac{BW}{\sigma\sqrt{2\pi}} \\
&= (5\times10^{11})\frac{1}{(100/2.35)\sqrt{2\pi}} \\
&= 4.69\times10^{9}
\end{aligned}
\tag{7}
$$

the observed signal in the frequency bin of maximum is 32.36 [nV] or equivalent to -138 [dBm].

Table 5: Beam parameters used to estimate the Schottky signal.

Parameter	Value
total number of particles N_{total}	5×10^{11}
rms beam size Δ [mm]	1
FWHM of betatron frequency spread [Hz]	100

References

[1]G. Jackson (ed.), "Recycle Ring Conceptual Design Study", Fermilab-TM-1936 (1995, unpublished).

[2]P.J. Chou, B. Fellenz and G. Jackson, "Transverse Schottky Detectors for the Fermilab Main Ring", Fermilab Report No. Fermilab-TM-1941 (in preparation).

[3]Edward C. Jordan (ed.), Reference Data for Engineers: Radio, Electronics, Computer, and Communications, 7th edition , Sams (Indianapolis, Indiana, 1989).

[4]R. Siemann, Fermilab Report No. Fermilab EXP- 155 (1987, unpublished).