Testing Coaxial Switches of BPM using a High-Resolution RF Detector

Takao Ieiri
KEK, National Laboratory for High Energy Physics
Oho 1-1, Tsukuba-shi, Ibaraki-ken, 305 Japan
Internet: IEIRIT@kekvax.kek.jp

ABSTRACT

A high-resolution rf detector has been developed in order to test a coaxial switch used in a beam-position monitor (BPM). The detector with a Digital Muti-Meter (DMM) has an rms resolution of the order of 10^{-6} in short time and a wide linear range of 50 dB. Though detected voltage depends on temperature, it can be compensated by measuring the detector temperature. The insertion loss and its stability of several types of switches were measured at 1.0 GHz using the detector. The normalized positions are kept within $\pm 3\times10^{-5}$, which corresponds to about ± 1.0 μm in a chamber of the KEKB. The detector is useful to evaluate the insertion loss of switches.

1. INTRODUCTION

The beam position is obtained by processing signals from pick-up electrodes. There are two basic methods for the signal processing. One is a parallel process, where the signals are detected at the same time. The other is a multiplexed method, where the signals are multiplexed by a switch and detected by a commom detector. Since the multiplexed method has generally better performance on the resolution than the parallel process without considering a real-time measurement, many storage rings employ the multiplexed method[1 - 5].

The TRISTAN MR employs the multiplexed BPM system[6]. About 400 mechanical switches are installed near pick-up electrodes. The picked-up signals are multiplexed by the switch and transfered to a control room via a long coaxial cable. A 380 MHz component of a beam pulse is detected. Measurement errors were noticed in some BPMs, which was mainly caused by a loose contact of a switch. A stability of the contact is reflected in that of the BPM system. When the insertion loss of one port of a switch slightly changes by 0.01 dB (0.1%), for instance, which causes a position change by more than 10 μm in the MR.

The KEKB[7] requires abou 920 BPMs in the two rings. The stability of a relative beam position rather than an absolute value is strongly demanded. The KEKB will also employ the multiplexed method. The detected frequency is about 1.0GHz, twice the accelerating frequency. A high-resolution detector is required to detect a change of less than 10^{-4} at 1.0 GHz in order to test the stability of a switch. A network analyzer and/or a spectrum analyzer cannot detect such a small change.

2. RF DETECTOR

Various techniques are used for linear detection of an rf signal. A most simple method is to use a diode. However, this method has poor linear characteristics and low sensitibity. The synchronous detection is widely used in BPM systems, where an rf signal is converted to a constant amplitude signal using a limiter and is multiplied with an input rf signal. The dynamic range is limited by that of a limitting amplifier. A phase error between the input rf and the limitted signal would yield a nonlinearlity in the detection.

A simple and precise rf detector has been developed using a DMM. Fig. 1 shows block diagram of the rf detector. The detector consists of a frequency converter, an rms detector and a charge ADC. The frequency converter lowers a frequeny of an input rf signal to 455 kHz. Its total gain is 23 dB. The latter two parts are installed in a commercially available DMM (Keithley, 2001). The DMM can measure a signal whose frequency is less than 2 MHz with a resolution of the order of 10^{-6} using an improved rms detector[8]. An rms value of the 455 kHz signal can be obtained by an analog circuit shown in Fig. 1 using the equation of $V_{rms} = Avg(V_{in}^2 / V_{rms})$. Here, V_{in} is an input voltage to the DMM. Noises caused by the power line can be reduced by locking a measurement cycle to the power line. The DMM is guaranteed that its temperature coefficient is $\pm 5\times10^{-5}$/°C [8].

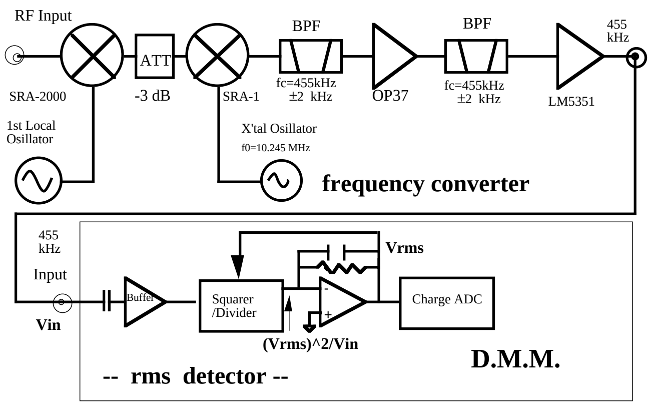

Fig. 1 Block diagram of RF detector.

Since one frequency component of a beam is usually detected, a continuous wave from a signal generator (SG, hp-8648C) is used as a beam signal. The signal is fed to the frequency converter and is read by the DMM. Fig. 2 shows a dynamic response of the detector. Even if the input frequency changes, the detector is available up to 2 GHz by adjusting the frequency of the 1st local oscillator as seen in Fig. 1. The linearity can be obtained from a ratio of two detected voltages between with and without a fixed attenuator of 1 dB. A linearity of less than ±0.1 %/dB over the range of 50 dB was obtained.

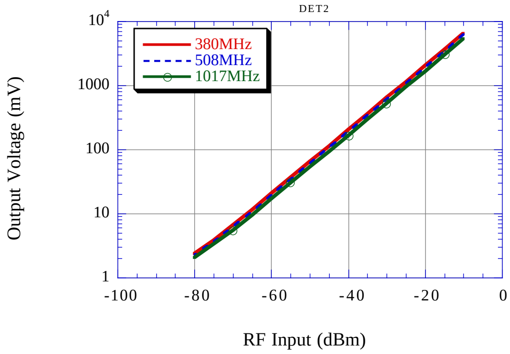

Fig. 2 Dynamic response of the detector.

A short-time stability was tested by measuring repeatedly detected voltages. It took about 5 seconds during a 100 times measurement. Fig. 3 shows the maximum deviation of the rms resolution defined as an rms value divided by an average over several measurements as a function of rf amplitude. The rms resolution seems to be best around -25 dBm, where the rms resolution within the order of 10^{-6} was obtained. When the rf level is low, the stability is worse due to a lower denominator.

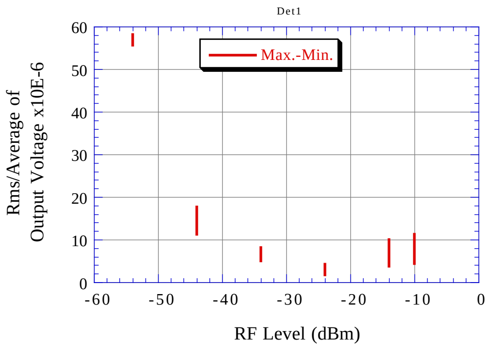

Fig. 3 Rms resolution of the detector as a function of rf level.

A drift of the output voltage was observed during a long time of more than 10 sec. The drift seemed to be very sensitive to the room temperature. In order to see the drift, the temperature on the chassis of the frequency converter was measured with a resolution of 0.01 °C and plotted together with detected voltages as seen in Fig. 4. One may notice a linear relation between the output voltage and the detector temperature. This linear relation was obtained when the temperature difference between the room and the detector was almost constant without using an air-conditioner. This may be because that an output level of the SG also depends on the room temperature. The measured temperature dependence of the detected voltage was 3.75 mV/°C at the rf level of -20 dBm. This temperature dependence seems to be an intrinsic property of semiconductor devices in the converter. However, the dependence was able to be compensated from the measured temperature (T_d) using a simple linear equation of $V_c = V_m + 3.75T_d$, where V_c and V_m are compensated and measured voltages respectively. The compensated voltages are kept within ±0.35 mV against a change of 6 °C as seen in Fig.4.

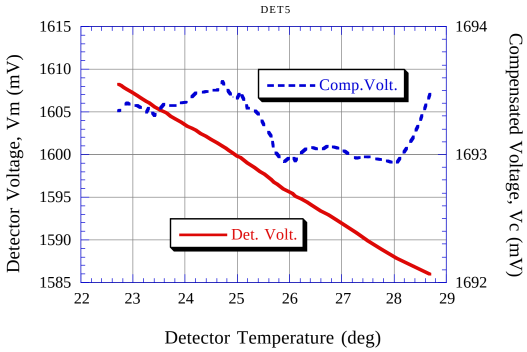

Fig. 4 Detected voltages as a function of the temperature measured at the detector and voltages compensated using the measured temperature.

3. COAXIAL SWITCH

Several types of coaxial switches are commercially available. One may classify the switches into two groups. One is a mechanical type, where a switch is actuated by a coil. There are two types of mechanical switches in air and in mercury evaporation. One may call the two types of switches 'mechanical' and 'mercury' in order to distinguish between them. These switches can be used even for a directly picked-up beam pulse with a high peak voltage. The other is semiconductor devices using a PIN diode and an FET. These semiconductor switches can make faster switching than the mechanical ones, but generally have weak points for a high peak-power pulse and for radiation enviroment.

The most important performance of a switch for a BPM system is the stability of the insertion loss. Fig. 5 shows an apparatus for measuring the stability. An output signal of the SG is demutiplexed into 4 ways using a power divider and fed to each port of a switch and multiplexed. An isolator is inserted in front of the frequency converter to avoid an effect of a reflection due to impedance mismatch. A multiplexed signal is detected and calculated by a personal computer. One obtains two normalized positions (Δ / Σ)s from four detected voltages as seen in Appendix. It takes about 5 seconds to scan the cycle. The obtained normalized positions do not show real values due to an effect of a cross-talk in the power divider but they are useful enough for measuring the stability. Before a switch was tested, temperature dependence of the apparatus was examined using another power divider instead of a switch. Fig. 6 shows measured normalized positions as a function of the detector temperature. One may notice that the normalized positions are independent of the temperature. The fluctuations are kept within $\pm 3\text{x}10^{-5}$ against a change of 4°C. Therefore, this apparatus is useful enough to evaluate the stability of the switches with the resolution of less than $1\text{x}10^{-4}$.

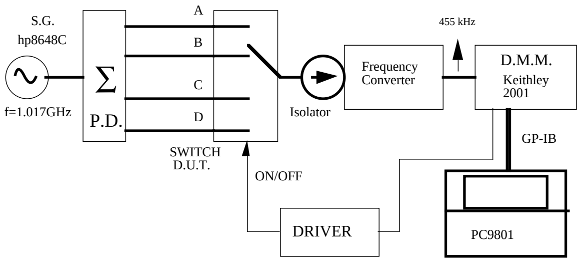

Fig. 5 Apparatus measuring the stability of the insertion loss.

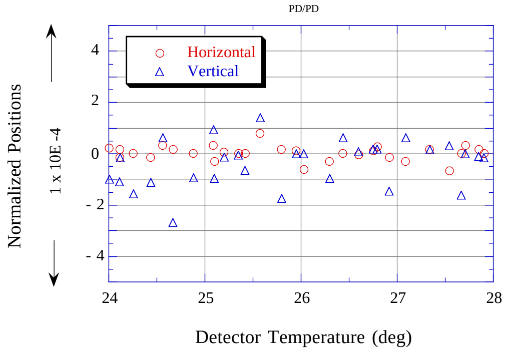

Fig. 6 Measured normalized positions as a function of the detector temperature.

Some switches were tested. An example of histograms of the normalized positions is shown in Fig. 7. They show that maximum deviations are $\pm 3\text{x}10^{-5}$, which corresponds a position of $\pm 1\mu$m in case of a chamber with an inner diameter of 100 mm as used in the KEKB. The deviations are comparable to the performance of the apparatus itself.

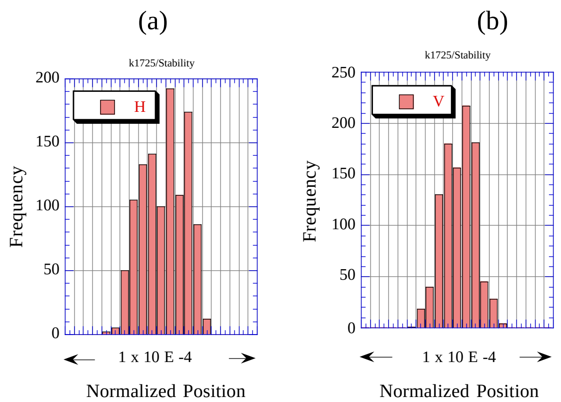

Fig. 7 Histrgrams of horizontal (a) and vertical (b) normalized positions of a mercury switch with 1000 cycles.

In order to measure an absolute value of the insertion loss, a reliable mechanical switch proved in the stability test was used instead of the power divider because the mechanical switch has the cross-talk of better than 80 dB. The losses can be measured within the accuracy of $\pm 2\text{x}10^{-4}$ using temperature-compensated voltages as shown in Fig. 4.

Table 1 shows the measured losses of sampled switches including the loss of the reference switch. The insertion losses of a sampled mechanical switch are the best performance and are well balanced within 0.1%. On the other hand, those of the others are not balanced with more than 0.2%. Since this imbalance yields an offset in the beam position, this measurement will be needed for all switches before installing.

Table 1 Insertion losses of sampled switches measured at 1.0GHz.

Type	Model	Ch1	Ch2	Ch3	Ch4
Mechanical	CS38S(1)	0.9969	0.9972	0.9967	0.9966
Mercury	UCL1G (2)	0.9368	0.9204	0.9289	0.9252
PIN diode	TS503(3)	0.9402	0.9418	0.9419	0.9400
GaAs FET	SW254 (4)	0.8574	0.8564	0.8630	0.8587

(1):Teledyne,USA (2):Sanyu, Japan
(3):Tokimec, Japan (4):Anzac, USA.

Acknowledgement

The author would like to thank colleagues of the KEKB monitor group for useful comments.

REFERENCES

[1] C. Carman and J.-L. Pellegrin, NIM 113(1973)p.423.
[2] D. Rice et al., IEEE Trans. Nucl. Sci. NS-30 (1983)p.2190
[3] R. Biscardi and J. Bittner, Proc. of 89PAC, Chicago, (1989)p.1516.
[4] F. Loyer and K.Scheidt, Proc. of 92EPAC, (1992)p.1112.
[5] K. Shinoe et al., Proc. of 93PAC, Washington D.C., (1993)p.2295.
[6] H. Ishii et al., The 6th Symp. on Accelerator Science and Technology, Tokyo, Japan (1987) p.207.
[7] S-I. Kurokawa, WPG04 in this conference.
[8] Keithley, the manual of D.M.M. model 2001.

Appendix

Horizontal and vertical beam positions are obtained by comparing four beam signals named V_A, V_B, V_C and V_D. They are expressed with a linear approximation as

$$X = k_H \cdot \frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D} = k_H \cdot \left(\frac{\Delta_H}{\Sigma}\right) \quad \text{and}$$

$$Y = k_V \cdot \frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D} = k_V \cdot \left(\frac{\Delta_v}{\Sigma}\right),$$

where k_H and k_V are position sensitivities determined by a mechnical arrangement of the electrodes. When four electrodes skewed by 45° with the axes are mounted on a chamber wall with a diameter of 100 mm, k_H and k_V are about 35 mm respectively. One may call the (Δ/Σ)s of the above equation normalized positions. The normalized positions are independent of beam intensity.