OPTICAL-FIBER NOTCH FILTER FOR STORAGE RING TRANSVERSE FEEDBACK SYSTEM

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Abstract

An optical-fiber two-tap FIR (Notch) filter has been developed for storage ring transverse feedback system of Hefei light source. The optical notch filter has advantages of low loss, which is not related to the size of the storage ring, high-frequency response, and compact in size. Measurements have been done with storage ring beam signals. The paper presents the principle and the experimental results

INTRODUCTION

For a storage ring of a synchrotron radiation light source, a transverse feedback system is often required to eliminate the transverse instabilities.

In order to do transverse feedback, the betatron oscillation $\omega_\beta = \omega_0 (n \pm \nu)$ has to be measured. ω_0 is revolution frequency. ν is the betatron tune. Since the power of the component of the revolution frequency detected from the beam position monitor is about 40 dB higher than the component of interest in the betatron oscillation, it is very important to eliminate the component of the beam revolution frequency from the beam signal. A notch filter, or Finite Impulse Response (FIR) filter, therefore, is needed.

Although the notch filter can also be built with a digital circuit, an analog notch filter sometimes is more convenient and accurate. The digital filter is limited with the dynamic range related to the beam revolution signal. If the signal of the revolution component is too strong, the circuit may get saturated, and the resolution of the circuit will be reduced.

The traditional analog notch filters are built with electrical transmission cables, but which is very bulky, and lossy and depressive. The Optical fiber Notch filter has many advantages over the cable notch filter. Initiated by Hefei light source, a two-channel optical fiber notch filter, YY-806, has been developed under the collaboration between the National Synchrotron Radiation Laboratory, the University of Science and Technology of China and YY Labs [1].

The principle of the Notch Filter can be described as in Fig 1.

$x(t)=\alpha x_0(t-t1)-\beta x_0(t-t1-T)$, where t1 is the delay caused by common transmission line before the 0^0-power combiner, therefore, it can be set to zero for simplification. In the frequency domain, x(t) is the output signal, $x_0(t)$ is the input signal; α is the coefficient of the short arm; β is the coefficient of the long arm; T is variable delay line, adjustable from 220.4ns to 220.7ns, equivalent to 4.537 to 4.531 MHz, which is the revolution frequency of Hefei storage ring. The input signal $x_0(t)$ is a continues wave, obtained by the process of the beam signal with the front-end electronics of the beam position monitor. The $x_0(t)$ has frequency response of 1 MHz to150 MHz, with V_pp of 1V.

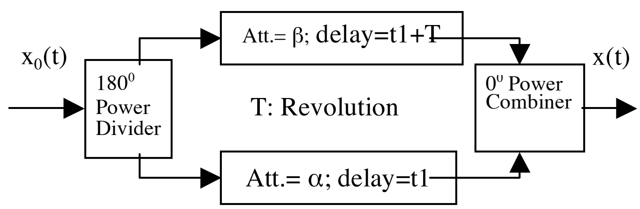

Figure 1: Notch Filter Principle

$$x(t)= \alpha x_0(\varphi(t))-\beta x_0(\varphi(t-T))$$
$$=[(\alpha-\beta\cos(2\pi\upsilon_{x,y}))^2+(\beta\sin(2\pi\upsilon_{x,y}))^2]^{1/2}\sin(\omega t+d\varphi_{x,y}) \quad [2]$$

The transfer function

$$H(\omega)= |x(\omega) /x_0(\omega)|=[\alpha^2+\beta^2-2\alpha\beta\cos(\omega T+\omega\delta T)]^{1/2}$$

The filtering depth

$$R=-20\log[|H(\omega)|_{max}/|H(\omega)|_{min}]=-20\log(\alpha+\beta)/(\alpha-\beta)$$

When $\alpha-\beta < 1\%$, R will be larger than 40 dB.

The Notch filter's phase function related to the frequency is:

$$d\varphi_{x,y}=\tan^{-1}[\beta\sin(2\pi\upsilon_{x,y})/ (\alpha-\beta\cos(2\pi\upsilon_{x,y}))]$$

When $\alpha=\beta$, $d\varphi_{x,y}=\tan^{-1}[\cot(\pi\upsilon_{x,y})]= \pi/2-\upsilon_{x,y}$

OPTICAL FIBER NOTCH FILTER WORKING PRINCIPLE

YY-806 Optical Fiber Notch Filter consists of two identical, independent channels. Each channel has its own laser source. In each channel, the RF-input signal, i.e. $x_0(t)$, is converted into an optical signal with a LiNbO3 MZ modulator. The output of the LiNbO3 MZ modulator contains two complimentary signals; both have the same waveform as the input RF signal waveform but with a phase difference of 180-degree. In order to linearly convert the electrical signal into an optical signal, the modulator has to be locked at the linear working point. A modulator bias controller (MBC), produced by YY Labs, has been used. A tap-coupler is used to split 1% optical signal to provide MBC a sensor signal.

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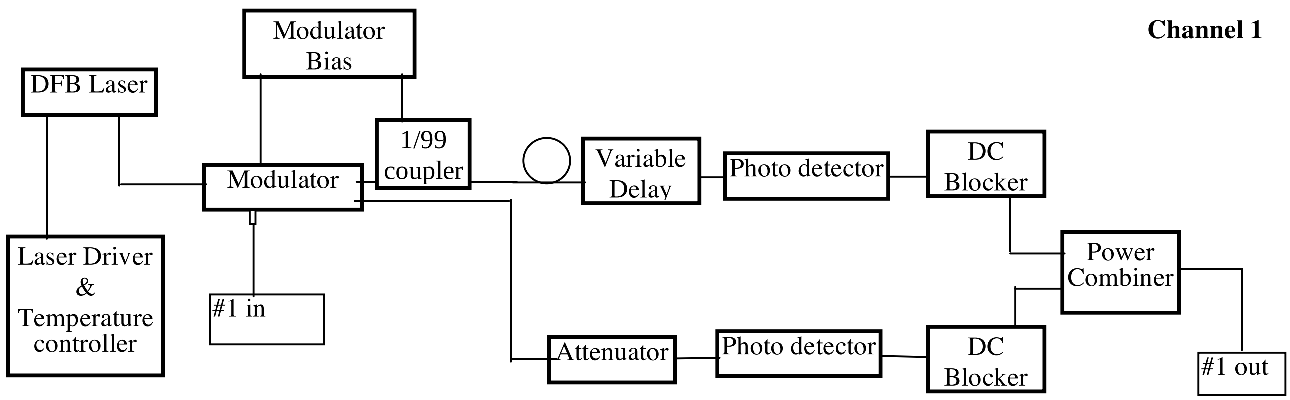

Figure 2: Optical Fiber Notch Filter (one channel)

The optical signals from the two arms will then be converted back to electrical signals by two Photo-detectors, and then combined by an electrical power combiner to form the Notch filter output signal.

The frequencies corresponding to the integer times delay time of beam revolution will be cancelled out in the output signal of each channel. The filtering depth of these frequencies depends on how good the cancellation is. In order to obtain the best results, the two signals in the two arms have to have the same amplitude, which can be tuned by a manually adjustable optical attenuator, see Fig. 2. The required notch frequency can be obtained by adjusting the variable optical delay line, see Fig. 2.

MEASUREMENTS

Measurements have been done with both network analyzer and beam signals. The optical Fiber Notch Filter has been in regular use at Hefei light source. The unevenness of the filtering depths in Fig. 3 is due to the limited sampling points. By reducing the scope of the frequency range, the filtering depths are displayed even. Fig. 4 only shows the measurement from 0.3 to 50 MHz, the filtering depths for each node are the same. This has also been verified by the S_{21} measurements made for each node within the full 150 MHz range.

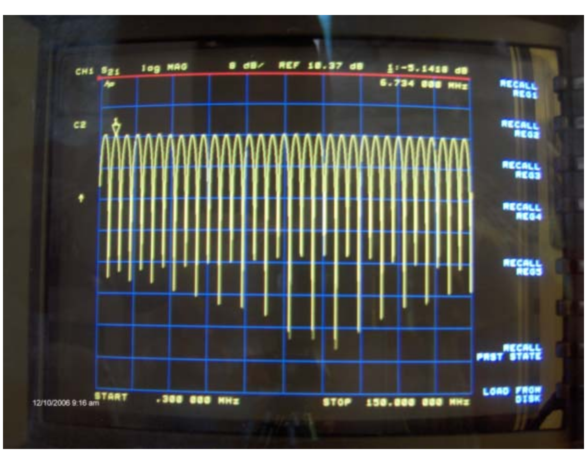

Figure 3: Optical Fiber Notch Filter S_{21} (-.3~150 MHz)

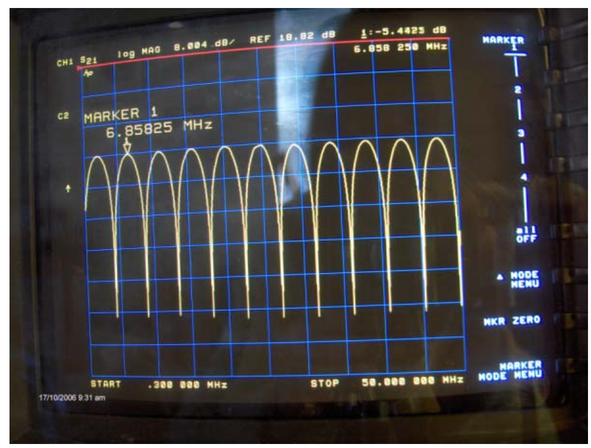

Figure 4: Optical Fiber Notch Filter S_{21} (0.3~50 MHz)

The measurements show that the filtering depth of the optical notch filter has reached 40 dB.

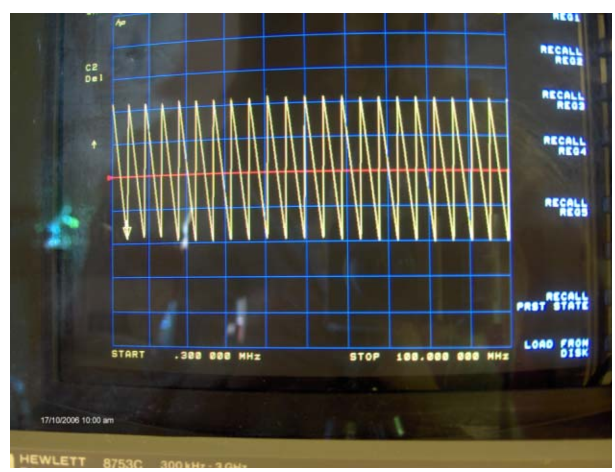

Figure 5: Optical Fiber Notch Filter S_{21} (Phase), (0.3~100 MHz)

Fig. 5 shows measurement of the phase shift for the Optical Fiber Notch Filter.

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COMPARISON WITH ELECTRICAL CABLE NOTCH FILTER

The optical fiber notch filter has many advantages over the traditional electrical cable notch filter. The Table 1 shows the comparison between the two filters.

Table 1: Comparison between the Notch Filters built with Optical fiber and Electrical cable

	Optical fiber	**Electrical Cable**
Frequency response	High	Limited by the cable and its length
Filtering depth	Good	Limited by the cable dispersion and loss, may not be even
Insertion Loss	Fixed insertion loss, not related to the fiber length (ring size)	Depends on the cable length, can be vary large for large ring
Size	Compact	Very bulky
Cost	Fixed for rings with different sizes	Depending on the ring size, and the quality of the cable, higher for larger rings.

Figure 6 shows the measurement of the cable notch filter built in Hefei Light Source. There is a frequency with a very good filtering depth, but the other frequencies do not have the same good filtering depth.

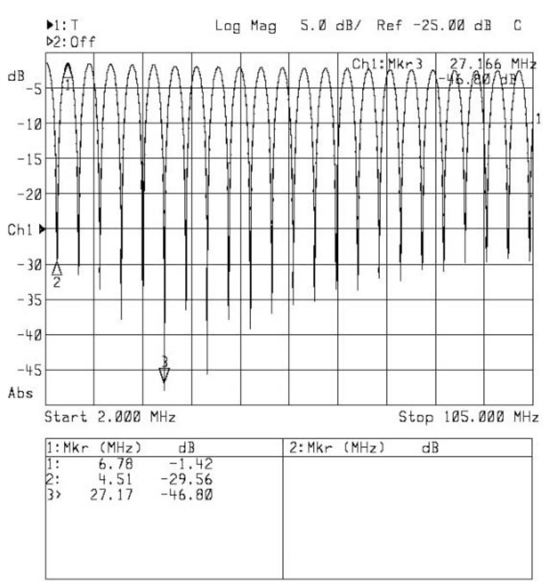

Figure 6: Cable Notch Filter S_{21}

The reason of the superior good performance of the optical fiber notch filter is due to the high frequency response and the low loss of the optical fiber. With diameter of only 9 μm, the optical fiber can transmit 100 GHz signal. The dispersion is negligible for the frequency range of the interests. The attenuation of the optical transmission single-mode fiber is only 0.25 dB/Km. The insertion loss of the optical notch filter, therefore, almost only depends on the conversion between the electrical signal and optical signal, and does not really depend on the attenuation of the fiber. So, the insertion loss is controllable to the desired value by setting the laser power and the gain of the photo-detector. The size of the instrument stays very compact, no matter how much kilometers fiber being used. For a large machine, this is very valuable. The price of the fiber is very cheap now, only about $0.1 per meter. The cost of the instrument will stay the same for all the rings with different sizes.

Figure 7: YY-806 optical Notch Filter

REFERENCES

[1] Junhua Wang et al, "Development of Transverse Feedback System and Instabilities Suppress at HLS, " PAC07, June, 2007

[2] Kai Zhang, et al "Bunch-by-Bunch Measurement and Feedback System of HLS," PAC07, June, 2007