DESIGN AND IMPLEMENTATION OF A DIGITAL RECEIVER BASED TUNE MONITOR

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Abstract

A digital receiver based tune measurement system is implemented recently. Novel digital receiver plays a central role for tune measurement. The output of digital receiver is further Fourier analysis by digital signal processor. Design considerations of this tune monitor such as, speed, resolution, dynamic range, control interface will discuss in this report. Comparing with traditional spectrum analyzer, spectrum analyzer with digital IF, modern vector signal analyzer, or tune measurement based upon turn-by-turn beam position are also included. Preliminary results will present on the conference.

1. INTRODUCTION

Beam instrumentation have been benefit from the emerging technology in software radios technology [1]. Various RF signal processing and feedback are transform from analog into digital. Tune measurement is also take this advantage. Vector signal analyzer, real-time signal/spectrum analyzer provide a various tune measurement options. Digital receiver [2] can be used in many difference systems, such as signal intelligence receiver, cellular phone base station, high performance radar applications, scanning receiver, tunable bandpass filter, vector signal analyzer, ...etc. Applied digital receiver as a dedicated tune monitor is a nature way to gain high performance by using mature technology in reasonable cost. Design considerations of this tune monitor such as, speed, resolution, dynamic range, control interface will discuss in this report.

2. SUMMARY OF TUNE MEASUREMENT METHODS

A lots of tune measurement methods are available. These methods can be classified as frequency domain and time domain methods. Summary of different approach as following :

Swept spectrum analyzer is the most popular instrument to observe beam spectrum. New generation of hybrid spectrum analyzer combines tradition swept techniques, digital IF and signal processing techniques to provide fast sweep capability. Latest and most modern instruments, such as Rhode & Schwarz spectrum analyzer Series FESB30/FSEM30 is in this category. It is an ideal instrumentation for various beam spectrum observations.

Using low frequency dynamic signal analyzer and frequency translator is another method. The methods are using digitized signal to perform FFT to get spectrum. However, most of the dynamic signal analyzer is working in 0 - 100 kHz range. Additional frequency translation should be done before its working.

Kick the beam and acquire turn-by-turn beam position information to perform FFT and extract tune is another method [3]. However, excitation level for turn-by-turn position observation is slightly large. It is out of tolerance for the light source operation during user service shift. Continue excite the beam and using PLL techniques to lock the tune frequency is also another method. This alternative make low level excitation is possible.

Using proprietary filter bank technology in a very fast real-time signal analyzer is also a promising method. Commercial products such as TEK 3052/3054 is most famous [4,5]. However, expensive and limited functions are its disadvantage.

Using digital signal processing techniques as core of vector signal analyzer is modern methods and provides various analysis options. Commercial products such as HP 89410 has been widely use in many facilities [6]. Speed is moderate for most of the applications.

Due to the advanced in radio communication, digital tuner and signal processing are widely use. Using commercial RF technology in beam instrumentation is series considered recently. Dedicated tune monitor based upon digital receiver made easily to attain the goals, such as fast response, flexibility, programmable, easily to integrated with control system, ...etc. Applied software radios techniques for tune measurement are come to age.

3. DIGITAL RECEIVER OPERATION PRINCIPLE

The digital receiver chip performs two major signal processing operations controlled by two programmable parameters as shown in Figure 1. The first is translation of the input signal down to DC controlled by the tuning frequency programmed into the local oscillator. The second low pass filtering where the bandwidth and output sampling rate are controlled by setting the decimation factor. There is no initial component tolerance or temperature variations, aging characteristics, calibration or preventive maintenance required.

Inside the digital receiver chip there are three major sections:

* Local oscillator
* Mixer
* Decimating low pass filter

The local oscillator is a direct digital frequency synthesizer (DDS) sometimes called a numerically controlled oscillator (NCO). The oscillator generates digital samples of two sine waves precisely offset by 90 degrees in phase creating sine and cosine signals. It uses a digital phase accumulator and sine/cosine look-up tables. The ADC clock is fed into the local oscillator. The digital samples out of the local oscillator are generated at a sampling rate exactly equal to the ADC sample clock frequency, fs. Since the data rates from these two mixer input sources are both at the ADC sampling rate, fs, the complex mixer output samples at fs. The sine and cosine input from the local oscillator create in-phase and quadrature (I and Q) output that are important for maintaining phase information contained in the input signal. The decimating low pass filter accepts input samples from the mixer output at the full ADC sampling frequency, fs. It utilities digital signal processing to implement a FIR (finite impulse response) filter transfer function. The filter passes all signals from 0 Hz up to a programmable cutoff frequency or bandwidth, and rejects all signals above that cutoff frequency. The digital filter is a complex filter which processes both I and Q signals from the mixer. At the output you can select either I and Q values or just real values, depending on system requirements.

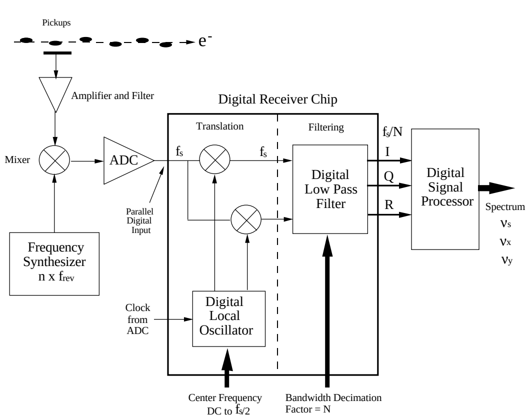

Figure 1: Functional block diagram of digital receiver

4. DIGITAL RECEIVER BASED TUNE MONITOR

A digital receiver based tune monitor has been implemented as dedicated system. The system includes RF front-end electronics and digital to analog converter, multi-channel digital receivers and digital signal processor as shown in Figure 2. Portion of the beam spectrum process by the RF front-end electronic and down convert to baseband signal. The ADC converts baseband signal to digital data streams and sends to digital receiver. Digital tuner performs digital mixer, low pass filtering and data formatting. Output I/Q data stream is processed by the DSP to get spectrum and perform peak identification. The ADC module, digital receiver module, and DSP module are host in VME crate. The 14 bits, 20 MS/sec ADC provides more than 70 db spurious free dynamic range, and 8 MHz real-time bandwidth. Narrow bandwidth white noise excitation is available if stored beam is quite. Off-the-shelf products are used in this design.

Frequency and decimation factor of the low pass filter are software programmable. The tune update rate is limited by the computation power of the DSP chips. Data output of three digital receivers is performed FFT by a single C40 DSP chip currently use. Spectrum update time is less than 10 msec. To increase the speed, multiple DSPs or new generation DSP (ex. 320C6x) is necessary for future upgrade. Processing gain for 1024 points FFT is about 30 dB for input signal with 0 dB SNR. Appropriate data average algorithms adopt for data smoothing. Measured tune update into machine database every 100 msec that is the data updates rate of control system. About 10 spectrum per second is display on console computer. User interface is developed by using PV-WAVE package. Histogram and spectrogram display are available to satisfy various purposes. Fast tune value update in msec time resolution is available in VME crate locally for accelerator physics study or monitor power supply ripple. Fast tune data with 1 msec time resolution is possible access through NFS file by user request.

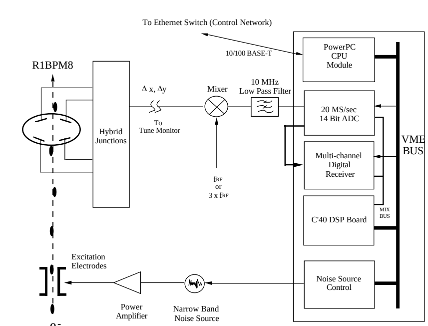

Figure 2: Functional block diagram of the digital receiver tune monitor and bunch-by-bunch current monitor.

5. USERS INTERFACE

The tune measured by VME crates are sent to console computer for display. Current update rate is 10 times per seconds. The display page on console is development by the aid of PV-WAVE package. Current display supports simple spectrum shown as Figure 3, waterfall, spectrogram display to satisfy various applications.

6. PRELIMINARY TEST RESULTS

To examine the performance of tune monitor, a sinusoidal wave current with 0.2 Amp peak-to-peak applied to a quadrupole trim as shown in Figure 4(a). Corresponding tune variation due to this excitation is about 0.0009 shown as Figure 4(b). It is estimated that resolution of tune monitor is about 0.0002. Results are consistent with parameters setting tune monitor. These parameters include sampling rate, decimation factor and data length.

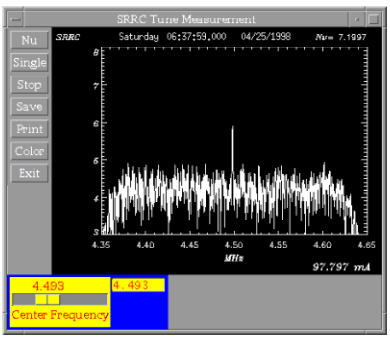

Figure 3: Simple user interface of tune monitor

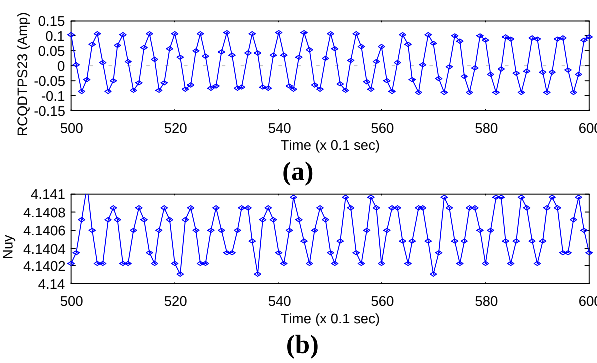

Figure 4: Tune variation due to 200 mA peak-to-peak sinusoidal wave applied to quadrupole trim (RCR1QDPS16).

Tune change due to focusing error of undulator U5 shown in Figure 5. The operation close the gap to 18.5 mm firstly, then open the gap to 220 mm again. The hysteresis loop near minimum gap is due to intentional 1 second delay in tune value update. Gap changing speed is 1 mm/sec for this test run.

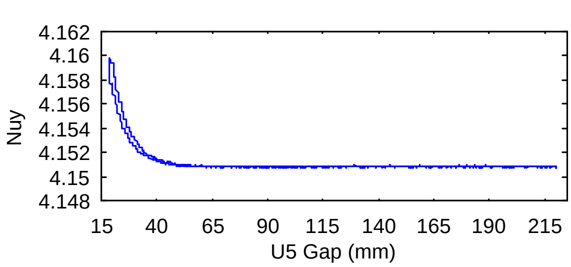

Figure 5: Vertical tune shift versus U5 gap.

Figure 6 shown the working point evolution on tune diagram during 1.3 GeV to 1.5 GeV energy ramping. In this test run, power supplies are increase linearly. Tune is scatter in a small region during this energy ramping scenario. Ramping route is not optimized for this test run.

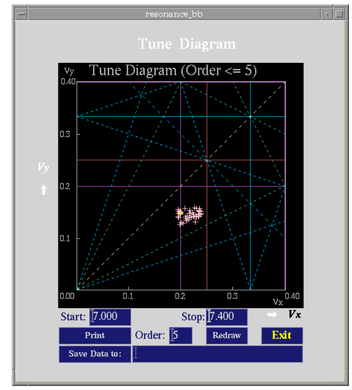

Figure 6: Tune evolution on tune diagram during energy ramping test run.

7. FUTURE PROSPECTS

A digital receiver based tune measurement system is implemented. Preliminary results shown that performance of digital receiver based tune monitor can meet the requirement of various purposes. Tune feedback to keep tune at fixed value during lattice parameter change is underway. Tested results confirm that digital receiver is a good candidate for dedicated tune measurement in light source.

The booster will install a dedicate tune monitor to aid tuning lattice parameters in near future. The booster is a 10 Hz machine. The 50 MeV electron beam injects into booster and ramp up to 1.3 GeV within 50 msec. It is require tune measurement should be in the order of milli-second or less. The system is expected using 512 points FFT to measure the tune. The system is similar the system that describes above. Except the tune value will converted to analog voltage. The tune voltage will feed into data acquisition that combine magnet current, RF voltage, beam current digitization system.

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