A 100MHz voltage to frequency converter

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Abstract. Voltage to frequency conversion is a data acquisition technique widely used in synchrotron radiation and other scientific applications that require the proper integration of analog signals during well defined time intervals synchronised with photon counting detectors. Here we present a new synchronous voltage to frequency converter with output frequency up to 100MHz, two orders of magnitude higher than current commercially available devices. The frequency enhancement of this new module overcomes the main limitation of previous devices by boosting the dynamic range and making the technique appropriate for data sampling in the kilohertz range. While the linearity and stability are comparable to existing units, the frequency enhancement pushes the dynamic range allowing for instance 16-bit effective resolution in measurements over 1ms integration time.

1. Introduction
Voltage to frequency conversion (VFC) is widely used as measurement technique of analog signals in synchrotron radiation experiments. In this technique, the analog signal to be measured, usually produced by an analog detector or a beam monitor, is fed into the VFC unit and the output pulses from the frequency output are sent to a digital pulse counter. The number of pulses accumulated by the counter during a given time interval is then directly proportional to the time integral of the analog signal during that particular interval.

This method has two main advantages. Firstly, it is not necessary to adjust the bandwidth of the analog chain to the sampling rate in order to optimize the signal-to-noise ratio. Both signal and noise are directly integrated during the given time interval and the higher frequency components are consequently suppressed. In that sense the analog signals are treated in a similar way than photon counting detectors and they can be seamlessly integrated into photon counting chains. In addition, the transmission of the converted data is noise free. If the VFC is installed at or very close to the analog signal source, the signal can be transmitted in digital form over long distance with no degradation. This is particularly convenient for synchrotron radiation beamlines as it allows concentrating signals from various monitors and sensors as well as analog and photon counting detectors into a central point and to implement synchronized integration in an easy and straightforward way.

The main limitation of the method is related to the maximum output frequency of the converters that restricts the maximum achievable dynamic range for short integration times. This prevents the use of VFC in fast data acquisition systems as the effective noise usually becomes totally dominated by the quantization noise of the frequency output. Currently available voltage to frequency converters operate up to one or few MHz and at such full scale output frequencies, data acquisition in the kilohertz range is limited to about 10 bits of effective resolution. This is largely insufficient for the majority of practical applications and this severe limitation has contributed to spread the wrong idea in the synchrotron community that VFC is not appropriate for scanning setups or other experimental
techniques that require data acquisition in the millisecond range. In this paper we present V2F100, a voltage to frequency converter recently developed at the ESRF that is able to operate with a full scale output frequency of 100MHz. As it is presented in the following sections this new module extends the usability of VFC to applications requiring millisecond and sub-millisecond data integration intervals.

2. Module description
The V2F100 implements a conventional synchronous voltage to frequency conversion scheme as it is described in the literature [1][2] and used in existing devices [3]. The output pulses are therefore synchronous with an internal fixed frequency clock. One of the singularities of the V2F100 with respect to existing VFC units, is that instead of relying on a fully single-chip analog design, it is based on a mixed mode circuitry combining analog and digital components. This allows reaching high full scale frequency at the digital output while keeping good signal characteristics determined by the analog input components. This mixed scheme also allows integrating additional outputs and functional modes than are usually not found in similar units. The number and type of outputs of the V2F100 has been designed for convenience in applications at the ESRF.

2.1. Functionality
The block diagram of each of the channels is depicted in figure 1.

![Figure 1. Functional block diagram of each of the two V2F100 channels](image)

The input signal is processed by a variable gain differential instrumentation amplifier and an ADC and fed into a synchronous digital value to frequency converter that produces a bipolar 200MHz full scale frequency output. The input signal polarity can be inverted as well as the voltage range selected among four available full scale values.

The frequency signal of the selected polarity goes through a variable frequency divider to produce the actual main output that is fed to the TTL output driver. In this way the output signal always presents a 50% average duty cycle. The maximum effective full scale output frequency is 100MHz but it can be further reduced down to 10MHz to be made compatible with the maximum frequency accepted by the pulse counters used in the application.

There is an additional bipolar frequency signal per channel. The bipolar information is coded as a 2-phase quadrature signal that can drive an up/down counter similar to those used for reading incremental position encoders. However in the case of the V2F100, the signed counter value accumulated during a certain time interval, corresponds to the integrated analog signal and not to a position increment. This output operates at a reduced 12MHz full scale frequency that is obtained by simple frequency division. In addition to the previous frequency outputs, the current signal value is made available at a third output by implementing an absolute digital SSI interface.

2.2. Implementation
The V2F100 is a mains powered stand-alone dual-channel module as depicted in figure 2. The two channels are fully functionally independent and each of them accepts a certain number of configuration options such as input voltage range and polarity or output full scale frequency. The
channel configurations can be changed by means of a manual interface and the current settings are stored permanently in an internal non-volatile memory.

![Dual-channel V2F100 module](image)

**Figure 2.** Front view of the dual-channel V2F100 module

The voltage input is applied to the high impedance differential instrumentation amplifier through an isolated BNC connector to remove common mode low frequency interferences such as those due to ground loops.

The electrical interface of the two-phase quadrature output and the SSI interface are implemented with standard differential RS422 transmitters and receivers connected to a single connector for each channel at the rear of the module. The TTL output is a coaxial connector located at the front panel and driven by a fast driver able to produce 5ns wide pulses and designed to drive long coaxial cables of 50 ohm characteristic impedance. The design is such that electrical levels at the receiver side are compatible with TTL logic whether the cable is terminated at high impedance or with a 50 ohm load.

By default, the TTL frequency output can only convert and transmit voltage signals with the selected polarity but in order to properly measure very small or even slightly negative signals, the signal driven to the TTL output can be optionally configured to shift the zero voltage input level to a fixed non-zero positive output frequency.

### 3. Results and discussion

A few prototypes have been built and used to perform preliminary evaluation tests. The temperature stability was studied by setting the output frequency to 25% of full scale and monitoring its value during 15 hours along with the temperature of the room. The observed drift was about 8 ppm/°C over few degrees. A better thermal control of some few critical components is expected to improve this parameter.

The internal module noise was measured by counting fluctuations of the frequency output integrated over intervals ranging from 100 microseconds to 10 seconds. The associated effective resolution obtained by this method is presented in figure 3. The theoretical quantization resolution limit is also depicted in the figure for comparison purposes (dashed line). At long integration times, the effective resolution is limited to about 20 effective bits (ENOB) due to 1/f noise effects. At shorter times the performance is close to the theoretical limit and the module provides more than 16 bits effective resolution with integration intervals of 1 msec.

The non-linearity was measured by counting the output pulses during 10 seconds for each value of the input voltage (0 to 10V in 100mV steps). The input voltage was supplied by a voltage generator and was monitored by a 6-1/2-digit voltmeter. This process was repeated 60 times and both counting and voltage values were averaged in order to derive the module non-linearity, i.e., the deviation from a best-fit line obtained from the experimental data. The results are shown in figure 4. With the exception of values close to input limits (0 and 10 V), the absolute non-linearity is maintained within ±5ppm of the full scale of the range.
4. Conclusions
This paper presents a new voltage to frequency converter, V2F100 as well as results of the first prototypes. The module is able of operating up to 100MHz of output frequency, an increase of dynamic range by two orders of magnitude compared to current available modules that extends the use of the VFC technique to millisecond and sub-millisecond data integration intervals applications.

The first measurements show that this new module provides very good performance adapted to the large majority of foreseen applications. Even though, a few relatively simple further improvements are still foreseen before starting the deployment of the final modules at the ESRF beamlines in the coming months. These improvements are expected to reduce non-linearity close to input limits down to few ppm F.S.

References
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