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Title: **V/F Parameters for Continuum Back Ends**

Author(s): James Lamb

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V/F Parameters for Continuum Back Ends

James Lamb

Introduction

Voltage to frequency (V/F) converters are used by NRAO to convert the voltage produced by the continuum square law detector to a digital signal. The block diagram of the system is shown in Fig. 1. The detector output v_{det} produces an output frequency from the converter of $f = \alpha_{VF}\, v_{det}$ which is then counted for some fixed time T_{samp}. This note gives some relationships between the various parameters as a design aid. Although these relationships may already be known, the purpose of the note is to make them generally available.

Choice of Parameters

The following parameters (not all independent) need to be considered.

- B_{HF} = pre-detection bandwidth
- D = dynamic range
- T_{samp} = time period for counting pulses (integration time)
- f_{max} = maximum output frequency from converter
- N_{max} = maximum number of counts to be accumulated
- $\varepsilon(\%)$ = percentage reduction in signal to noise due to digitization allowed

It will be assumed that the counter is enabled and disabled by pulse edges from the converter, that the start of the sampling interval is asynchronous with the V/F converter output, and the sample time is fixed. Under these conditions the following relationships may be derived

$$N_{max} = D\left(\frac{33B_{HF}\ T_{samp}}{\varepsilon(\%)}\right)^{\frac{1}{2}} \qquad (1)$$

$$f_{max} = \frac{N_{max}}{T_{samp}} = D\left(\frac{33B_{HF}}{\varepsilon(\%)\ T_{samp}}\right)^{\frac{1}{2}} \qquad (2)$$

The number of bits needed in the counter is

$$n = \text{int}\ (\log_2 N_{max}) + 1 \qquad (3)$$

where int(x) denotes the integer part of x. Note that D corresponds to 3dB/bit.

Comments

Different V/F conversion schemes may be considered. For example the start of the integration time may be synchronized with a pulse edge from the counter. This would reduce the digitization noise by a factor $\sqrt{3/2} \cong 0.87$ and add a systematic offset of 1/2 count to the total.

Another scheme would be to time a given number of pulses. This would allow the V/F converter to operate at much lower frequencies (though the timing clock would still need to operate at $\sim f_{max}$ given by (2)). However, the required bandwidth may not be reduced since the pulse edges still need to be sharp for accurate timing. Furthermore, the variability of the timing interval could be a problem.

Appendix I: Equivalent Noise Due to Converter

The discrete counting of pulses leads to an error in the analog to digital conversion which may be calculated as follows.

It will be assumed that the counting of pulses starts at some time independent of the pulse edges, and the counter is enabled at that time to detect the next rising edge. There will be a delay time t_1 before the first edge (Fig. 2) so that the number of pulses counted is too small by an amount $\Delta N_1 = t_1 f$ where

$$0 \leqq \Delta N_1 < 1$$

within a uniform probability

$$P_1(\Delta N_1) = \begin{cases} 1, & 0 \leqq \Delta N_1 < 1 \\ 0, & \text{otherwise} \end{cases}$$

Similarly the last count will be initiated by an edge at some time t_2 before the end of the timing interval so that the total count will be too large by an amount $\Delta N_2 = 1 - t_2 f$ where

$$0 \leqq \Delta N_2 < 1$$

again with uniform probability

$$P_2(\Delta N_2) = \begin{cases} 1, & 0 \leqq \Delta N_2 < 1 \\ 0, & \text{otherwise} \end{cases}$$

The total count will be in error by

$$\Delta N = \Delta N_2 - \Delta N_1$$

For long pulse trains it may reasonably be assumed that t_1 and t_2 are independent so that probability function for ΔN is given by

$$P(\Delta N) = \int_{-\infty}^{\infty} P_1(\Delta N_1)\ P_2(\Delta N + \Delta N_1)\ d(\Delta N_1)$$

$$= \begin{cases} 1 - \Delta N, & -1 < \Delta N < 1 \\ 0, & \text{otherwise} \end{cases}$$

(See Fig. 2). The rms of this probability function is

$$\Delta N_{rms} = \left[\int_{-\infty}^{\infty} \Delta N^2\ P(\Delta N)\right]^{\frac{1}{2}} = \sqrt{\frac{2}{3}} \cong 0.8$$

If the start of the timing period is synchronized with a pulse edge, then the only contribution to the error is the uncertainty in the time for the last pulse. This will just be $\Delta N = \Delta N_2$ with probability $P_2\ (\Delta N_2)$. This has a mean and rms of

$$\overline{\Delta N} = \frac{1}{2}$$

$$\Delta N_{rms} = \frac{1}{2}$$

Appendix II: Derivation of Equations (1)

The noise output from the detector is given by

$$\frac{\sqrt{\Delta v}_{rms}}{v_{det}}^{2} = \frac{1}{B_{HF} T_{samp}}$$

Since the noise due to analog to digital conversion is independent of this, it must be added in quadrature:

$$\delta^2 = \left(\frac{\Delta v_{rms}}{v_{det}}\right)^2 + \left(\frac{\Delta N_{rms}}{N}\right)^2$$

where δ is the fractional uncertainty in the digitized sample. The percentage increase in noise due to the digitization is therefore

$$\varepsilon(\%) \cong 100 \times \frac{1}{2}\left(\frac{\Delta N^2_{rms}\ v_{det}^{\ 2}}{N^2\ \delta v^2_{rms}}\right)$$

This may be inverted to give N. For a dynamic range D the maximum value of n required is then

$$N_{max} = D\left(\frac{33\ B_{HF}\ T_{samp}}{\varepsilon(\%)}\right)^{\frac{1}{2}}$$

which is eq. (1).

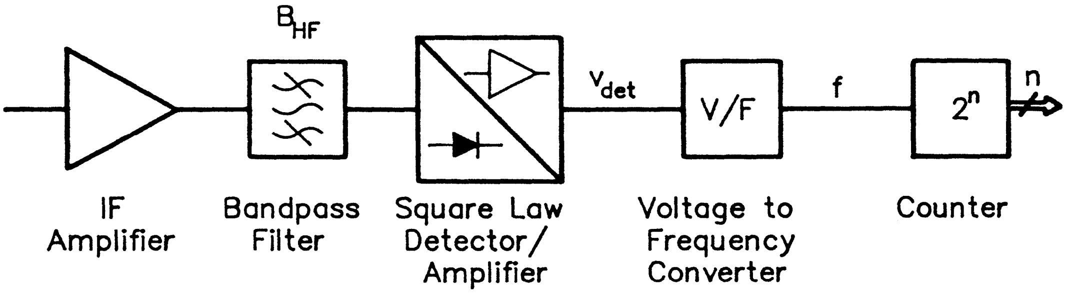

Figure 1. Voltage to frequency converter block diagram.

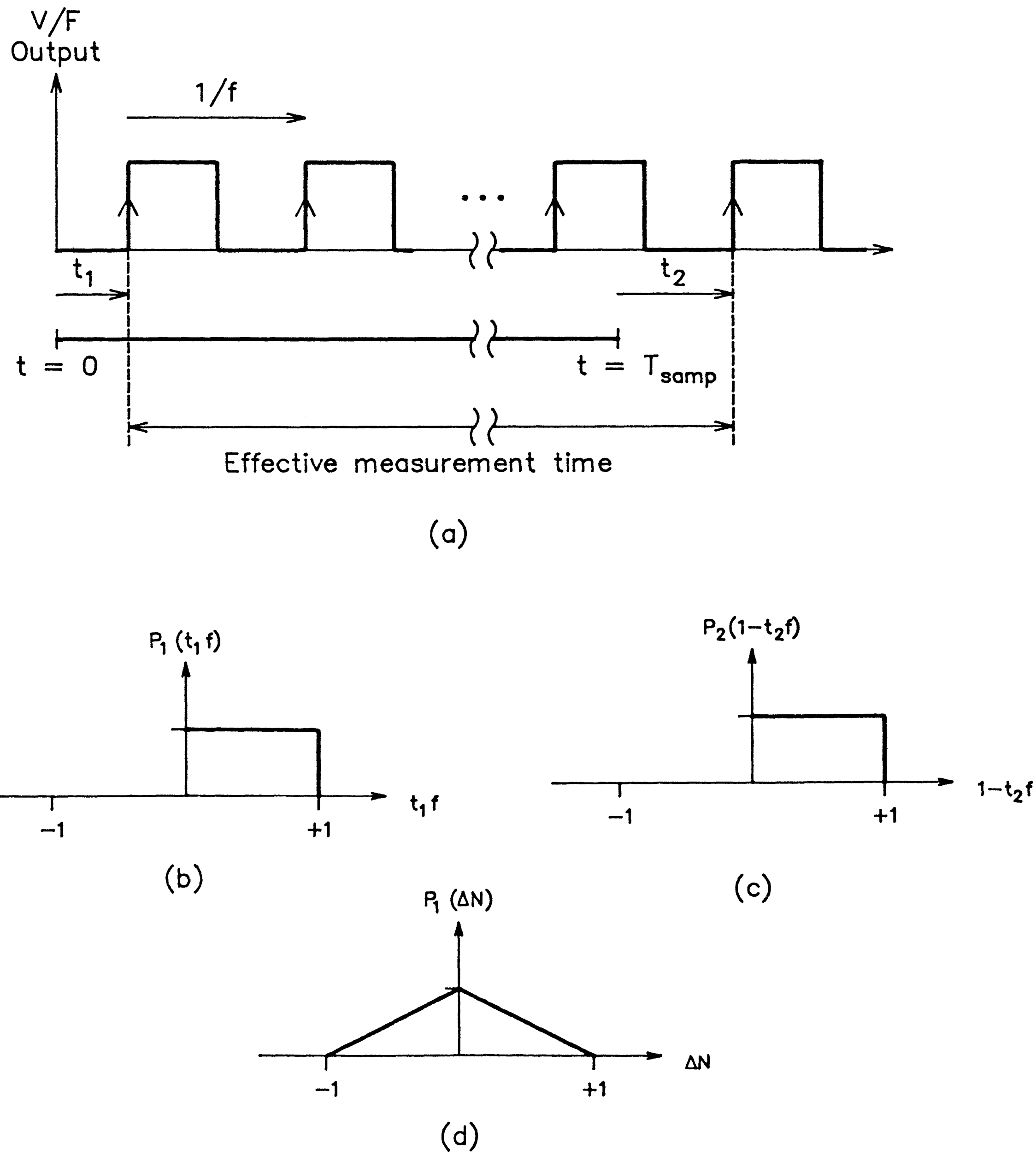

Figure 2. (a) Timing diagram for conversion, (b) probability function for error at start of conversion, (c) probability function for error at end of conversion, and (d) probability for resultant error.