# A Novel Method of Noise Suppression in Beam Transfer Function Measurements

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*Abstract*

Beam transfer functions (BTF), giving the frequency domain response of the beam to an external excitation, are widely used to measure the impedance of the beam environment, to analyse stability conditions and to determine the true momentum distribution in spite of strong signal shielding in dense, cooled beams. A problem encountered in low intensity (antiproton and rare ion) storage rings is the unwanted noise on the BTF signal.

We have developed a method of noise suppression which may be viewed as gating in time domain: Transforming (by software) the BTF into time domain, cutting off the tail after the response decayed and going back into frequency space we obtain a significantly cleaner signal. The tail of the time response contains information on beam and system noise which can be treated separately. Results obtained on the low energy antiproton ring LEAR are discussed.

## I. THE TIME GATING TECHNIQUE

### A. *The time gating technique and its application to BTF measurements*

*Definitions:*

$A(t)$ = digitized time trace containing the excitation signal

$B(t)$ = digitized time trace containing the beam response signal

$B_{corr}(t)$ = part of the beam response, which is correlated to the excitation signal

$B_{nonc}(t)$ = part of the beam response, which is not correlated to the excitation signal

$\tilde{A}(\omega)$ = discrete (complex) Fourier transform of $A(t)$ [1]

The fast Fourier transformer, which is used here to measure the frequency response of the beam to a band-limited noise excitation, digitizes the two time traces $A(t)$ and $B(t)$. The two data sets are then Fourier transformed into frequency domain and the ratio

$$S(\omega)=\frac{\tilde{B}(\omega)}{\tilde{A}(\omega)}$$

is displayed as the frequency response function [2] (Fig. 1). The beam response consists of a signal contribution $B_{corr}(t)$, which is correlated to the excitation and which represents the BTF proper, and of non-correlated signal contributions $B_{nonc}(t)$, which are due to noise. The measurement data $S(\omega)$ can be transformed back into time domain by a software implemented inverse Fourier transform:

$$\tilde{S}^{-1}(t)=\frac{\tilde{B}_{corr}(t)}{\tilde{A}(t)}+\frac{\tilde{B}_{nonc}(t)}{\tilde{A}(t)}$$

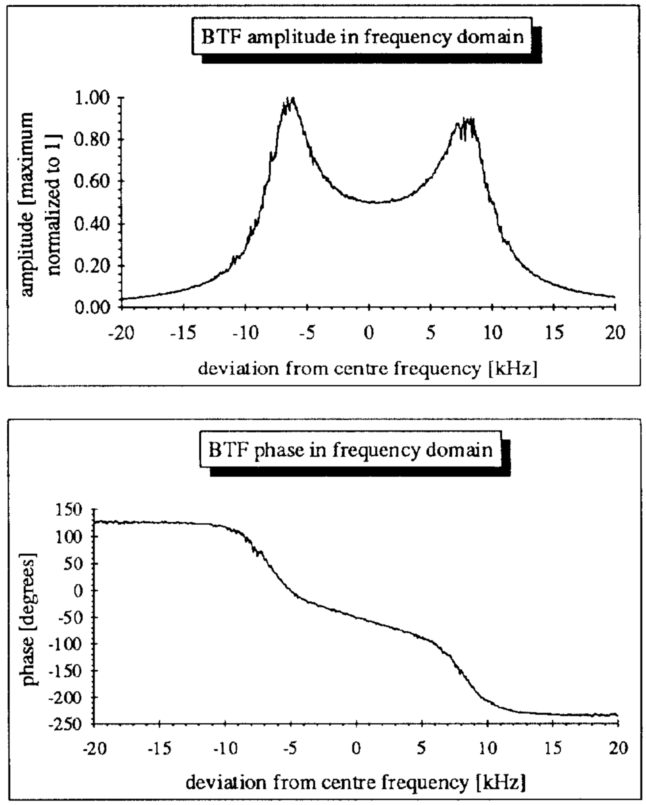


Figure 1. $S(\omega)$ of a longitudinal BTF measurement with a coasting beam of $7.6\cdot 10^9$ protons at 200 MeV/c in LEAR, revolution frequency = 0.796 MHz, centre frequency = 42.17 MHz, $(\Delta p/p)_{FWHH}=1.6\cdot 10^{-4}$

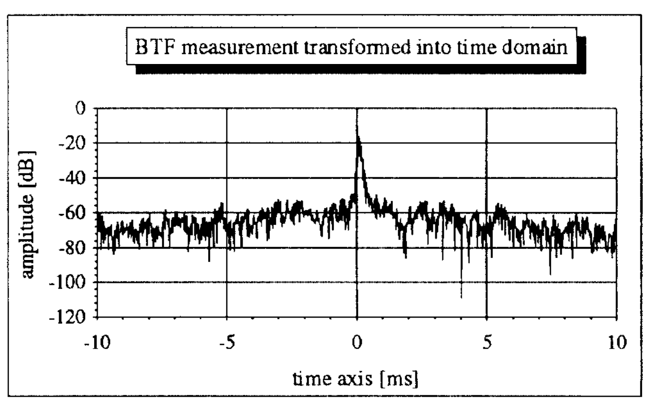


Figure 2. The inverse Fourier transform of the BTF represents the beam response to an impulse excitation.

In time domain the correlated part of the signal represents the response of the beam to an impulse excitation. For the damped system this response decays rapidly, whereas the non-correlated part is distributed over the whole time interval (Fig. 2).

It is possible to separate the two signal contributions by applying a weighting function to the data in time domain [3]. This procedure, which is used to leave the information included in a specified time interval unchanged and which suppresses signal contributions outside this time window, is called time gating. By applying a weighting function with a special shape (Hanning window) one avoids unwanted weighting effects, which are due to discontinuities at the borders of the time gate. This technique is implemented in certain network analysers and frequently used to separate and suppress reflection contributions from the required signal [4],[5],[6].

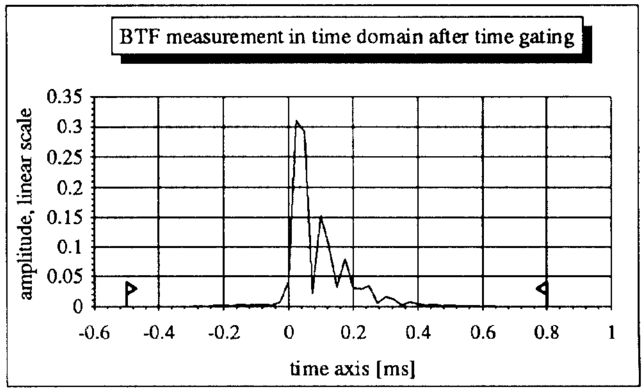


Figure 3. In time domain an interval can be specified, in which the coherent response is present. The information outside - which is due to noise - is suppressed. This procedure is called time gating.

*B. Suppression of the non-correlated signal contributions*

Once the time interval including the correlated information is established and the time gating is performed (Fig. 3), the Fourier transform into frequency domain leads to a significantly cleaner BTF signal (Fig. 4):

$$S_{gated}^{corr}(\omega) \approx \frac{\tilde{B}_{corr}(\omega)}{\tilde{A}(\omega)} \equiv BTF$$

*C. Analysis of the non-correlated signal*

It is also possible to suppress the correlated information included in the specified time interval. The remaining non-correlated signal can be Fourier transformed to analyse its frequency domain behavior.

The resulting spectrum consists of noise from the electronics and most importantly in the present case from the beam itself, divided by the amplitude of the excitation signal. If the power of the exciting signal is constant over the frequency range of the measurement, this signal represents the Schottky signal, that would have been observed without exciting the beam:

$$\left|S_{gated}^{nonc}(\omega)\right| \approx \frac{\left|\tilde{B}_{nonc}(\omega)\right|}{\left|\tilde{A}(\omega)\right|} \equiv Schottky\ power\ spectrum$$

Direct Schottky measurements using a spectrum analyser are often done just before or after a BTF measurement, because the knowledge of both makes it possible to calculate the coupling impedance of the beam with its environment and to reconstruct the true momentum distribution [7],[8]. The comparison of the Schottky-like signal with the Schottky measurement is a tool to check, if the cooling (electron or stochastic) of the beam was in an equilibrium state during both measurements and to optimize the excitation strength for the BTF measurement.

Fig. 5 gives the stability diagrams derived from the longitudinal BTF data either directly smoothed in frequency

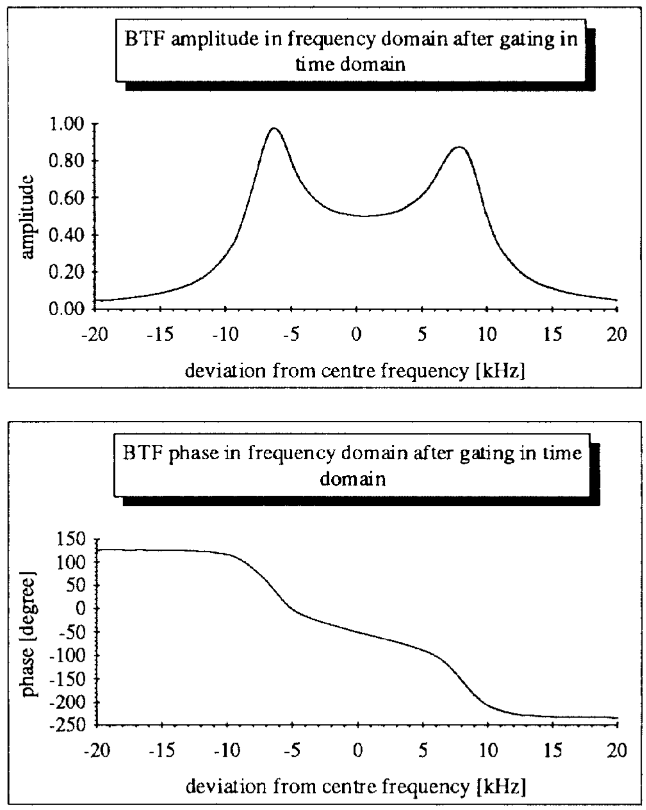


Figure 4. Gating in time domain and transforming back into frequency domain leads to a significantly cleaner BTF. Analysis of the signal outside the time gated range shows that its main contribution is due to beam Schottky noise.

domain or cleaned by time gating. One notes the difference near the "shaft" of the stability curve. In many situations beam stability is highly sensitive to this shaft region, which is obtained with higher accuracy by gating out the noise on the BTF. To avoid unwanted weighting effects in this region the width of the time gate has to be large compared to the damping time $\tau$ of the beam response (typically 10 $\tau$).

## II. CONCLUSION

The application of the time gating technique allows an efficient separation of the BTF signal from noise.

The suppression of the beam Schottky noise is of great importance. Using time gating, the BTF excitation strength can be decreased, measurements can be performed with beams of lower intensity, and the stability conditions of the beam can be determined with high precision.

By comparing the Schottky-like non-correlated signal contribution with a normal Schottky measurement, the excitation strength can be controlled.

Apart from the narrow band measurements, broad band BTF data from the CERN antiproton machines have been cleaned using the time gating technique to adjust e.g. the stochastic cooling systems.

## III. ACKNOWLEDGEMENTS

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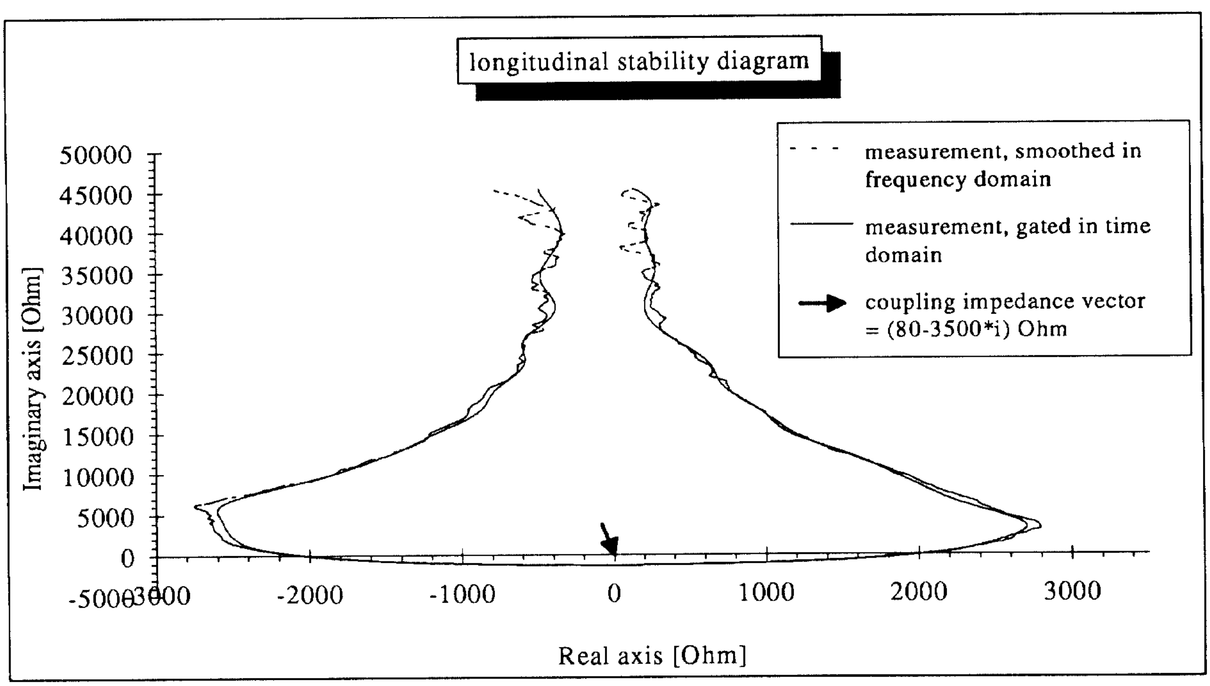


Figure 5. In this "stability diagram" the beam response of figure 1 and figure 4 is shown in the complex plane rather than in an amplitude and phase diagram. The effect of time gating becomes important at low particle numbers and low excitation strength.