Fast System Identification for Barrier Bucket Input Signal Generation*

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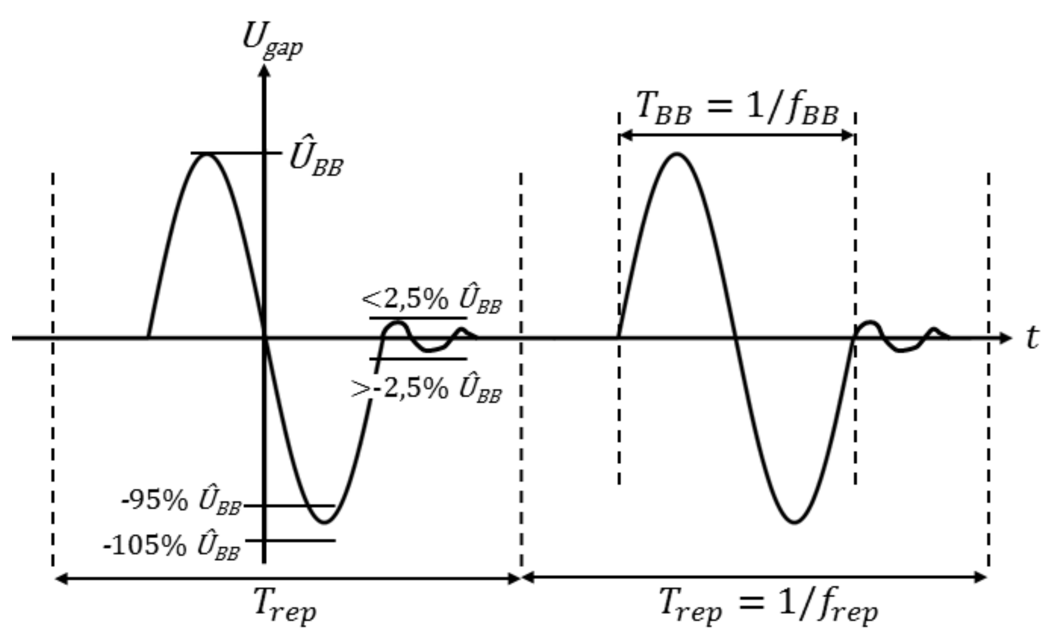
1 Introduction

At GSI, Barrier Bucket RF systems are currently designed for the SIS 100 synchrotron (part of the future accelerator facility FAIR) and the Experimental Storage Ring (ESR). In order to facilitate a large variety of longitudinal bunch manipulations these systems have to provide high quality single-sine gap voltages (right-handed figure). To achieve the desired output signal quality, a proper mathematical modeling of the system is needed to estimate the required input signal.



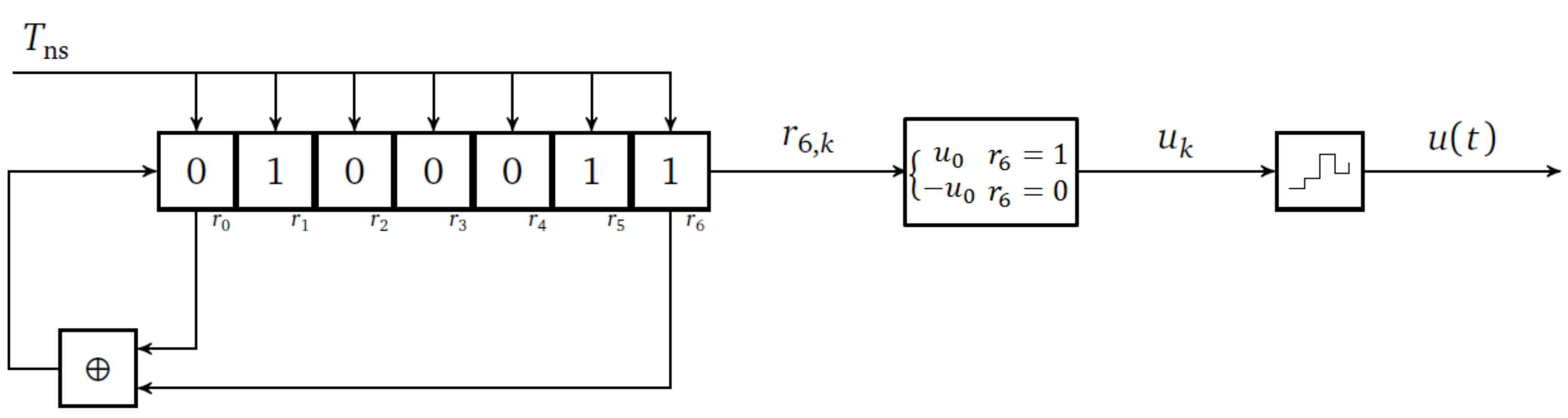
Desired output gap voltage.

2 Linear region

Fourier decomposition of the ideal output signal yields

$$U_{out}(t) = \sum_{n=1}^{\infty} \underbrace{\hat{U}\frac{T_{BB}}{T_{rep}}\left[\mathrm{si}\left(\pi\left[n\frac{T_{BB}}{T_{rep}}+1\right]\right) - \mathrm{si}\left(\pi\left[n\frac{T_{BB}}{T_{rep}}-1\right]\right)\right]}_{b_{n,\mathrm{out}}} \cdot \sin(n\omega_{rep}t).$$

In the linear region $\underline{U}_{in}(\omega) = \underline{U}_?(\omega) = \underline{U}_{out}(\omega)/\underline{H}(\omega)$ holds. The frequency response $\underline{H}(\omega)$ is measured using Pseudo Random Binary Signals (PRBS) as input. Such signals can be generated using a shift register, which is shown for a register of the length $b = 7$ hereafter.



Shift register of length $b = 7$

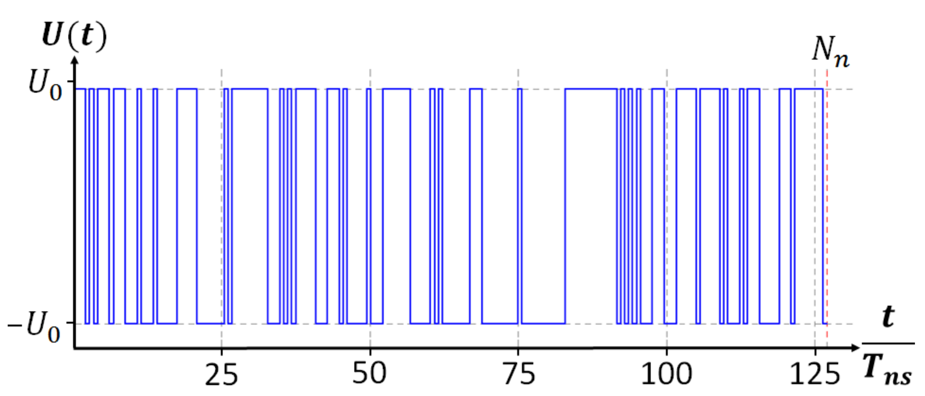
Two parameters can be varied to change the signal properties: The length b and the clock frequency f_{ns} of the register. f_{ns} is given by the maximum frequency, which has to be measured. As the PBRS spectrum can be described by

$$|\underline{u}_l| = U_0\sqrt{\frac{N_n+1}{N_n}}\left|\mathrm{si}\left(\frac{l\cdot T_{ns}\cdot\pi}{T_P}\right)\right|,$$

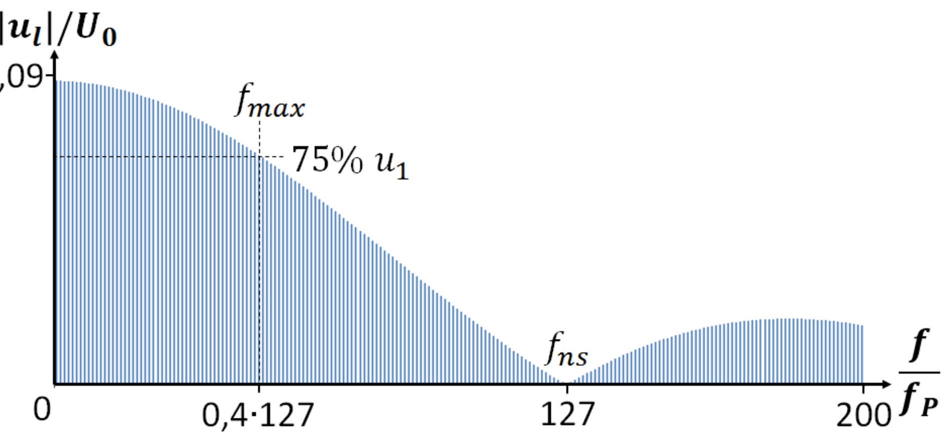
$f_{ns} = 2,5\cdot f_{max} = 2,5\cdot 80$ MHz is chosen. b determines the signal length $T_P = N_n \cdot T_{ns}$ with $N_n = 2^b - 1$ and therefore defines the frequency resolution f_p of the measurement. Thus,

$$b = \left\lceil \ln\left(2,5\frac{f_{max}}{f_{p,min}}+1\right)\ln(2)\right\rceil$$

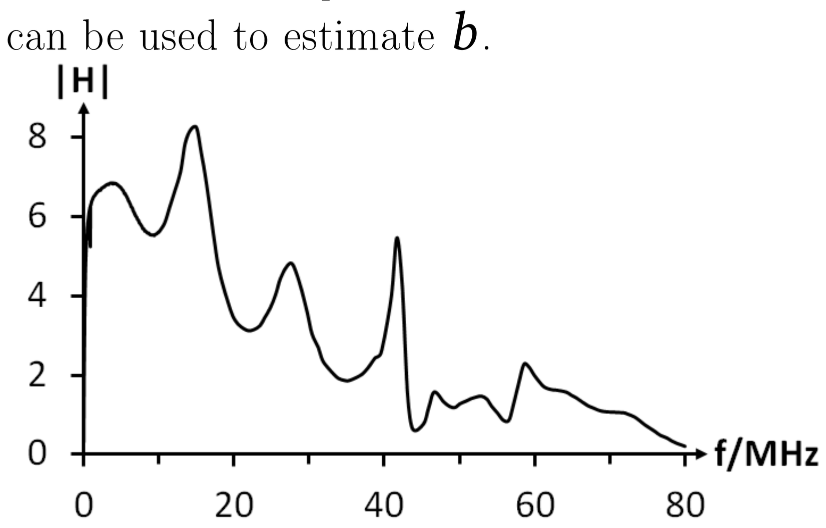
can be used to estimate b.



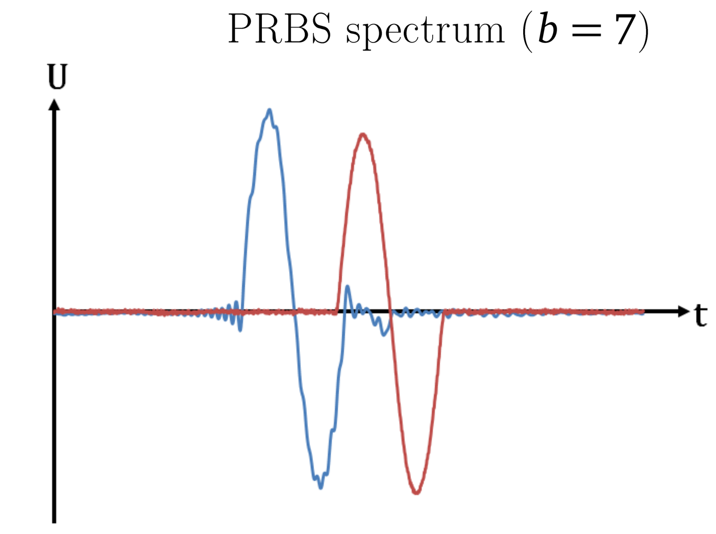
PRBS input signal ($b = 7$)



PRBS spectrum ($b = 7$)

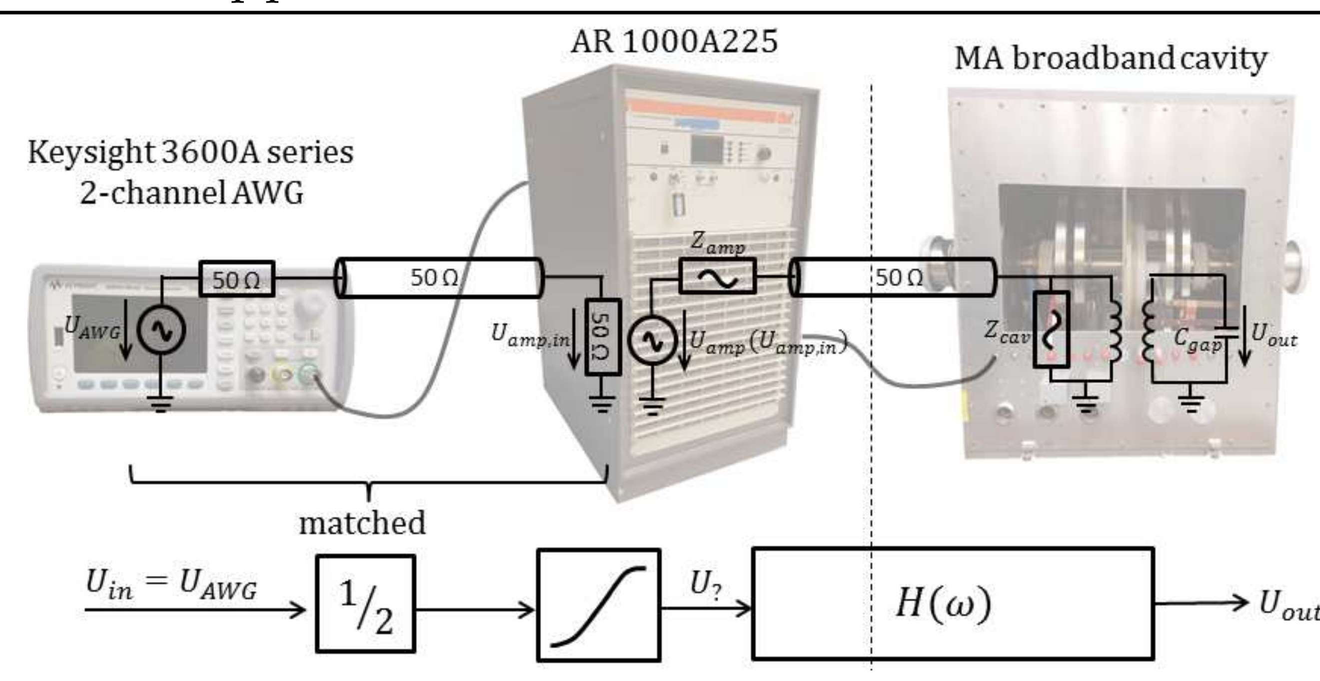


Measured amplitude response of the ESR BB prototype system.



Measured input and output signal in the linear region ($\hat{U}_{BB} = 520\,V$).

3 Nonlinear Approach



Hammerstein modeling of the ESR BB prototype system.

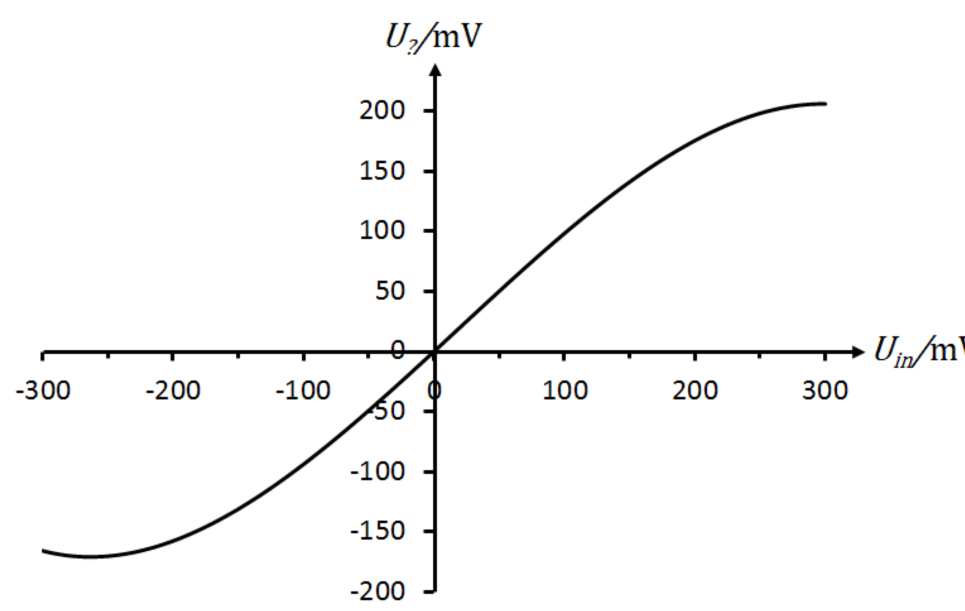
To characterize the static nonlinearity, a power series ansatz was chosen:

$$U_?(t) = f\left(U_{in}(t)\right) = \sum_{n=1}^{N} a_n\left[U_{in}(t)\right]^n.$$

As $U_?(t)$ can't be measured directly, it is calculated from $U_{out}(t)$ using $\underline{U}_?(\omega) = \underline{U}_{out}(\omega)/\underline{H}(\omega)$. Afterwards, the coefficients a_n can be calculated by solving the linear optimization problem

$$\begin{pmatrix} U_{in,1} & U_{in,1}^2 & \cdots & U_{in,1}^N \\ U_{in,2} & U_{in,2}^2 & \cdots & U_{in,2}^N \\ \vdots & \vdots & \ddots & \vdots \\ U_{in,M} & U_{in,M}^2 & \cdots & U_{in,M}^N \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_N \end{pmatrix} = \begin{pmatrix} U_{?,1} \\ U_{?,2} \\ \vdots \\ U_{?,M} \end{pmatrix}.$$

with $U_{in}(t)$ and $U_?(t)$ consisting of M samples. Best output signals were achieved using 3rd or 4th order power series and a linearly presdistorted testsignal. The inverse characteristic f^{-1} can be calculated from measurement data and is stored in form of a look-up table. With the measured frequency response $\underline{H}(\omega)$ and the inverse characteristic f^{-1}, the input signal is computed as shown below.

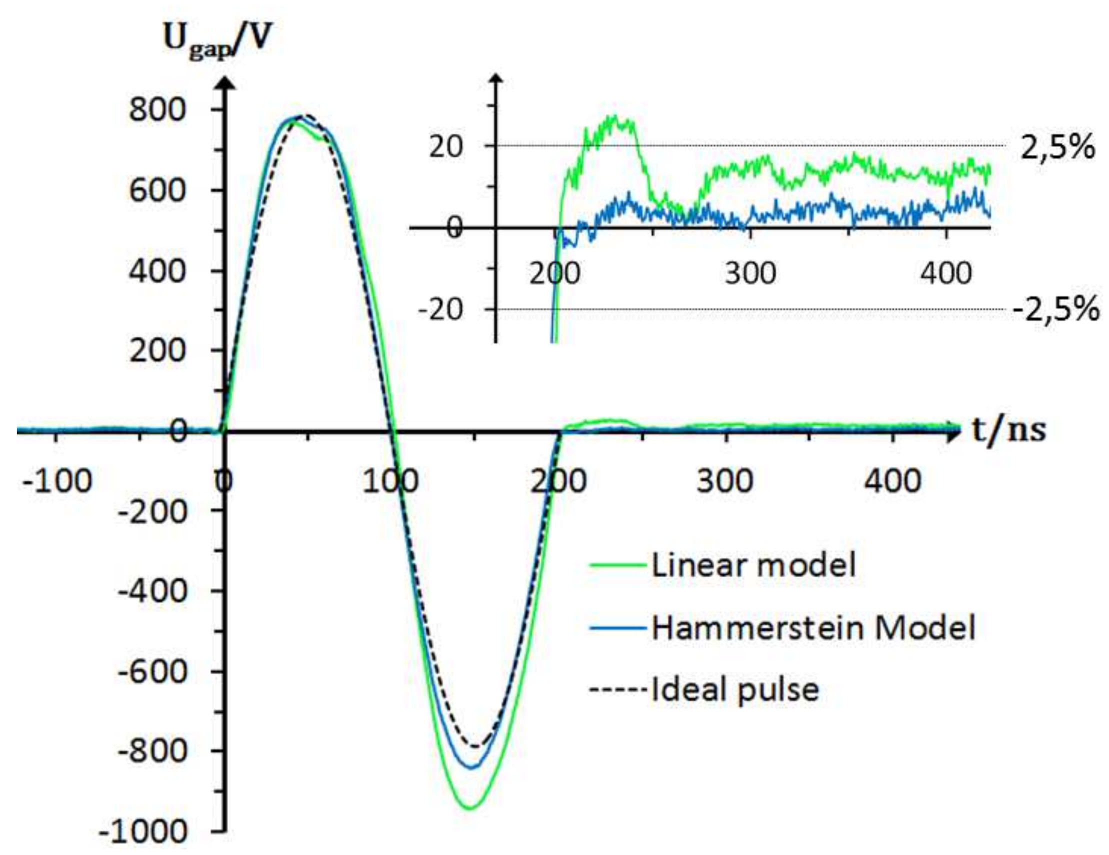


Measured 3rd order polynomial nonlinearity.

$$U_{out}(t) \to \boxed{\mathscr{F}\{U\}} \xrightarrow{\underline{U}_{out}(\omega)} \boxed{\underline{H}^{-1}(\omega)} \xrightarrow{\underline{U}_?(\omega)} \boxed{\mathscr{F}^{-1}\{U\}} \xrightarrow{U_?(t)} \boxed{f^{-1}(U)} \to U_{in}(t)$$

Different steps to compute the input signal $U_{in}(t)$ for a desired output $U_{out}(t)$

4 Results



Resulting voltages for linear and nonlinear predistortion for $\hat{U} = 800\,V$.

- Reduction of ringing to below 1%.
- Reduction of difference in half-cycles from 22% to 7%.
- Fulfills requirements for $\hat{U}_{out}(t) < 760$ V.
- Reduction of measurement time from >1 h to <1 min.

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