

# Fast System Identification for Barrier Bucket Input Signal Generation\*

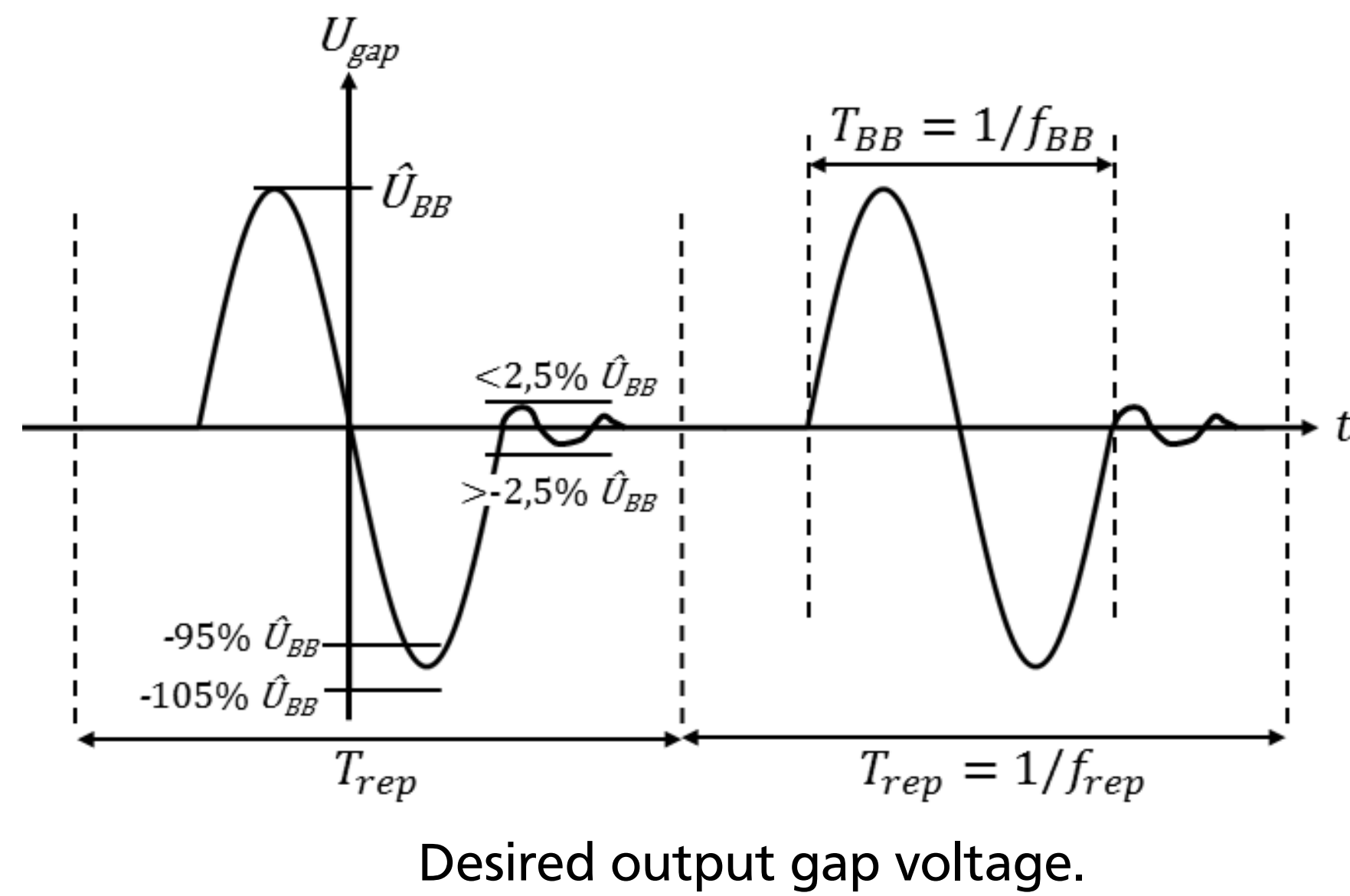


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## 1 Introduction

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.

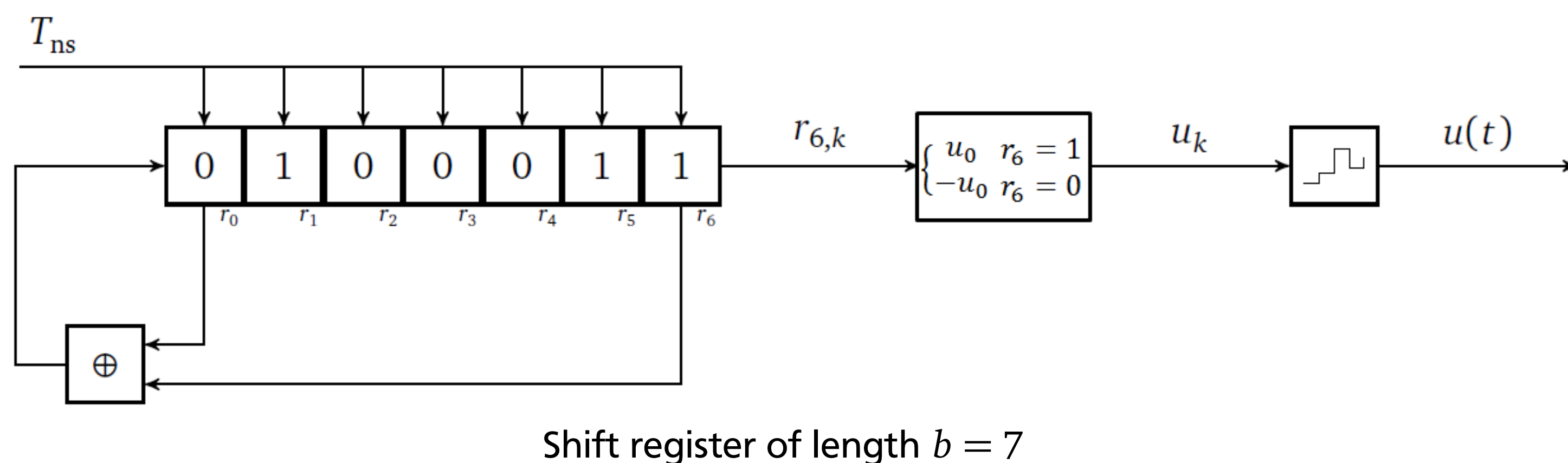


## 2 Linear region

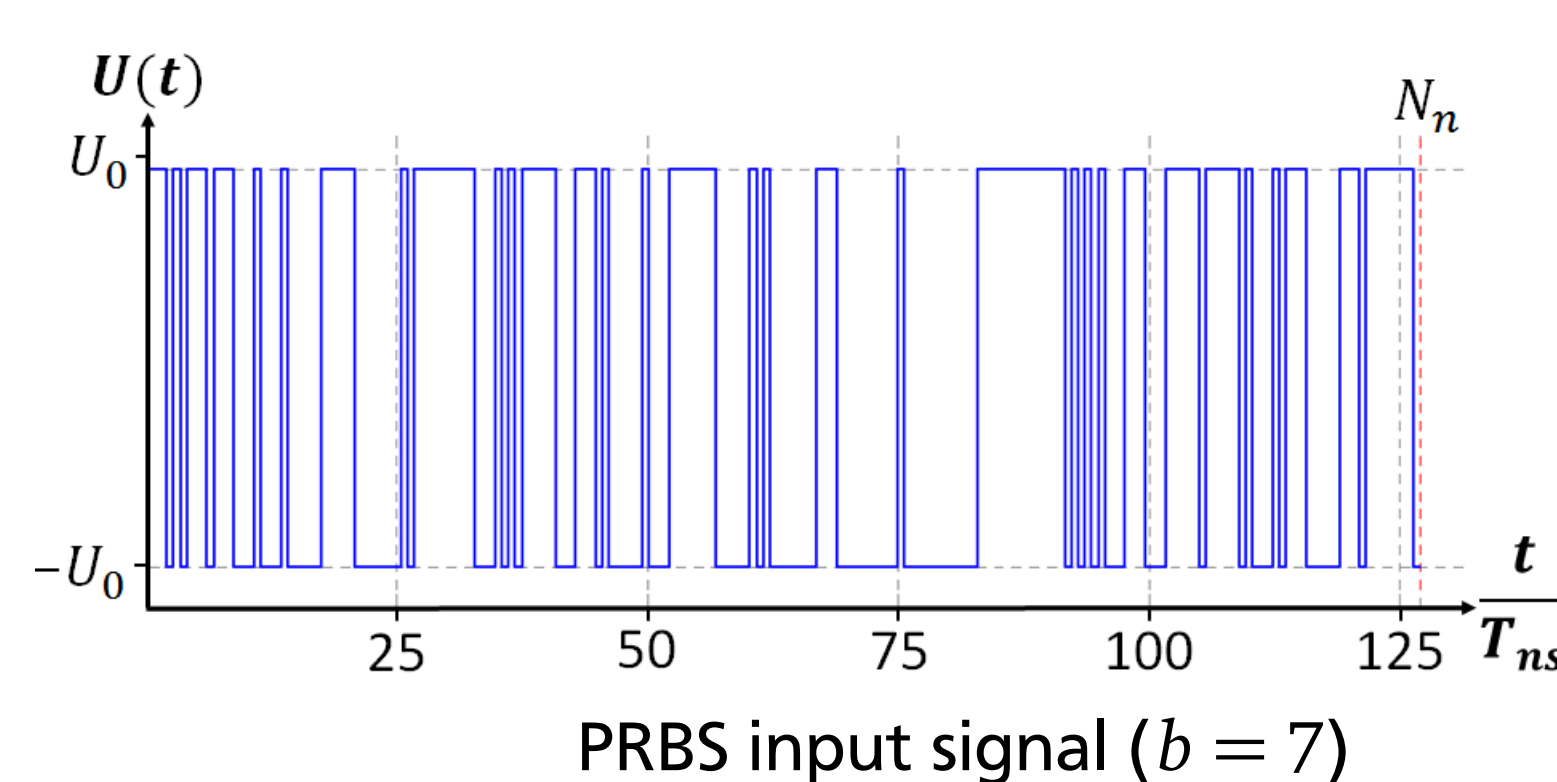
Fourier decomposition of the ideal output signal yields

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

In the linear region  $\underline{U}_{in}(\omega) = \underline{U}_{\gamma}(\omega) = \underline{U}_{out}(\omega)/H(\omega)$  holds. The frequency response  $H(\omega)$  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.



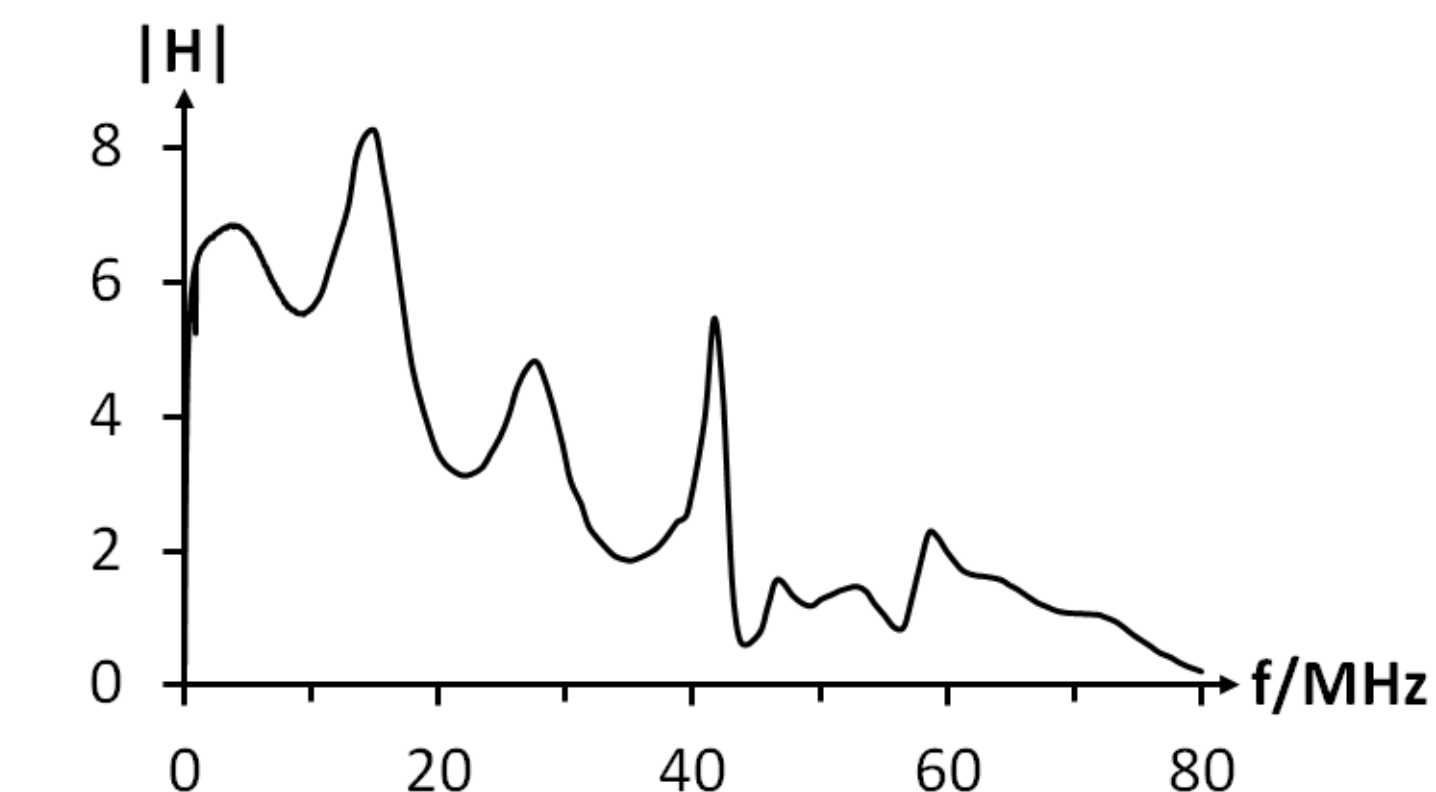
Two parameters can be varied to change the signal properties: The length  $b$  and the clock frequency  $f_{ns}$  of the register.  $f_{ns}$  is given by the maximum frequency, which has to be measured. As the PRBS spectrum can be described by



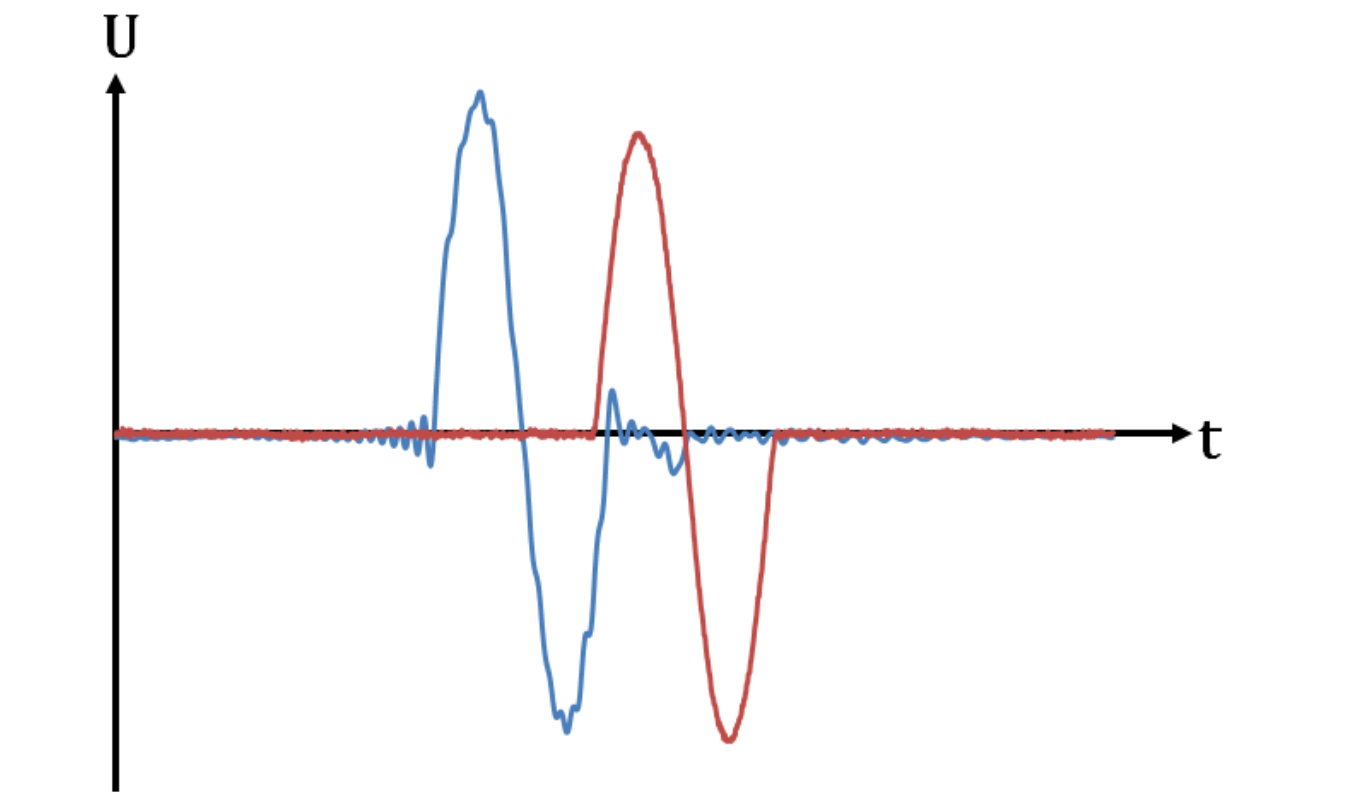
$|u_l| = U_0 \sqrt{\frac{N_n+1}{N_n}} \left| \text{si} \left( \frac{l \cdot T_{ns} \cdot \pi}{T_p} \right) \right|$ ,  
 $f_{ns} = 2,5 \cdot f_{max} = 2,5 \cdot 80 \text{ MHz}$  is chosen.  $b$  determines the signal length  $T_p = N_n \cdot T_{ns}$  with  $N_n = 2^b - 1$  and therefore defines the frequency 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  $b$ .

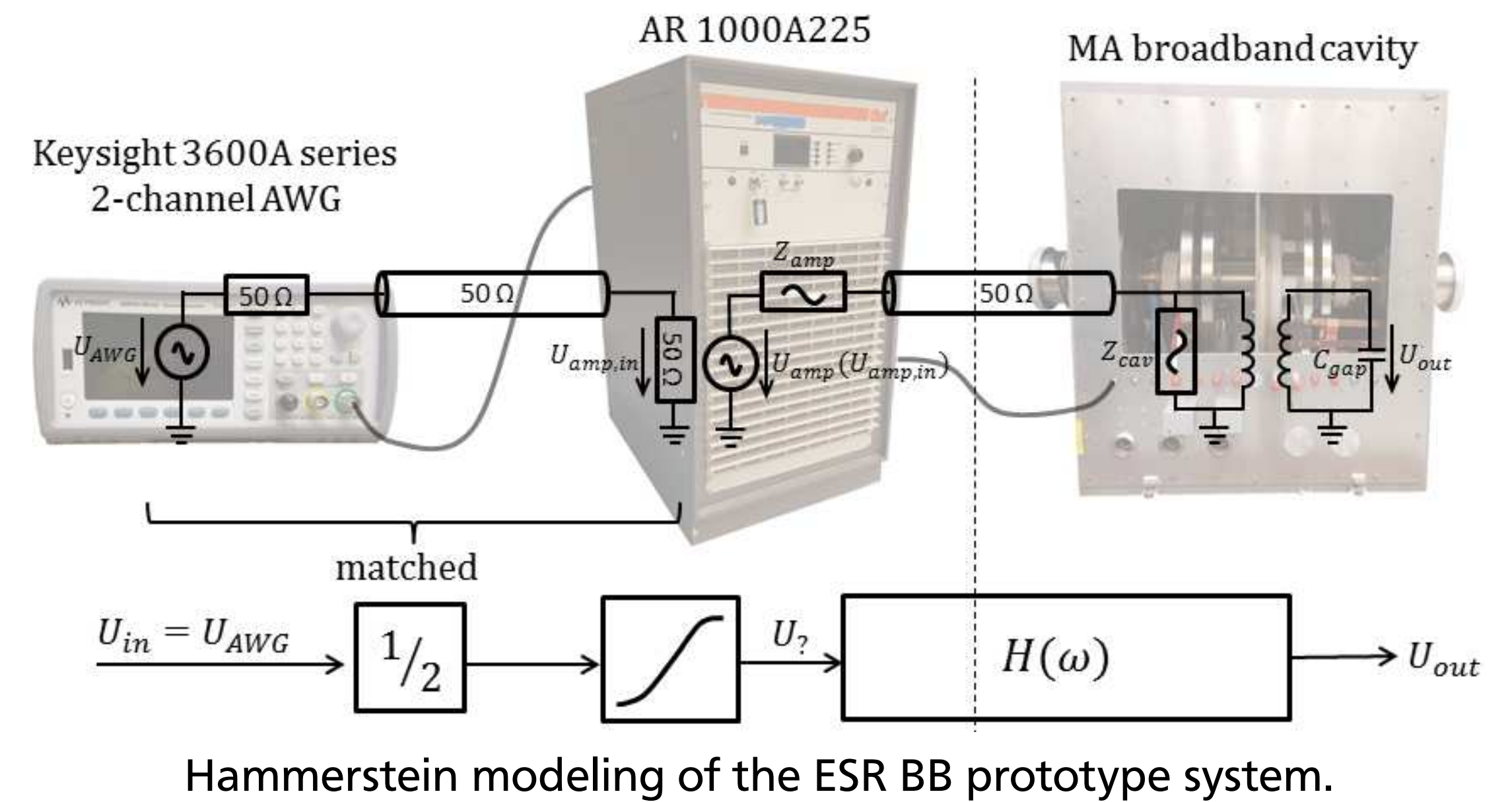


Measured amplitude response of the ESR BB prototype system.



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

## 3 Nonlinear Approach



Hammerstein modeling of the ESR BB prototype system.

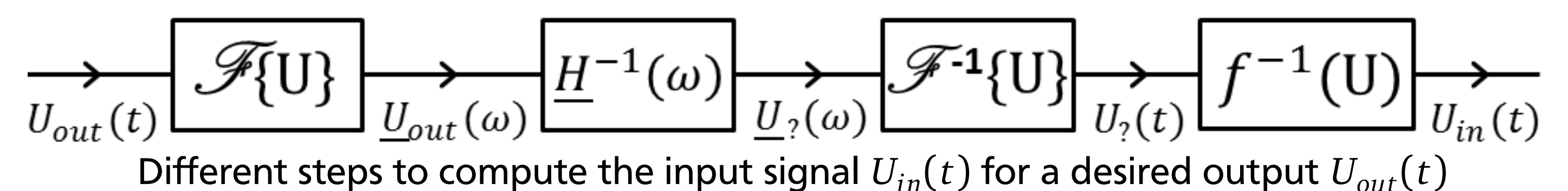
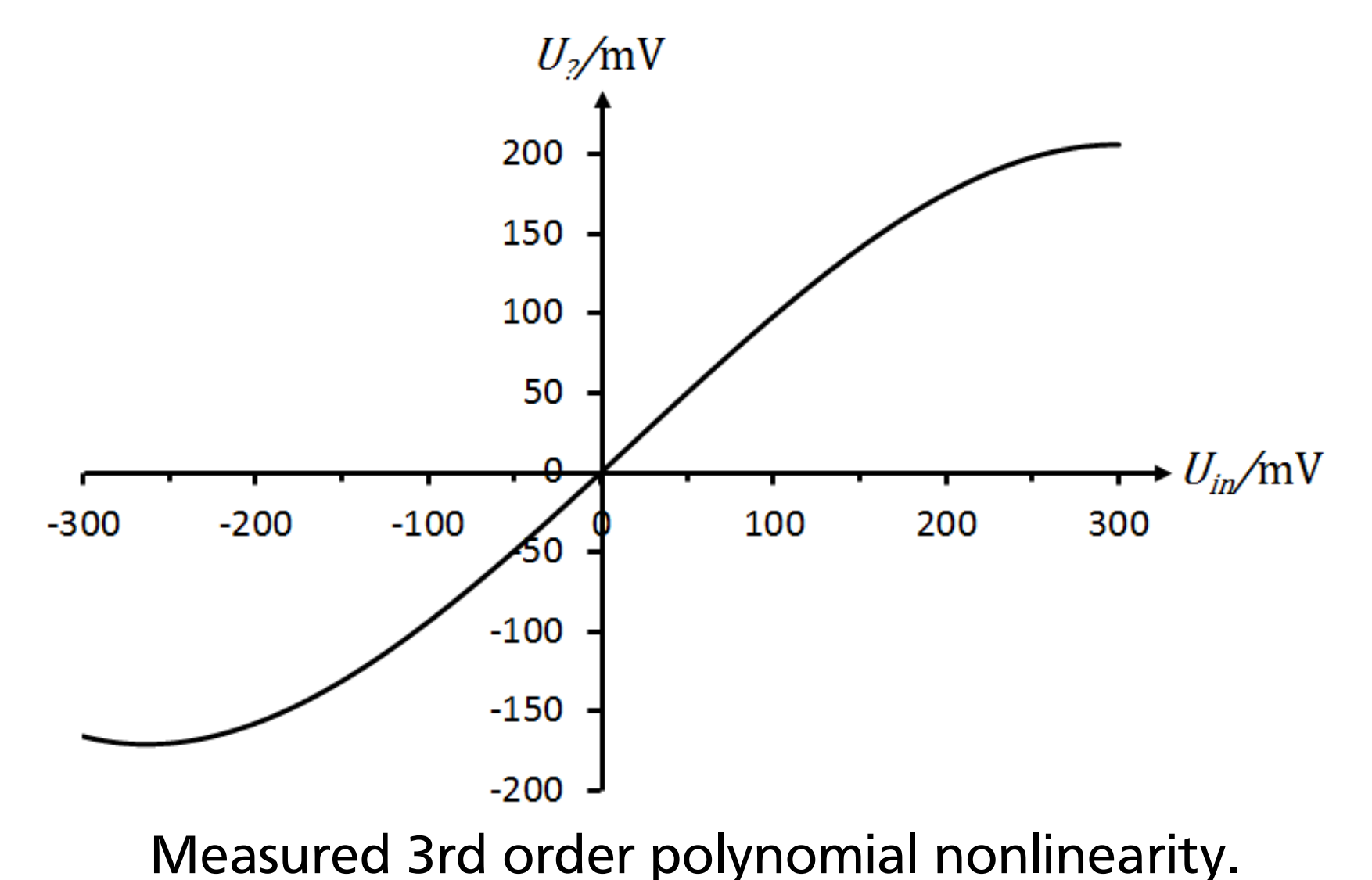
To characterize the static nonlinearity, a power series ansatz was chosen:

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

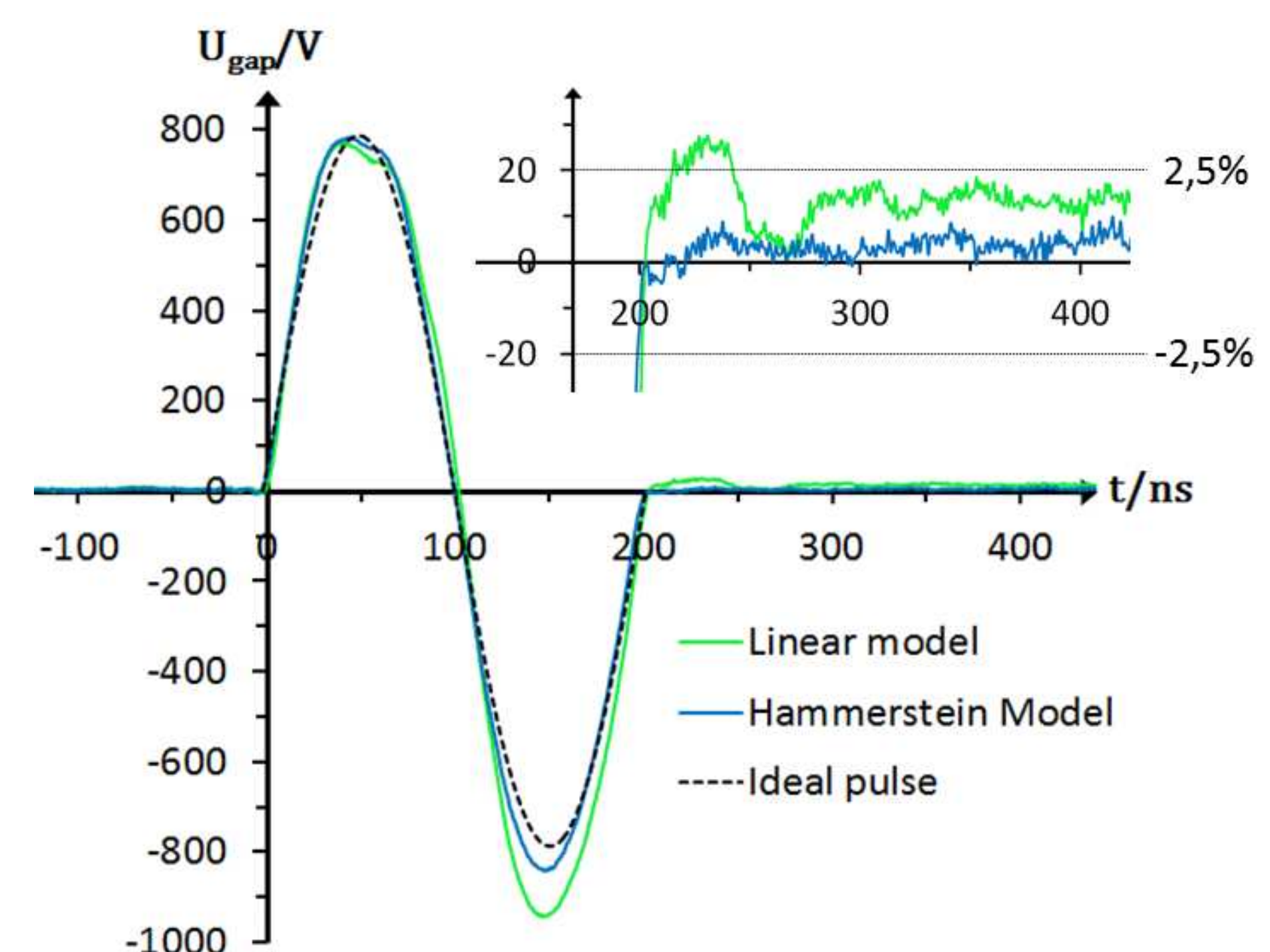
As  $U_{\gamma}(t)$  can't be measured directly, it is calculated from  $U_{out}(t)$  using  $\underline{U}_{\gamma}(\omega) = \underline{U}_{out}(\omega)/H(\omega)$ . Afterwards, the coefficients  $a_n$  can be calculated by solving the linear optimization problem

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

with  $U_{in}(t)$  and  $U_{\gamma}(t)$  consisting of  $M$  samples. Best output signals were achieved using 3rd or 4th order power series and a linearly predistorted test signal. 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  $H(\omega)$  and the inverse characteristic  $f^{-1}$ , the input signal is computed as shown below.



## 4 Results



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

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



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