Monitoring mechanical characteristics of MEMS switches with a microwave test bench

D. Mercier, P. Blondy, A. Pothier
IRCOM, Faculté des sciences, 123 av. A. Thomas 87060 LIMOGES cedex – FRANCE

Method interest

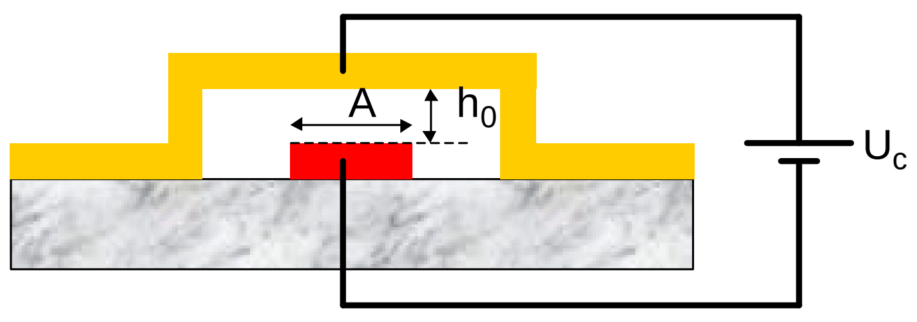
Conventional method

mechanical test bench → mechanical parameters
RF test bench → electrical parameters

New method

RF test bench → mechanical parameters
↳ electrical parameters

Mechanical movement equation



$$m\frac{d^2z}{dt}+x\frac{dz}{dt}+kz+F_c=F_{el}$$

m: membrane effective mass (kg)
k: spring constant (N/m)
ξ: mechanical damping coefficient (N.m-1.s)

Electrostatic force (N)

$$F_{el}=\frac{1}{2}\frac{U_c^2 e_0 e_r A}{(h_0-z)^2}$$

A: actuation area (m²)
U_c: biasing voltage (V)
h_0: membrane initial height (m)

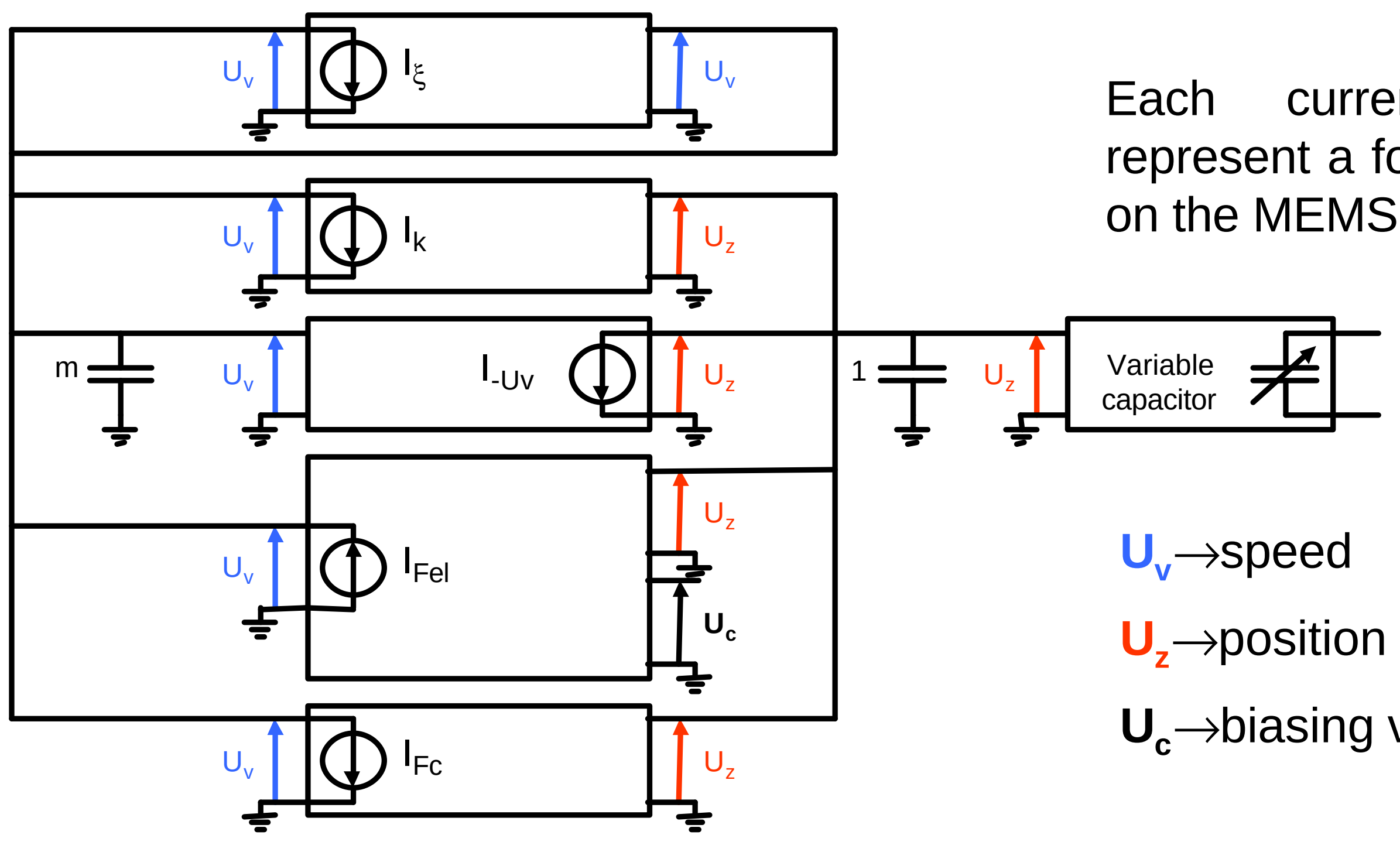
Contact force (N)

$$F_c=\left(e^{-a(h_0-z)^b}-1\right)*U(z-h_0)$$

$$U(z-h_0)=\begin{cases}0 \text{ if } z<h_0\\ 1 \text{ if } z>h_0\end{cases}$$

Electromechanical model

Voltage controlled current sources model



Each current source represent a force applied on the MEMS beam

U_v → speed
U_z → position
U_c → biasing voltage

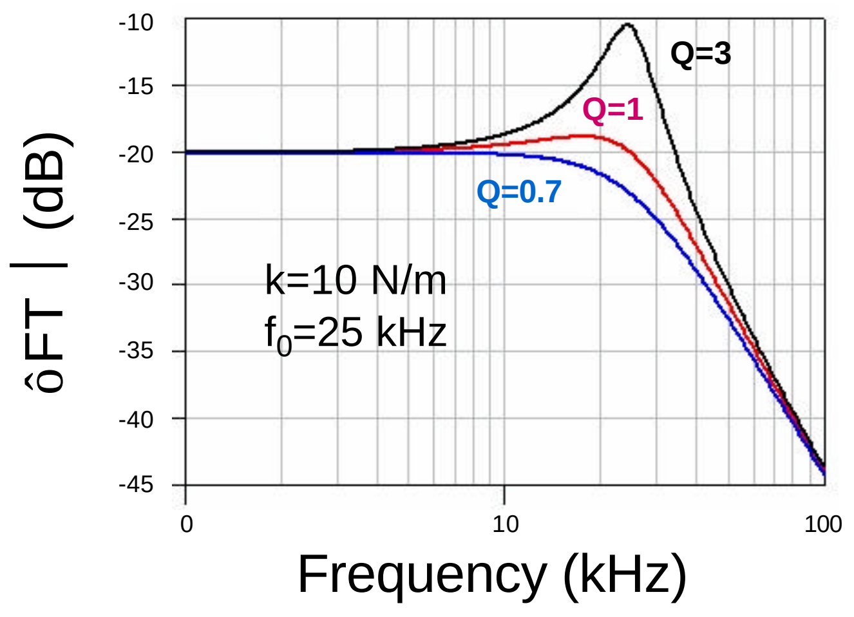
MEMS frequency response

MEMS transfer function

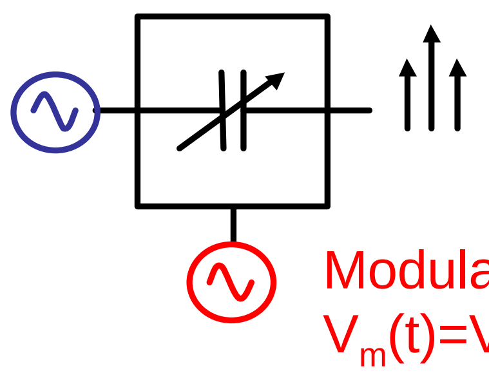
$$FT(jw)=\frac{1}{k}\left(\frac{1}{1-\frac{w^2}{w_0^2}+\frac{jw}{Qw_0}}\right)$$

Mechanical resonant frequency f_0 and quality factor

$$w_0=\sqrt{\frac{k}{m}} \quad \text{with } \omega_0=2\pi f_0 \qquad Q=\frac{k}{w_0 x}$$



Modulation



RF Source
$V_p(t)=V_{p0}*\sin(\omega_p t)$

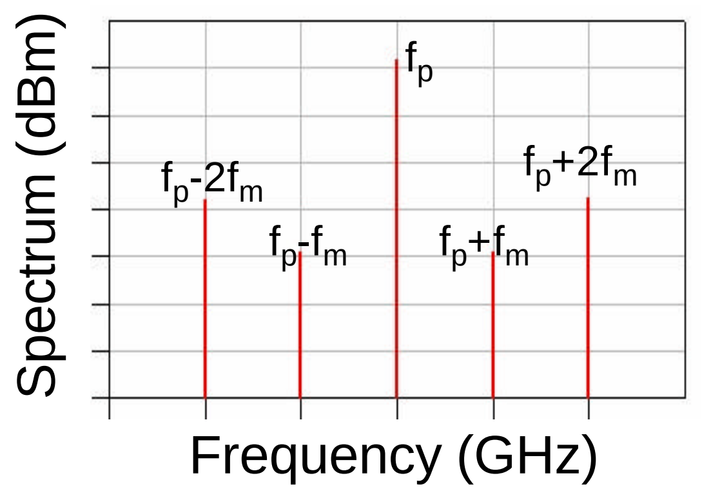
Modulated signal

Modulating low frequency signal
$V_m(t)=V_0+V_{m0}*\sin(\omega_m t)$

The modulation is proportional to the MEMS frequency response

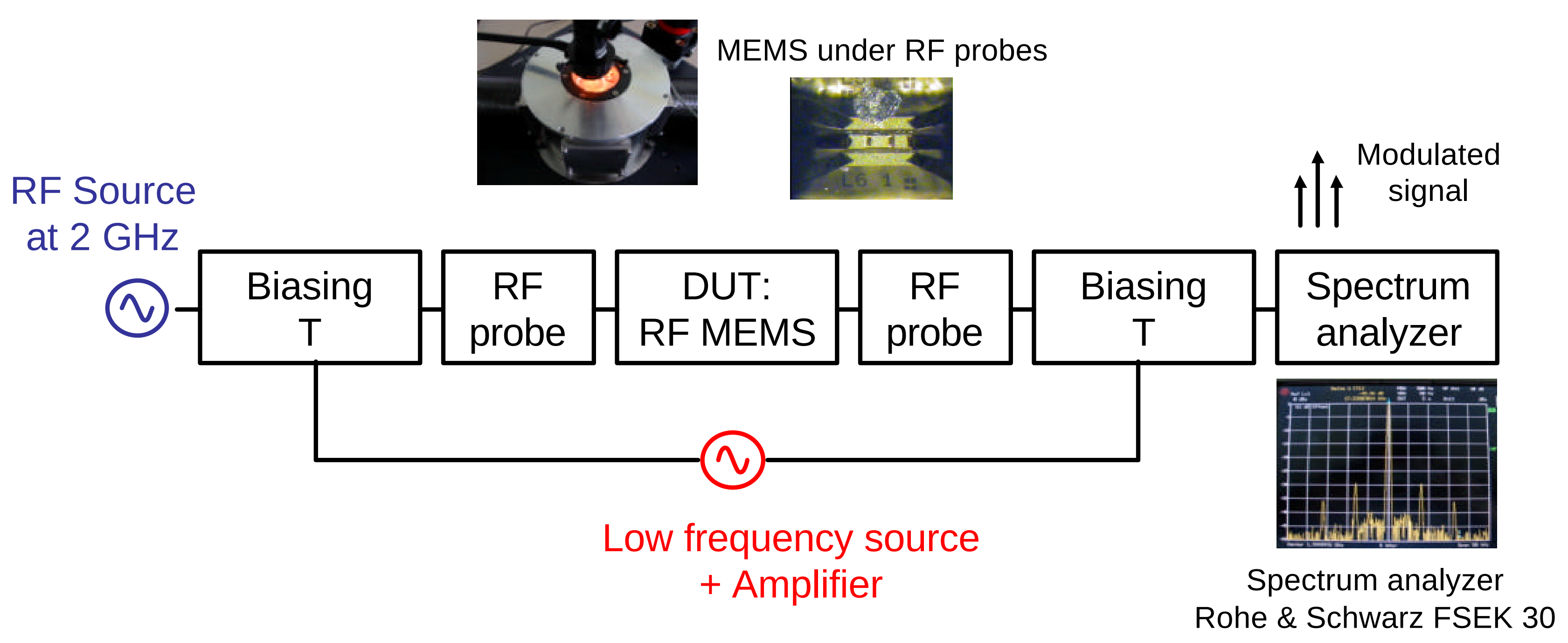
$$P_{w_m}=\left(V_0V_{m0}\frac{Cf}{2kh_0^2}\right)^2\times\begin{cases}1 & \omega<\omega_0\\ Q^2 & \omega=\omega_0\\ \left(\frac{w}{w_0}\right)^4 & \omega\gg\omega_0\end{cases}$$

$$P_{2w_m}=\left(\frac{V_{m0}^2}{4}\frac{Cf}{2kh_0^2}\right)^2\times\begin{cases}1 & \omega<\omega_0\\ Q^2 & \omega=\omega_0\\ \left(\frac{w}{w_0}\right)^4 & \omega\gg\omega_0\end{cases}$$



C: MEMS capacitance
$\phi=-2C\,\omega Z_0$: phase shift due to C

Microwave test bench



Vacuum test chamber

MEMS under RF probes

RF Source at 2 GHz

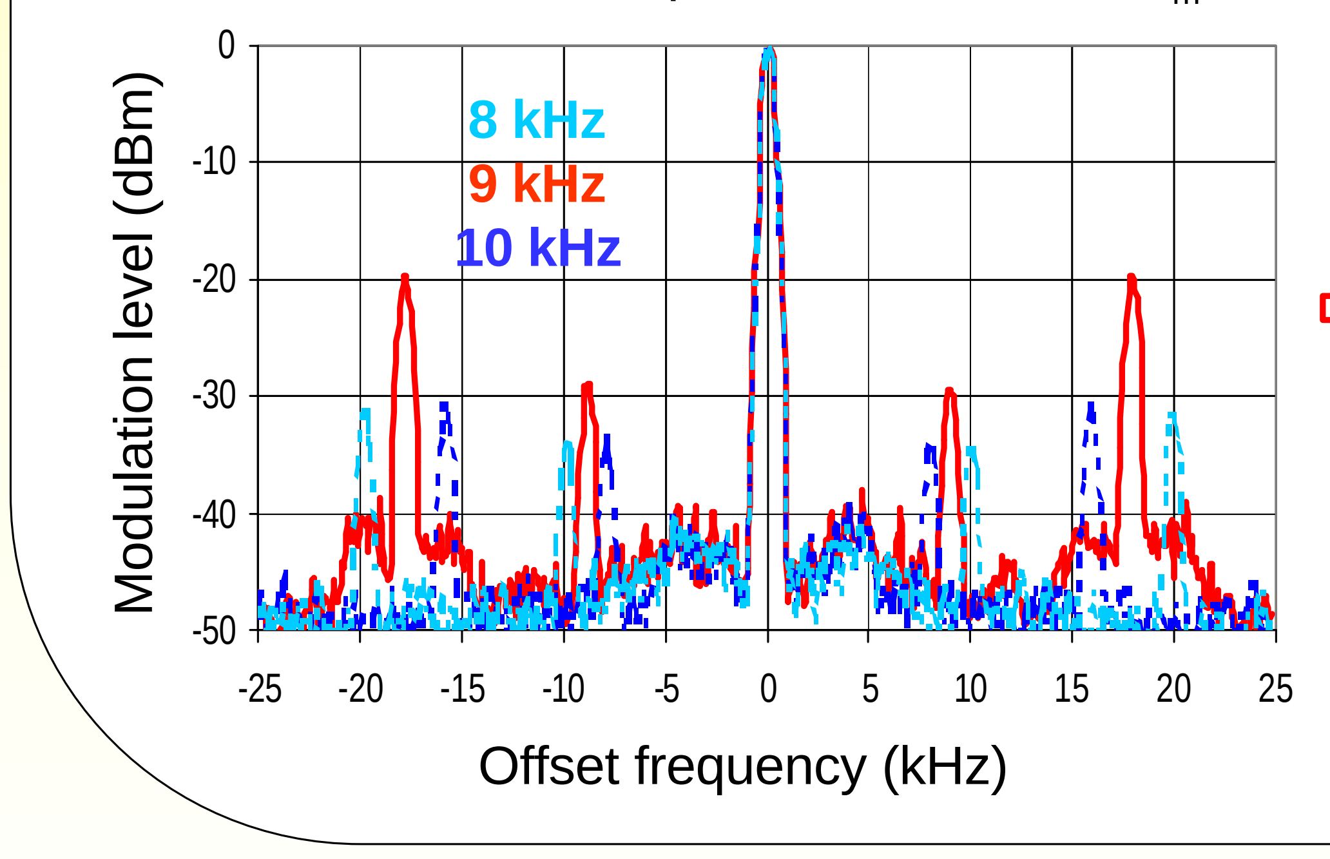
Biasing T → RF probe → DUT: RF MEMS → RF probe → Biasing T → Spectrum analyzer

Modulated signal

Low frequency source + Amplifier

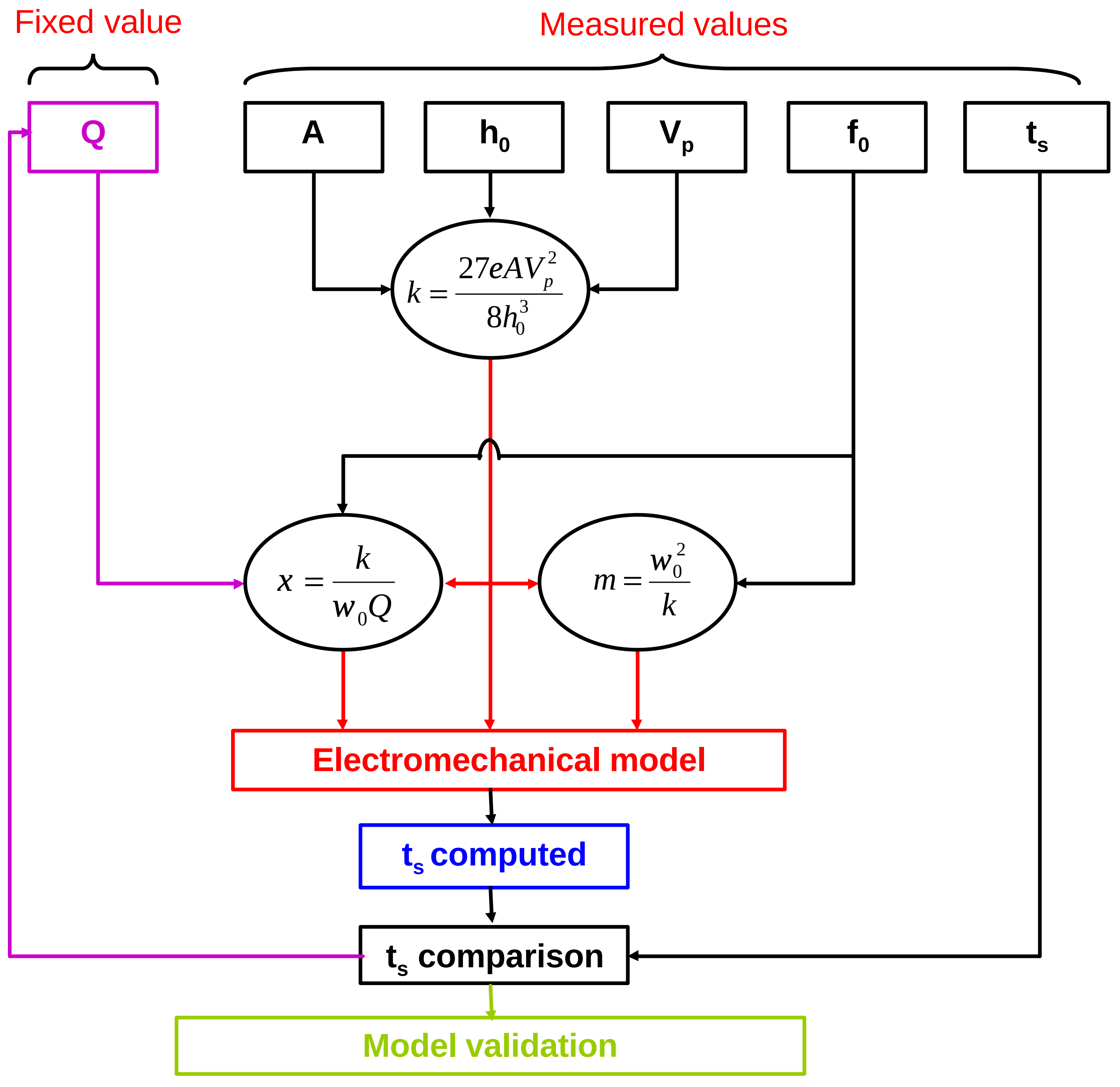
Spectrum analyzer
Rohe & Schwarz FSEK 30

Measured spectrum for different f_m



⇨ Detection of the mechanical resonant frequency at the maximum modulation level: 9 kHz

Modeling methodology



Fixed value
Measured values

Q
A
h_0
V_p
f_0
t_s

$$k=\frac{27eAV_p^2}{8h_0^3}$$

$$x=\frac{k}{w_0Q} \qquad m=\frac{w_0^2}{k}$$

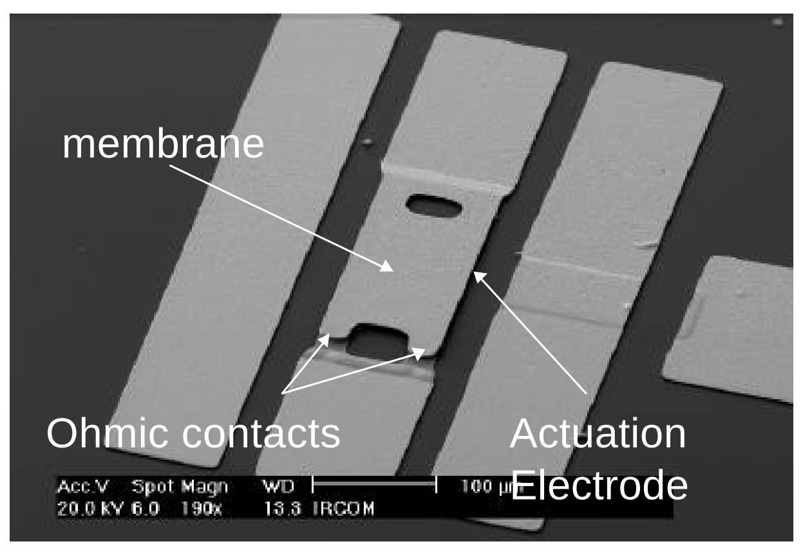
Electromechanical model

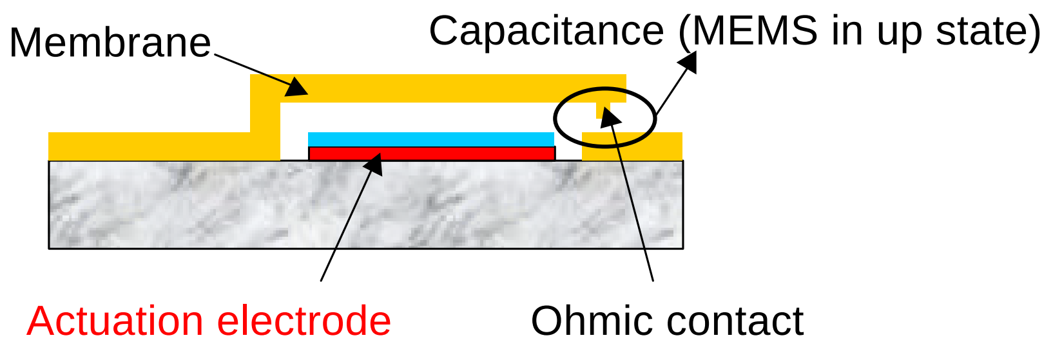
t_s computed

t_s comparison

Model validation

Ohmic series switch modeled





Measurements:
A=9,25e-9
h_0=2,5 µm
V_p=38 V
f_0=9 kHz
t_c=27 µs (V_{polar}=40 V)
Computed spring constant:
k=38 N/m
Deduced Q:
Q=10