

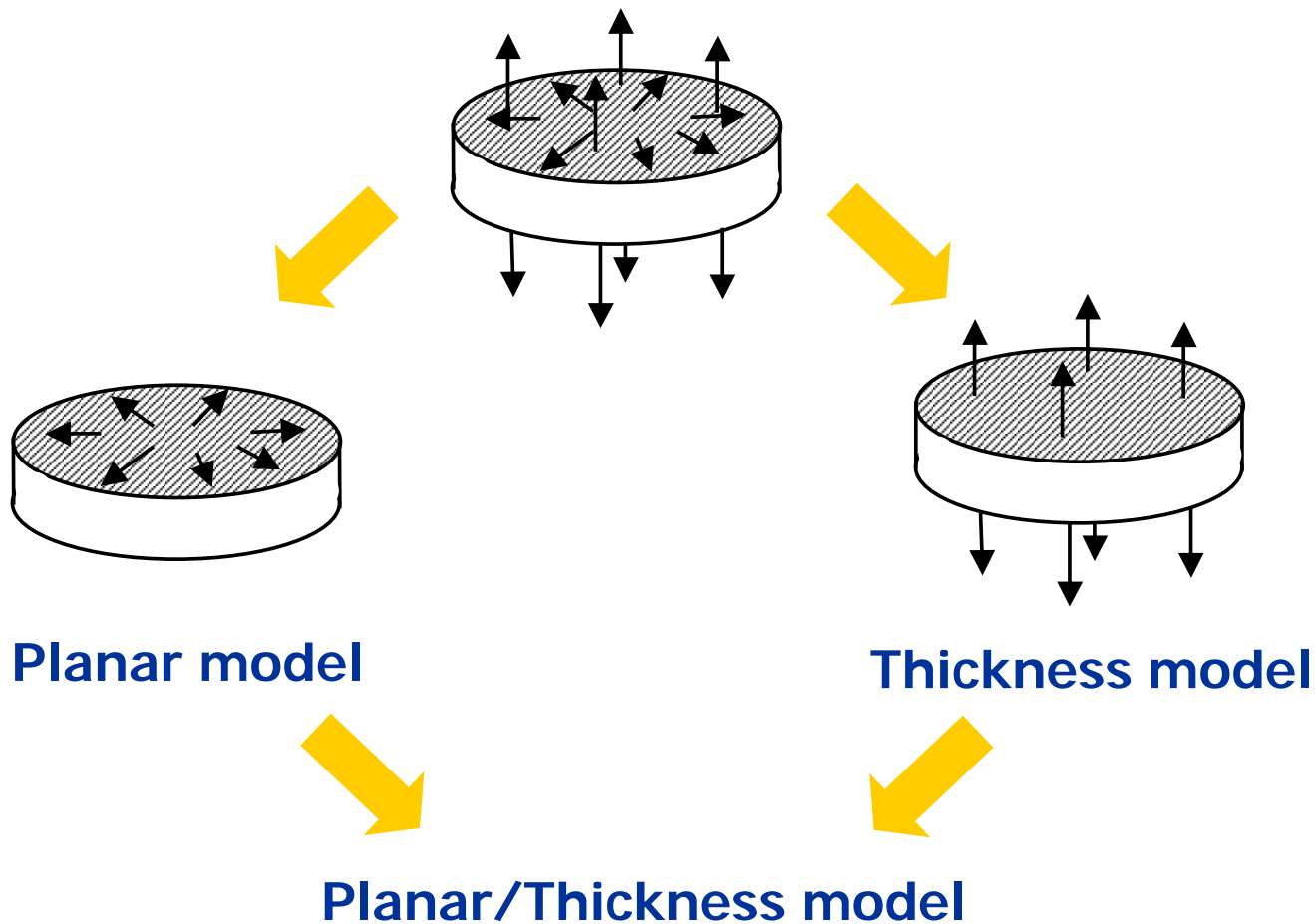
BMAS 2007
San Jose

**A Unified Electrical SPICE
Model for Piezoelectric
Transducers**



Motivation

Polytech' Montpellier

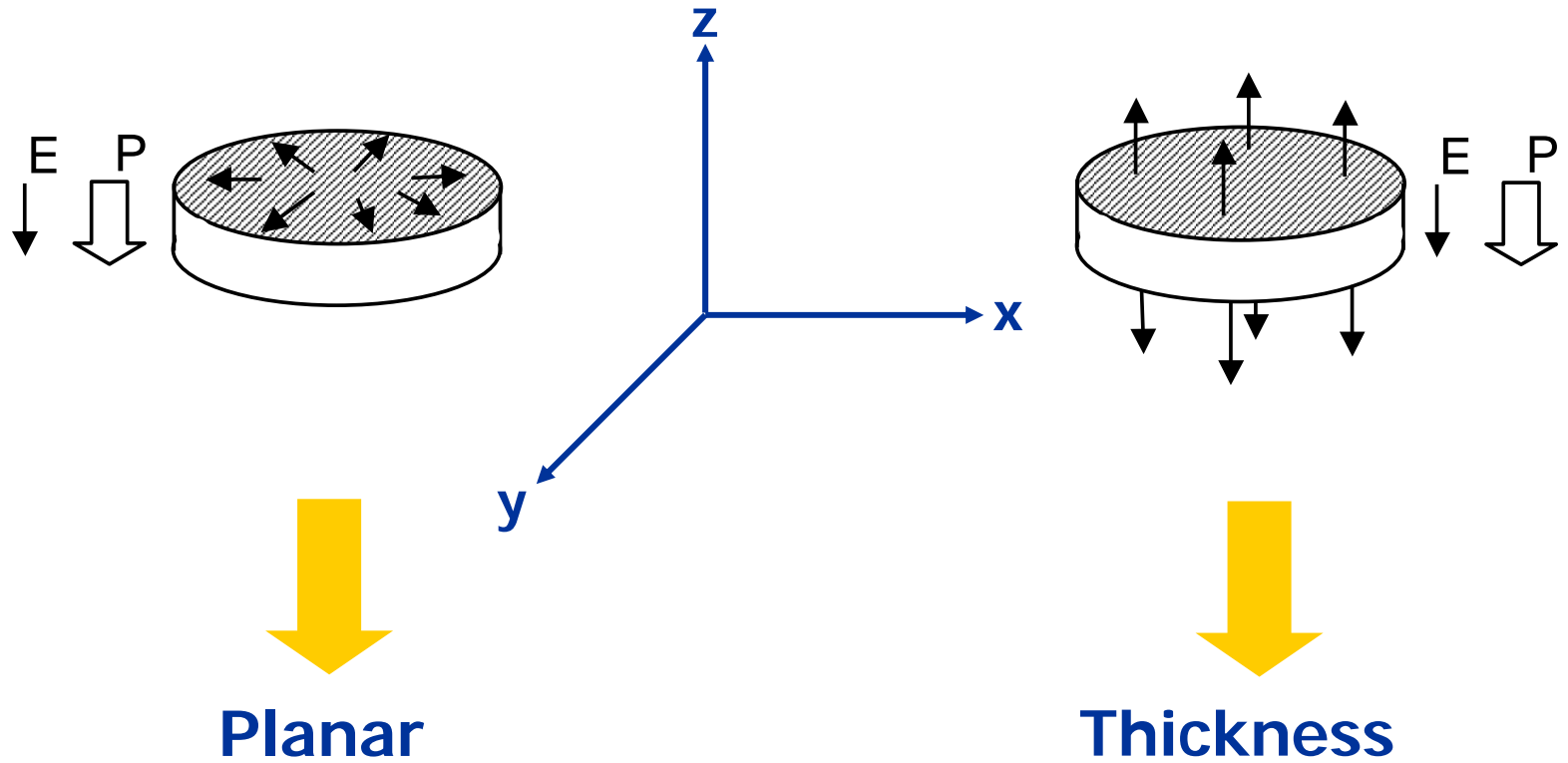




- **Introduction**
- **Electrical Models (Thickness/Planar)**
- **New Unified Model**
- **Conclusion and Future Works**

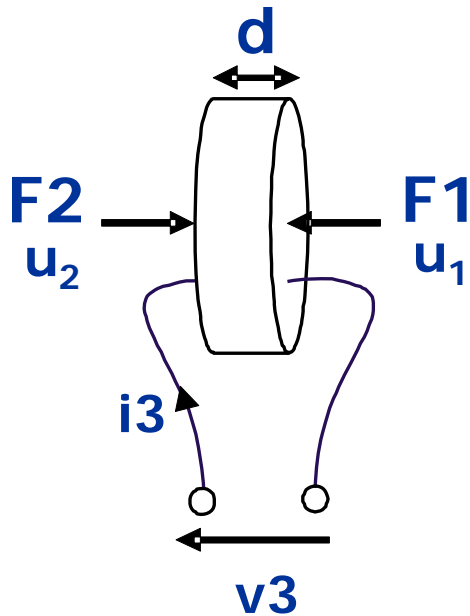


Introduction





Impedance Matrix



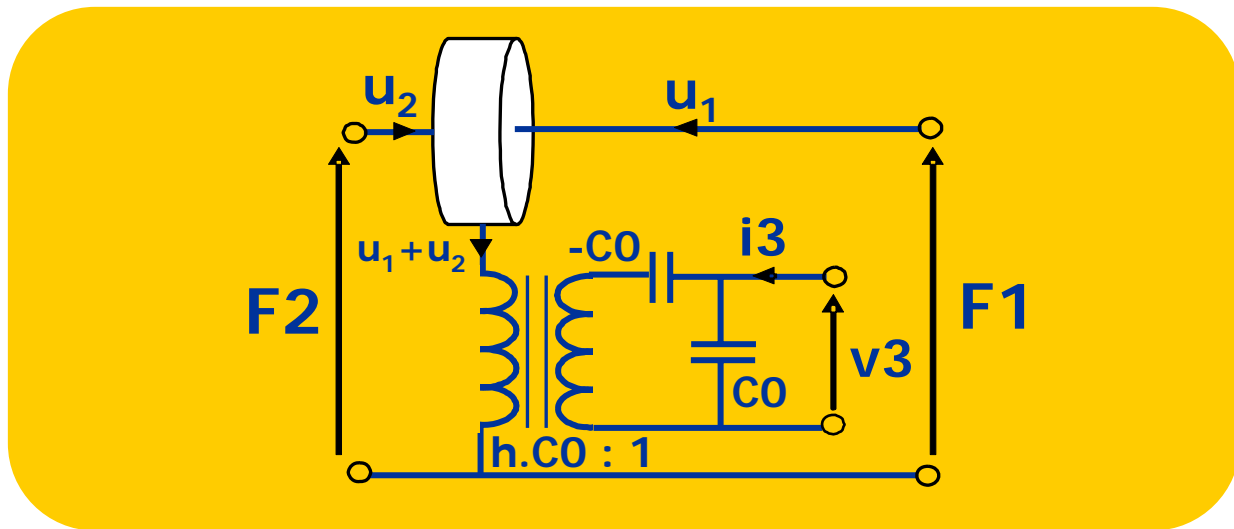
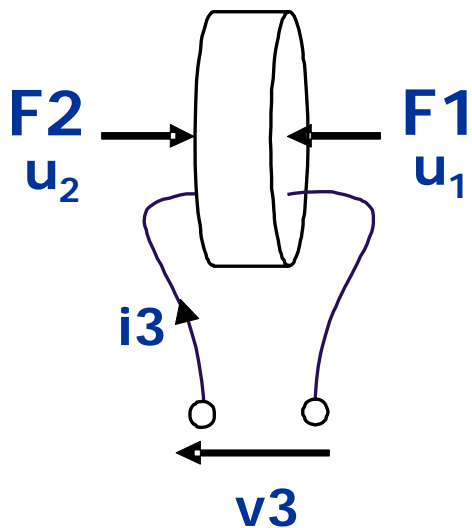
$$\begin{pmatrix} F1 \\ F2 \\ v3 \end{pmatrix} = -j \cdot \begin{pmatrix} Z/\tan(wd/u) & Z/\sin(wd/u) & h/w \\ Z/\sin(wd/u) & Z/\tan(wd/u) & h/w \\ h/w & h/w & 1/wC0 \end{pmatrix} \cdot \begin{pmatrix} u1 \\ u2 \\ i3 \end{pmatrix}$$

$C0 = \epsilon A / d$; $Z = \rho u A$; h piezoelectric constant



Introduction

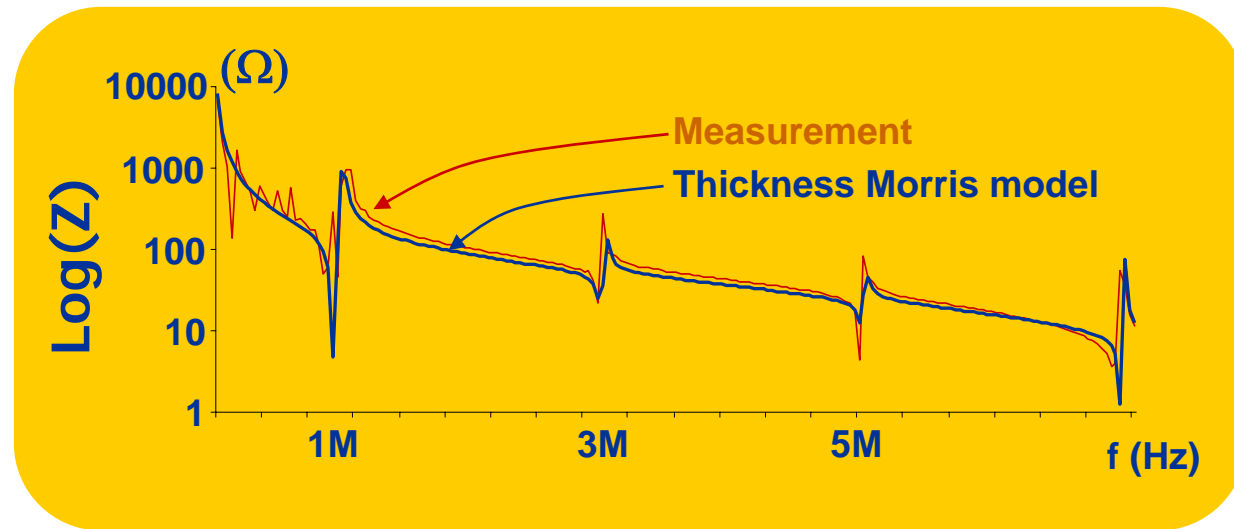
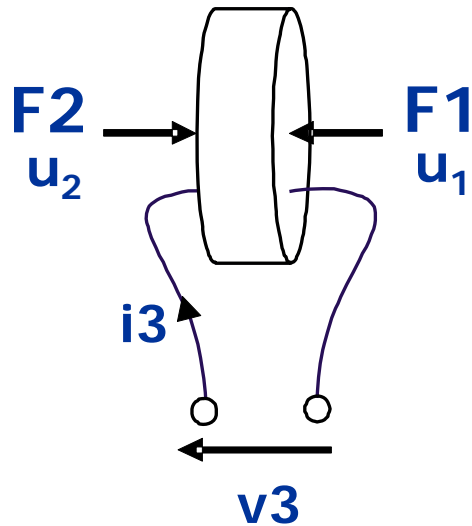
Redwood's Model





Introduction

Redwood's Model



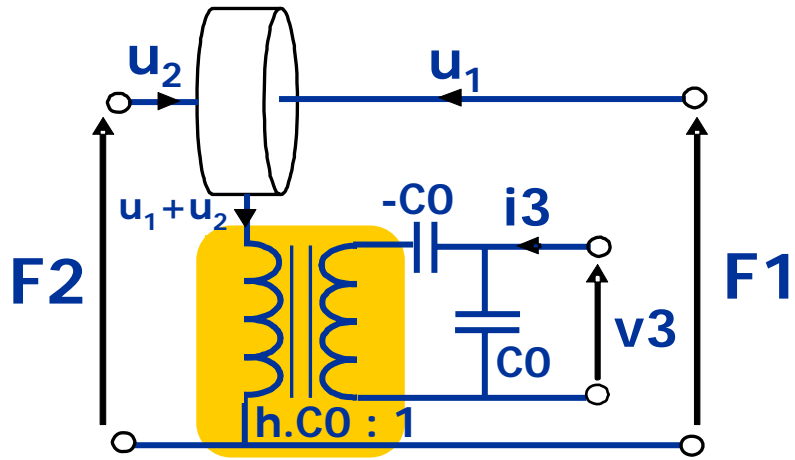


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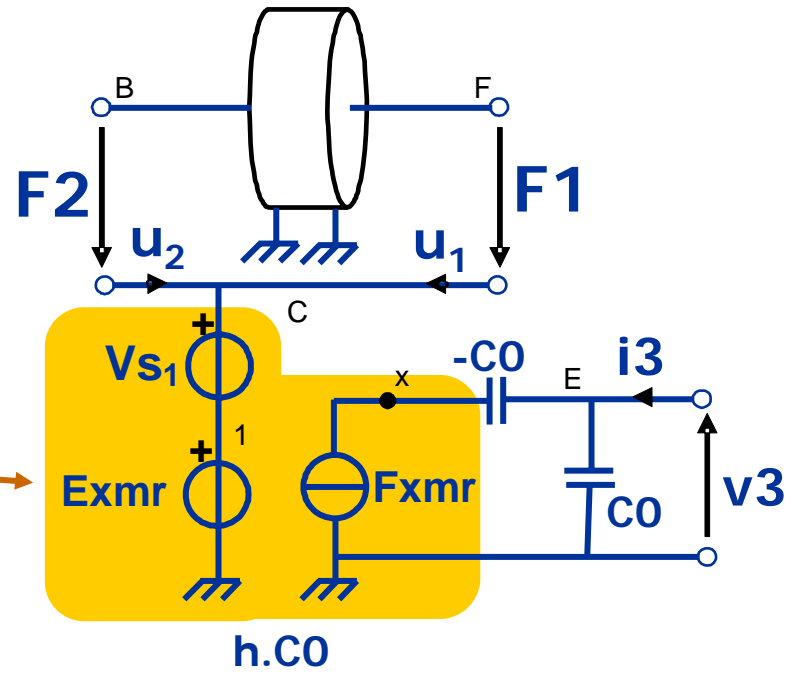


Electrical Models

Redwood's Model



PSPICE Model



Ideal Transformer



Electrical Models

PSPICE netlist

```

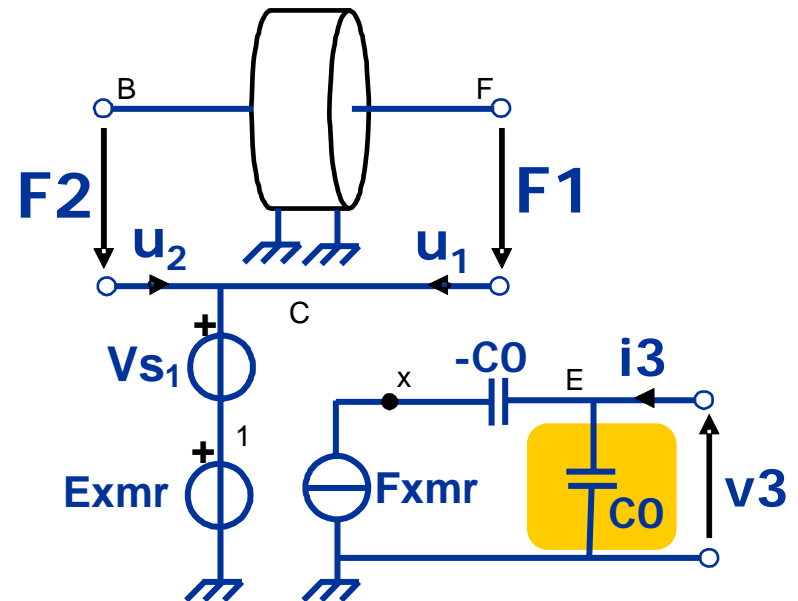
.subckt Thickness E F B C

c0 E 0 {C0}
cneg E x {-C0}
r1 x 0 100meg
fxmr 0 x vs1 {h*C0}
exmr 1 0 x 0 {h*C0}
vs1 C 1
tech F 0 B 0 z0={ZpztT} td={tdT}

.ends

```

PSPICE Model





Electrical Models

PSPICE netlist

```

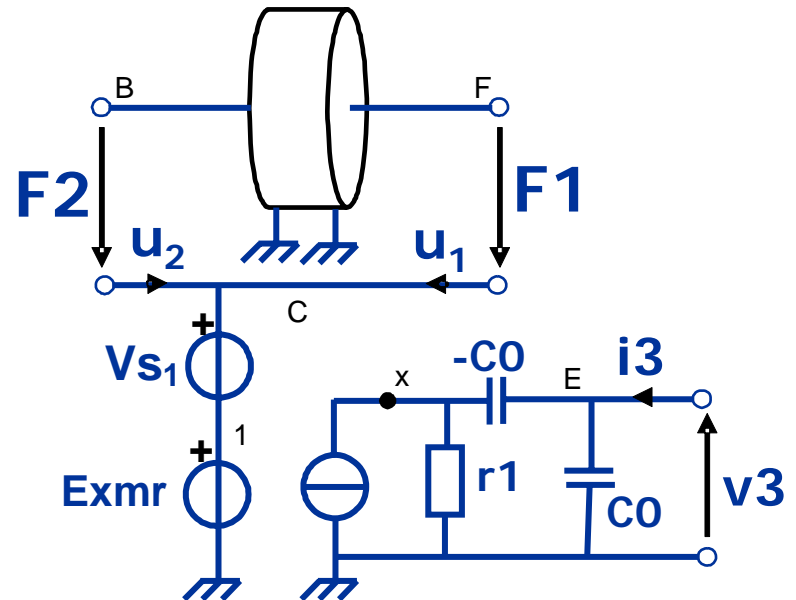
.subckt Thickness E F B C

c0 E 0 {C0}
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```

PSPICE Model





Electrical Models

PSPICE netlist

```

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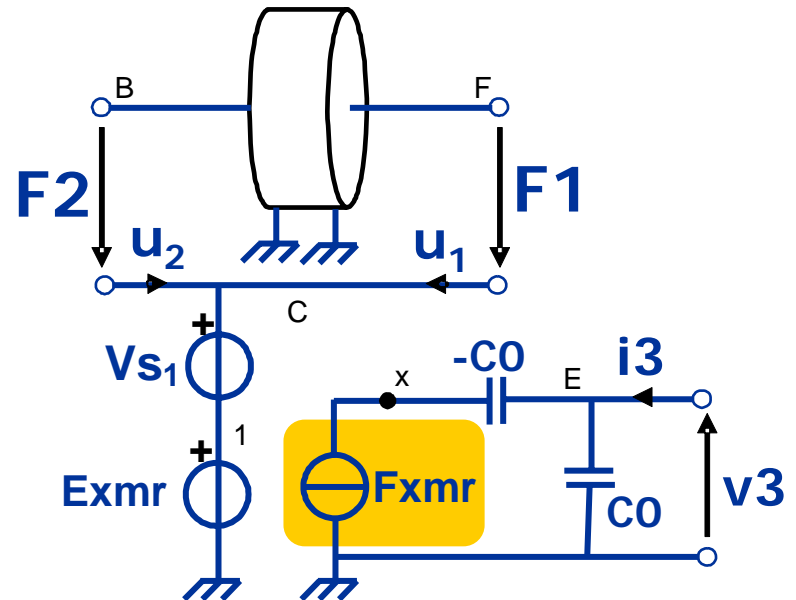
c0 E 0 {C0}
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r1 x 0 100meg
fxmr 0 x vs1 {h*C0}
exmr 1 0 x 0 {h*C0}
vs1 C 1
tech F 0 B 0 z0={ZpztT} td={tdT}

.ends

```

thickness

PSPICE Model





PSPICE netlist

```

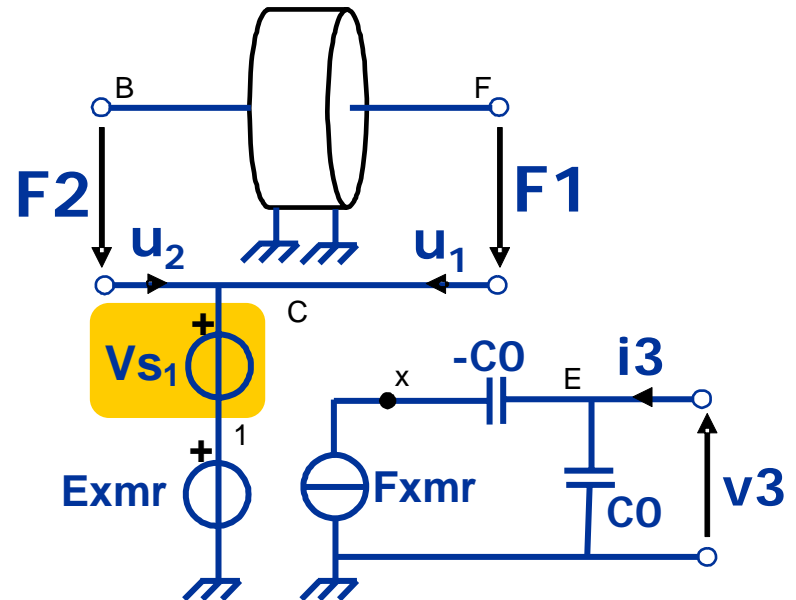
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```

PSPICE Model





Electrical Models

PSPICE netlist

```

.subckt Thickness E F B C

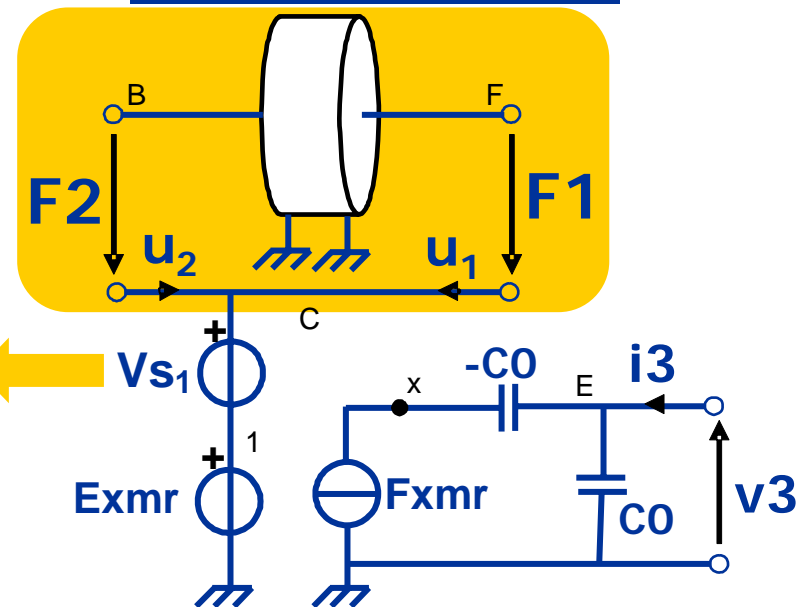
c0 E 0 {C0}
cneg E x {-C0}
r1 x 0 100meg
fxmr 0 x vs1 {h*C0}
exmr 1 0 x 0 {h*C0}
vs1 C 1
tech F 0 B 0 z0={ZpztT} td={tdT}

.ends

```

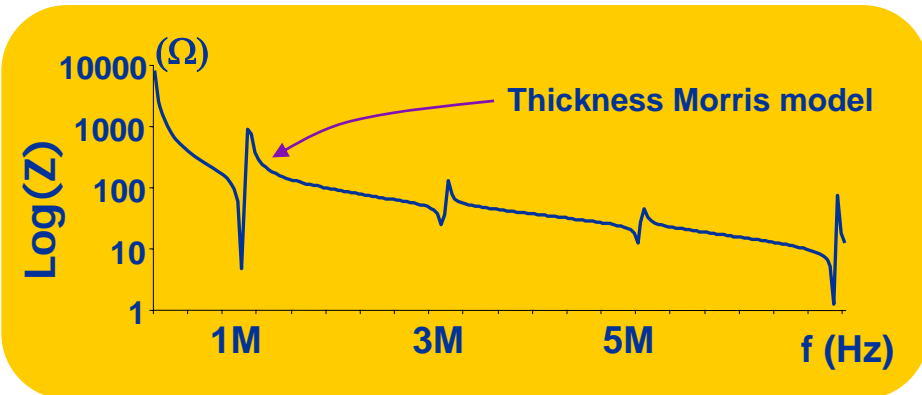
thickness

PSPICE Model

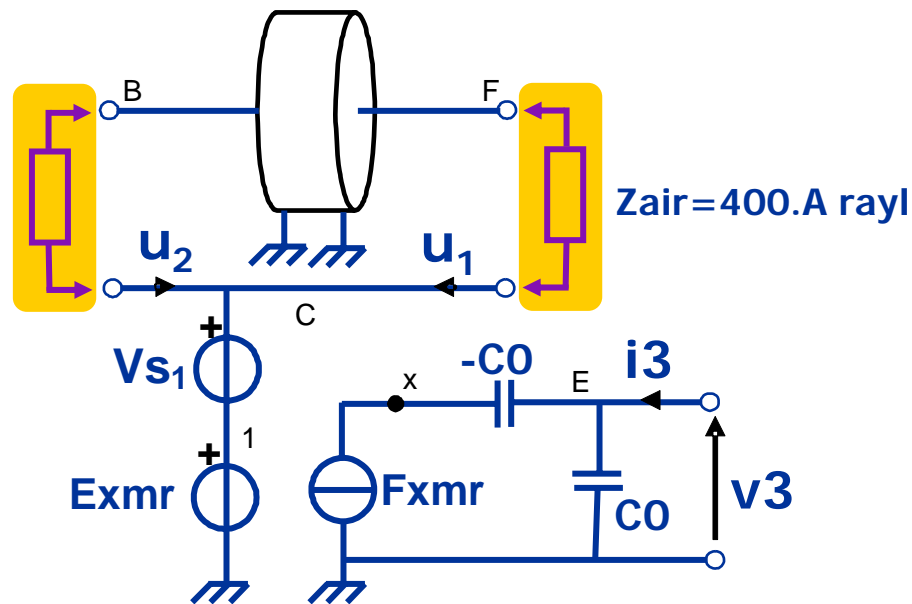




Electrical Models

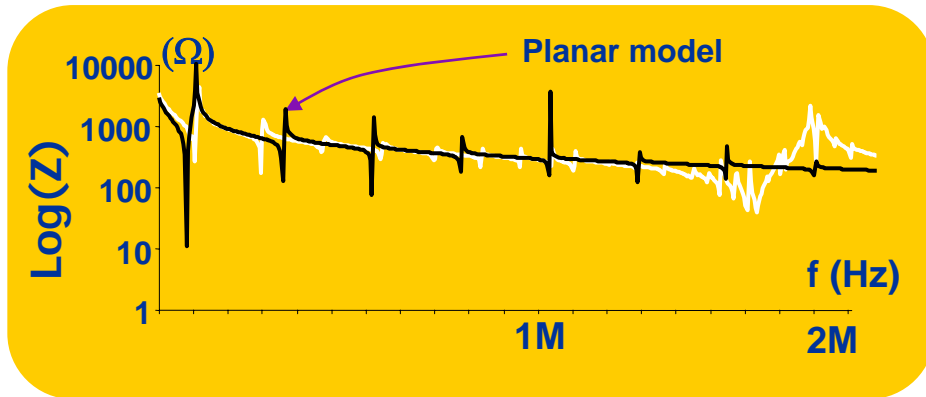


PSPICE Model

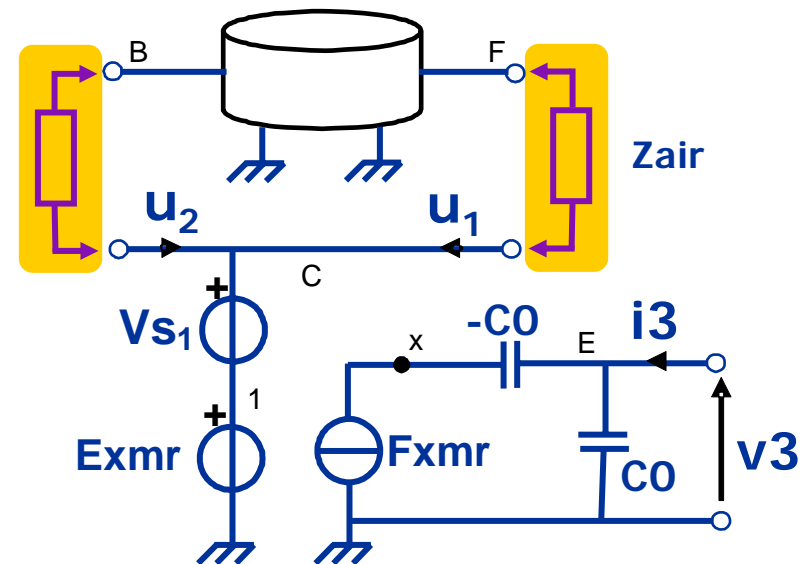




Electrical Models



PSPICE Model



Z_{pz} tT
 $t dT$
 h

planar direction



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New Unified Model

A. Iula et al.,

IEEE Trans. On Ultrasonics, Ferroelectrics and Frequency Control, 1998

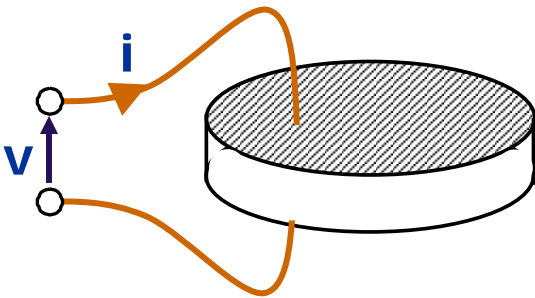
$$v = \frac{h_{33}}{j\omega} (u_1 + u_2) + \frac{kh_{31}}{j\omega} (u_3 + u_4) + \frac{i}{j\omega C_0}$$

with

$$k = 2t/r$$

h : piezoelectric constant

u : particle velocity



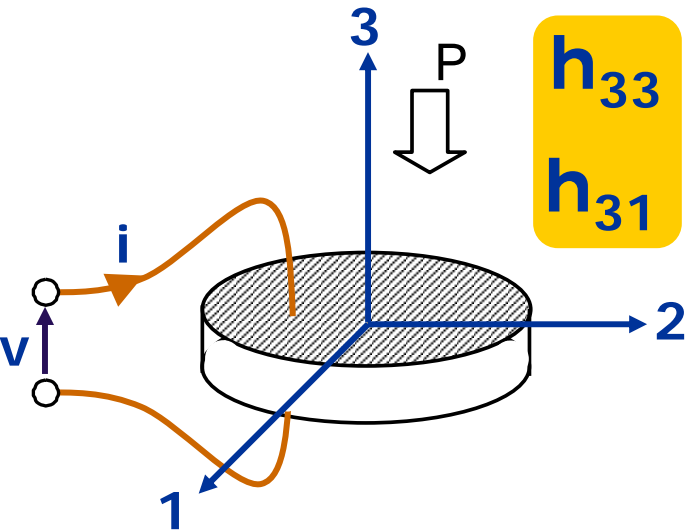


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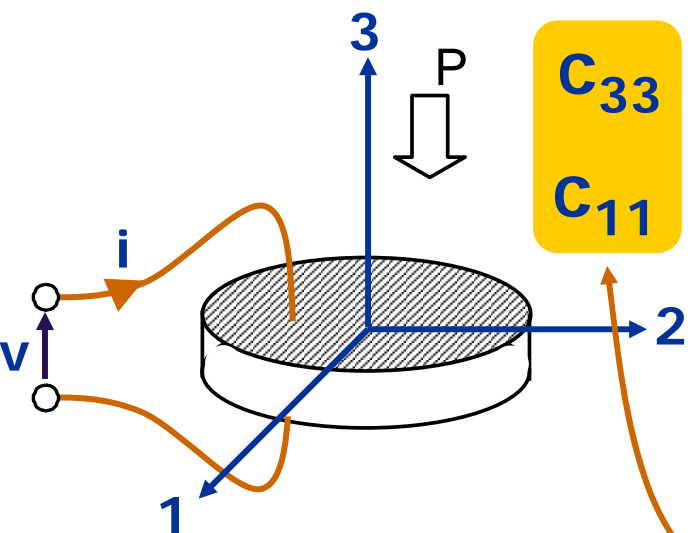


New Unified Model

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$$v = \frac{h_{33}}{j\omega} (u_1 + u_2) + \frac{kh_{31}}{j\omega} (u_3 + u_4) + \frac{i}{j\omega C_0}$$



with

$$k = 2t/r$$

h : piezoelectric constant

u : particle velocity

$$u = (c/\rho)^{1/2}$$



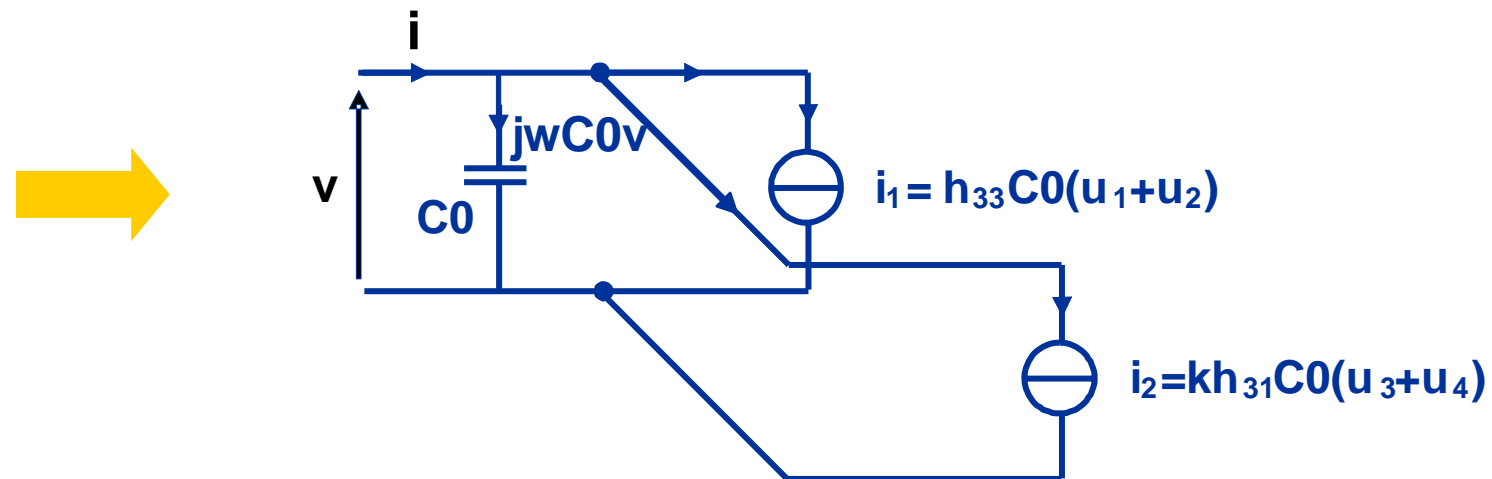
New Unified Model

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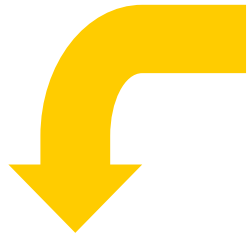
$$v = \frac{h_{33}}{j\omega} (u_1 + u_2) + \frac{kh_{31}}{j\omega} (u_3 + u_4) + \frac{i}{j\omega C_0}$$

➔ $i = j\omega C_0 v - h_{33} C_0 (u_1 + u_2) - kh_{31} C_0 (u_3 + u_4)$





New Unified Model



$$\begin{cases} i = j\omega C_0 v - h_{33} C_0 (u_1 + u_2) - kh_{31} C_0 (u_3 + u_4) \\ f_{\text{thickness}} = h_{33} i / j\omega & f_{\text{planar}} = h_{31} i / j\omega \end{cases}$$

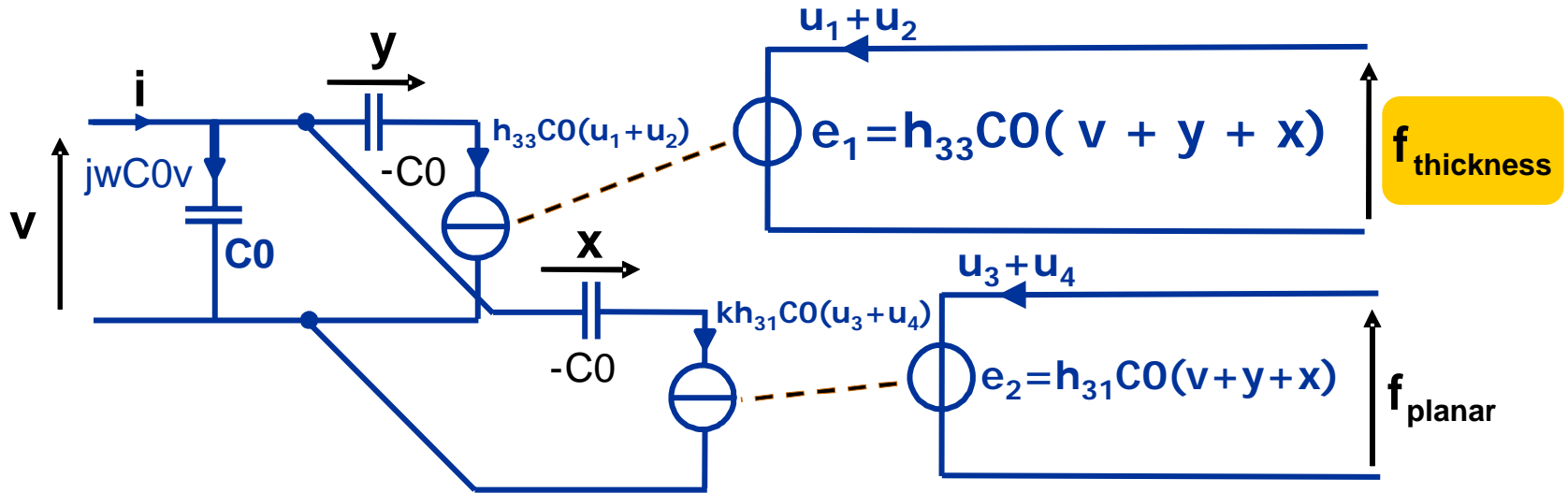
$$f_{\text{thickness}} = h_{33} C_0 \left[v - \frac{1}{j\omega C_0} h_{33} C_0 (u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31} C_0 (u_3 + u_4) \right]$$

$$f_{\text{planar}} = h_{31} C_0 \left[v - \frac{1}{j\omega C_0} kh_{31} C_0 (u_3 + u_4) - \frac{1}{j\omega C_0} h_{33} C_0 (u_1 + u_2) \right]$$



New Unified Model

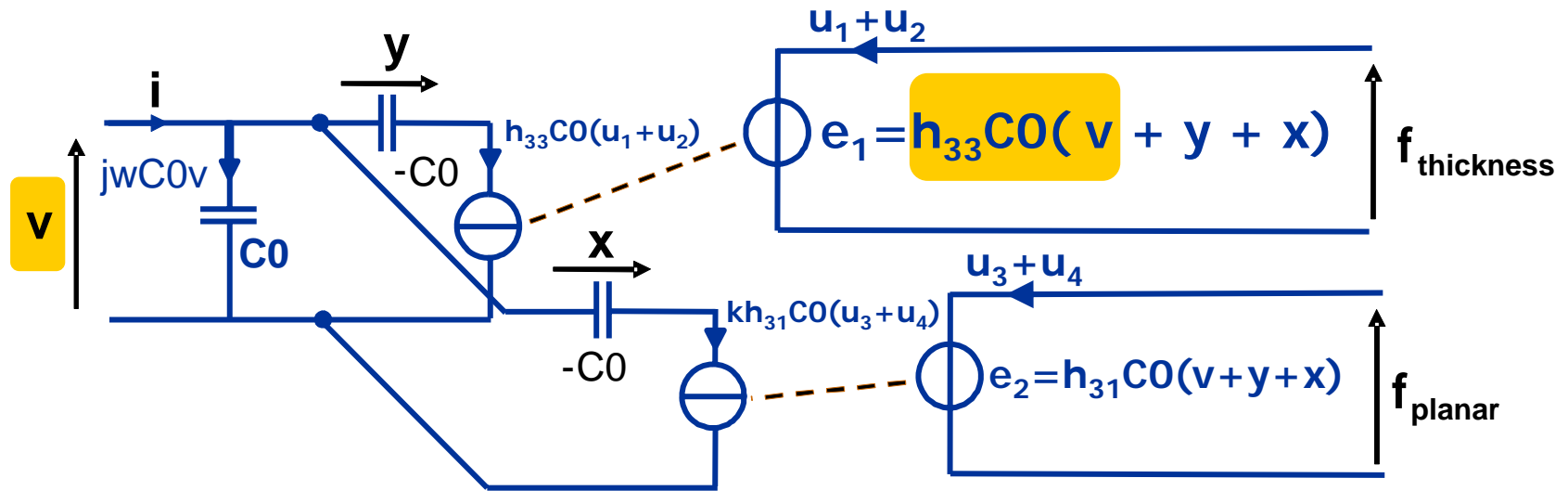
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





New Unified Model

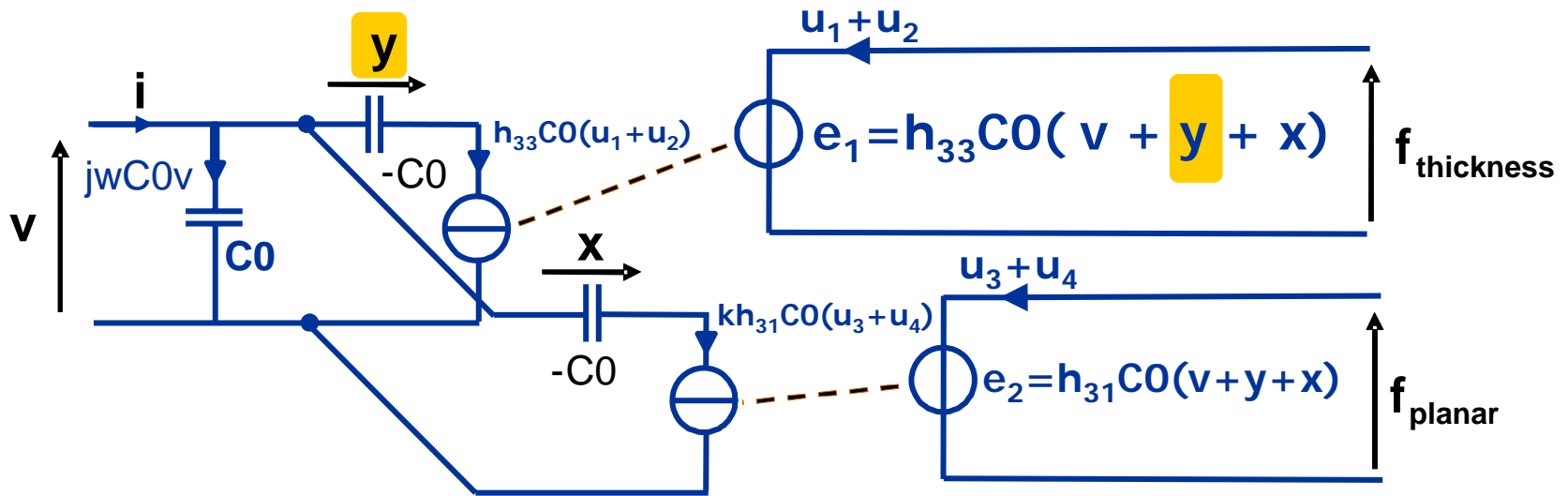
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





New Unified Model

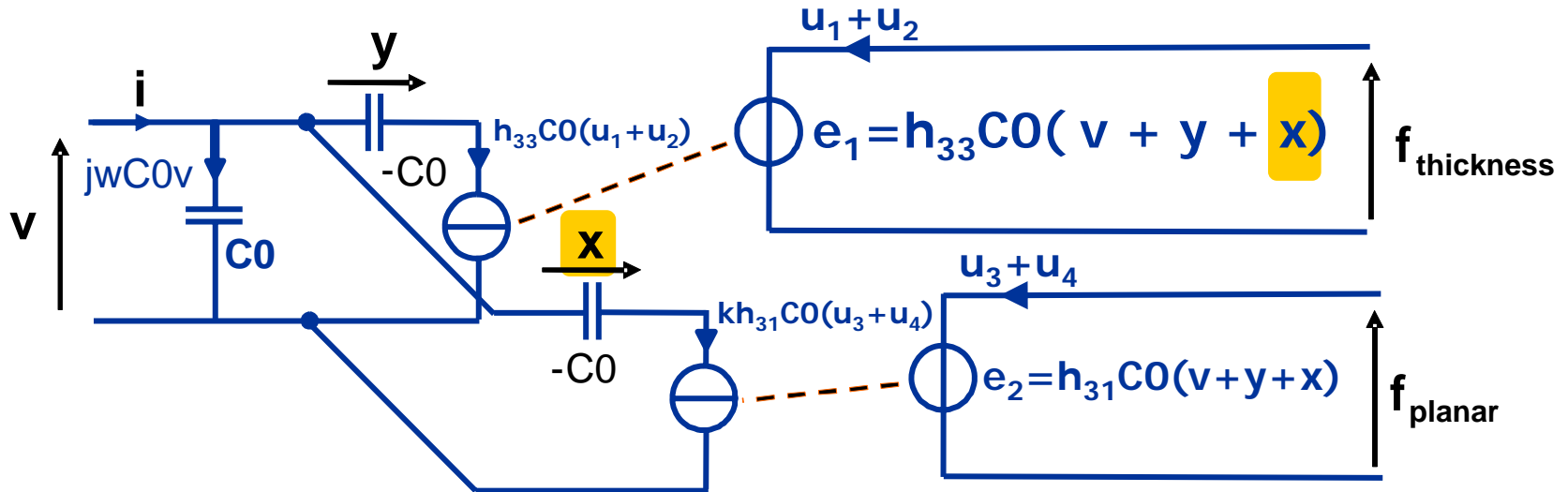
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





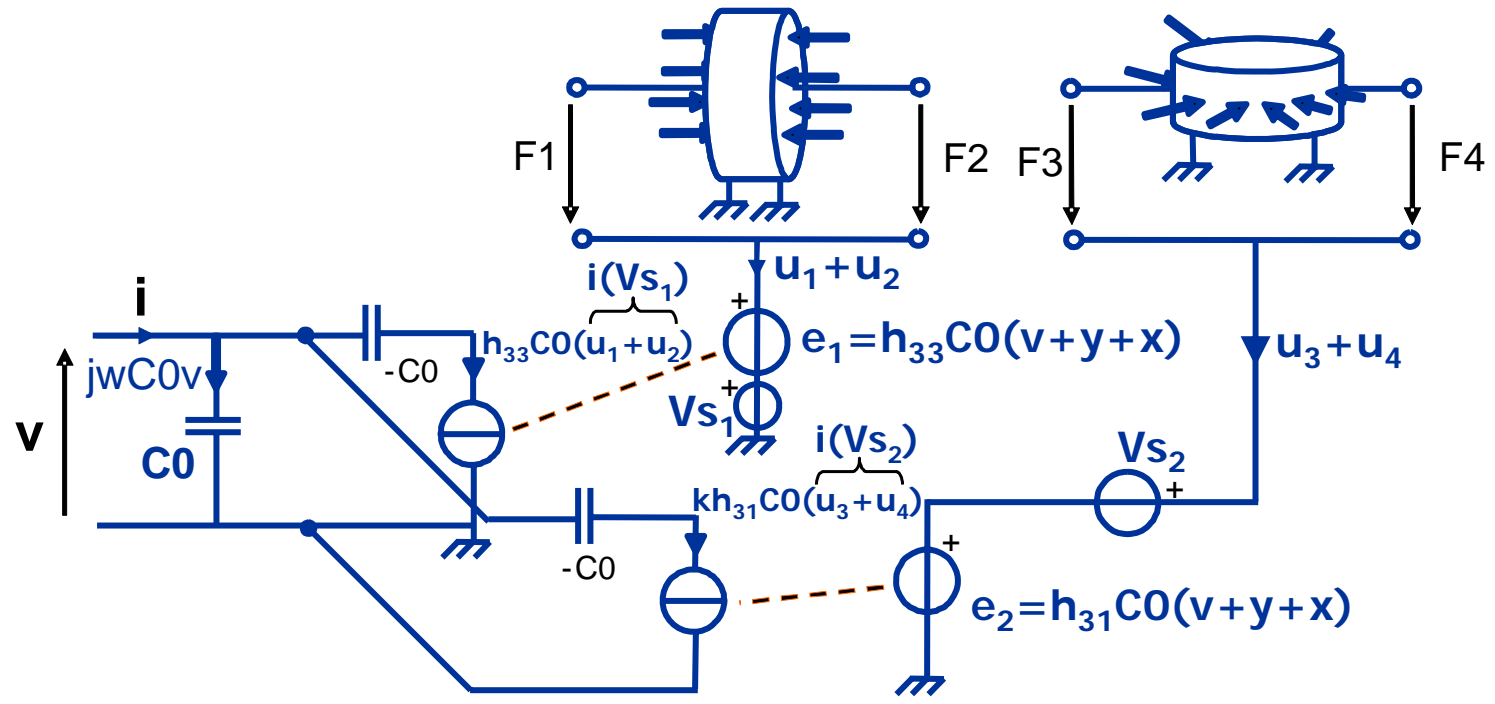
New Unified Model

$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





New Unified Model

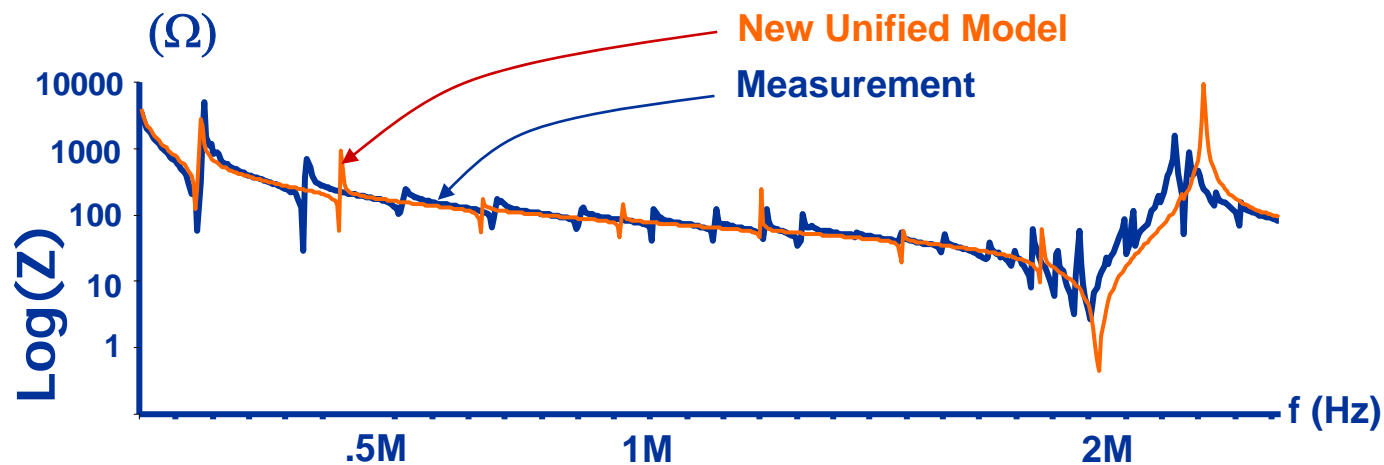
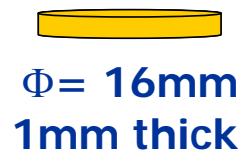
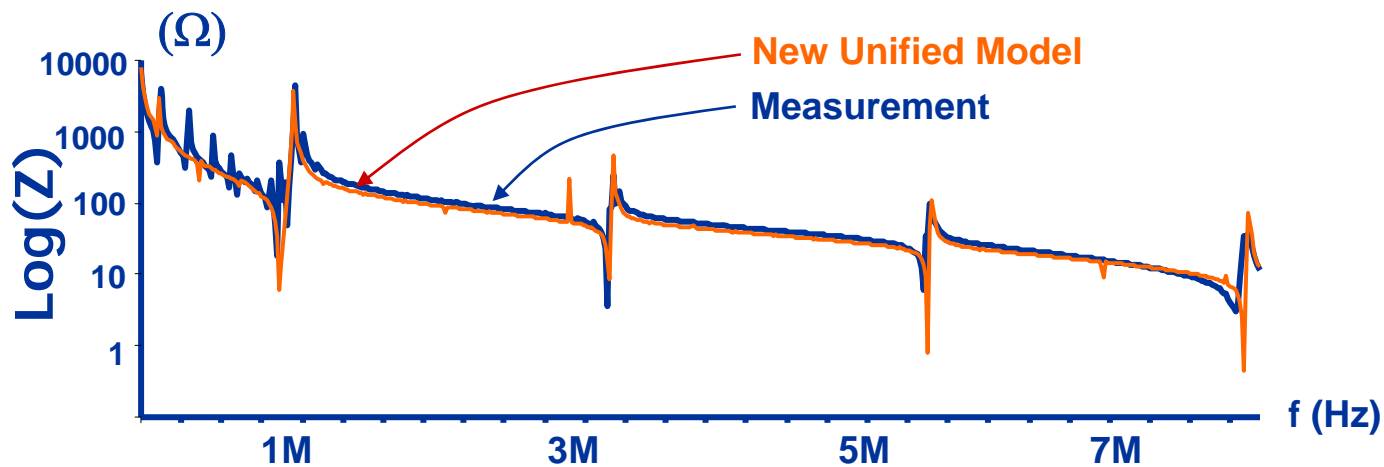
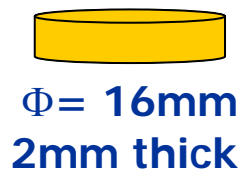




New Unified Model

Polytech'Montpellier

Introduction E. Model U. Model Conclusion





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Electrical Models (Thickness/Planar)

New Unified Model (PSPICE)

Experimental Validation

Future Works

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