

BMAS 2008
San Jose

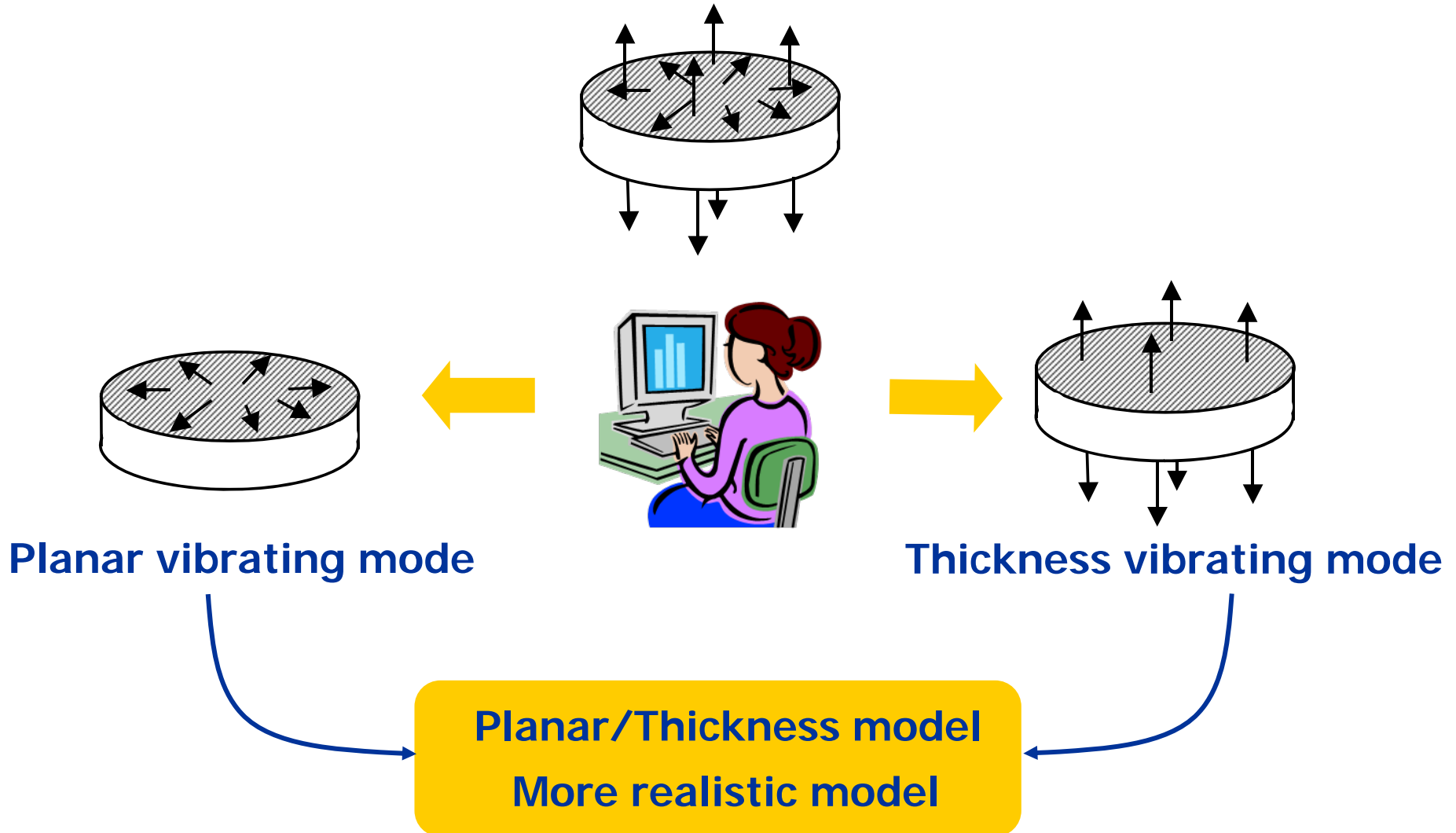
**A 2-D VHDL-AMS Model for
Disk-Shape Piezoelectric
Transducers**

**Jean-Marc Gallière
Philippe Papet
Laurent Latorre**



Motivation

Polytech'Montpellier

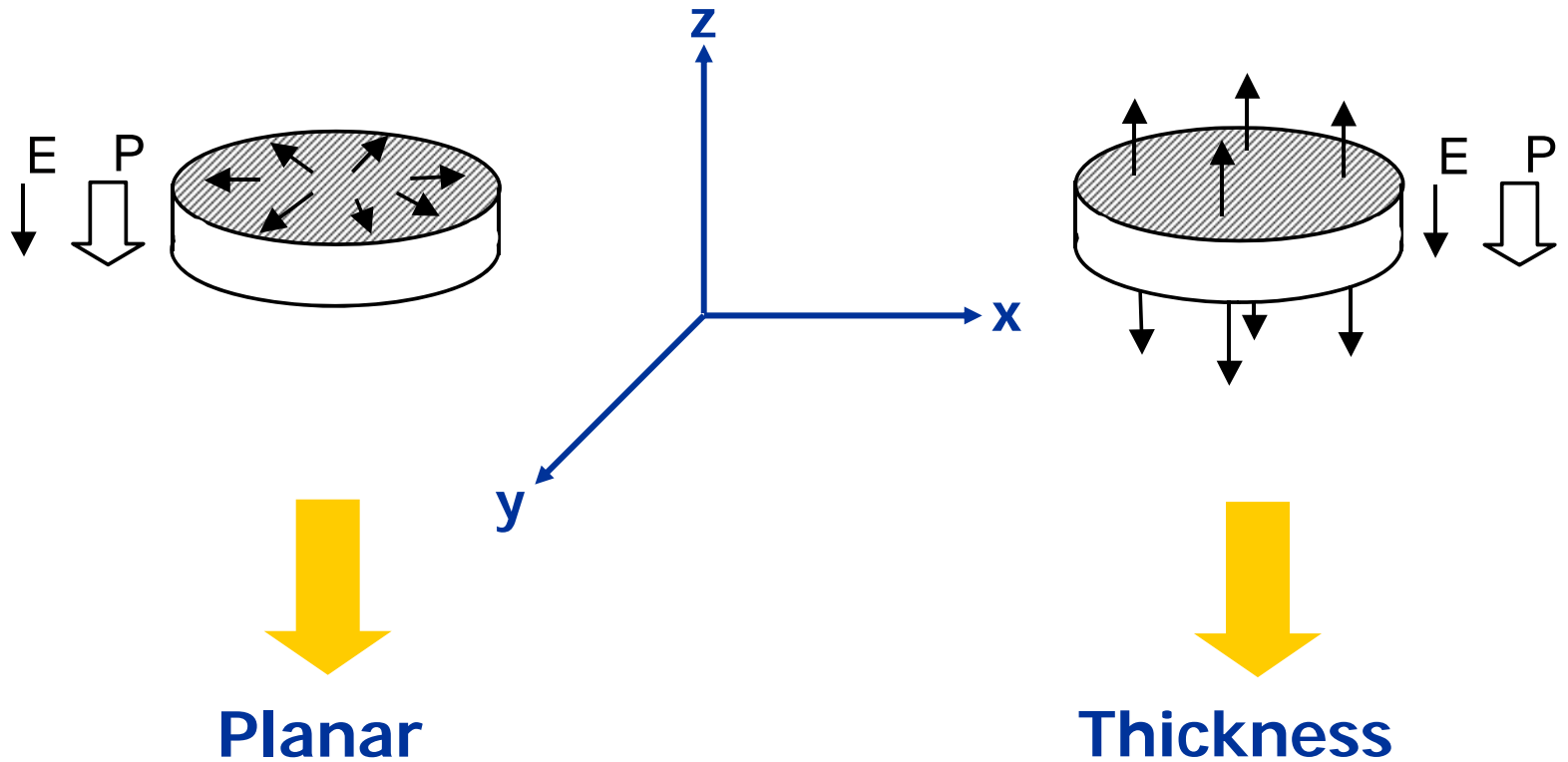




- **Introduction**
- **Behavioral Models**
(Thickness)
- **New Unified Model**
- **Conclusion and Future Works**



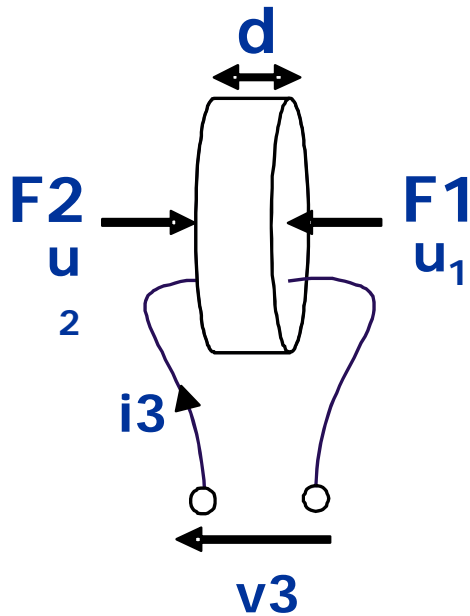
Introduction





Introduction

Impedance Matrix



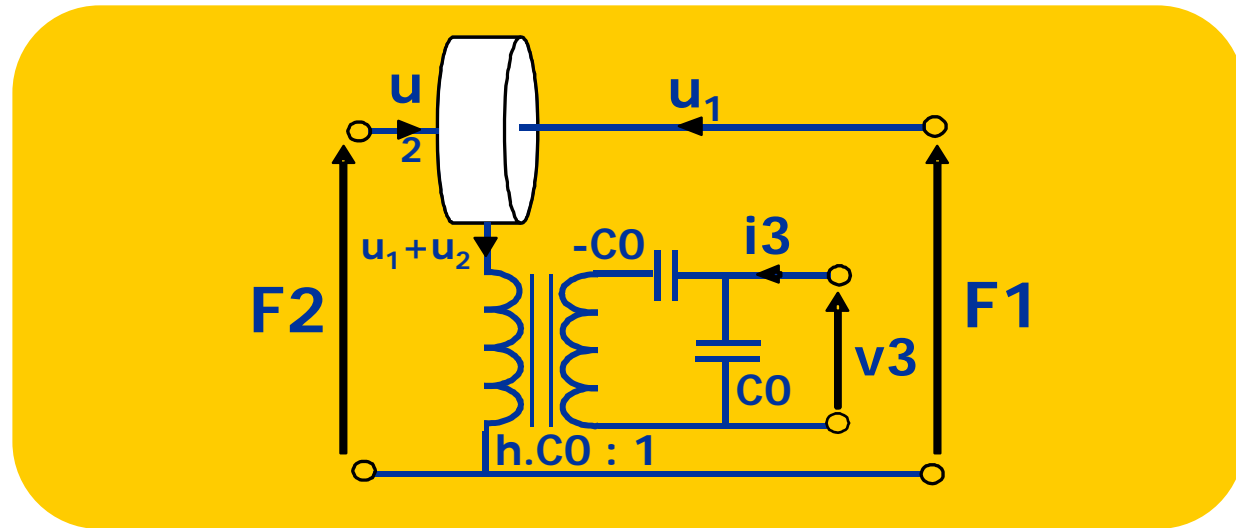
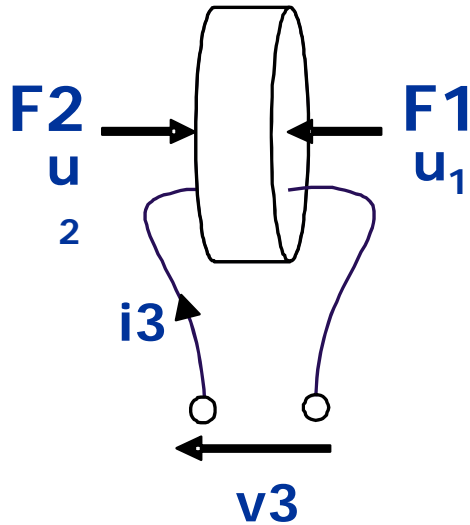
$$\begin{pmatrix} F1 \\ F2 \\ v3 \end{pmatrix} = -j \cdot \begin{pmatrix} Z/\tan(wd/u) & Z/\sin(wd/u) & h/w \\ Z/\sin(wd/u) & Z/\tan(wd/u) & h/w \\ h/w & h/w & 1/wC0 \end{pmatrix} \cdot \begin{pmatrix} u1 \\ u2 \\ i3 \end{pmatrix}$$

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



Introduction

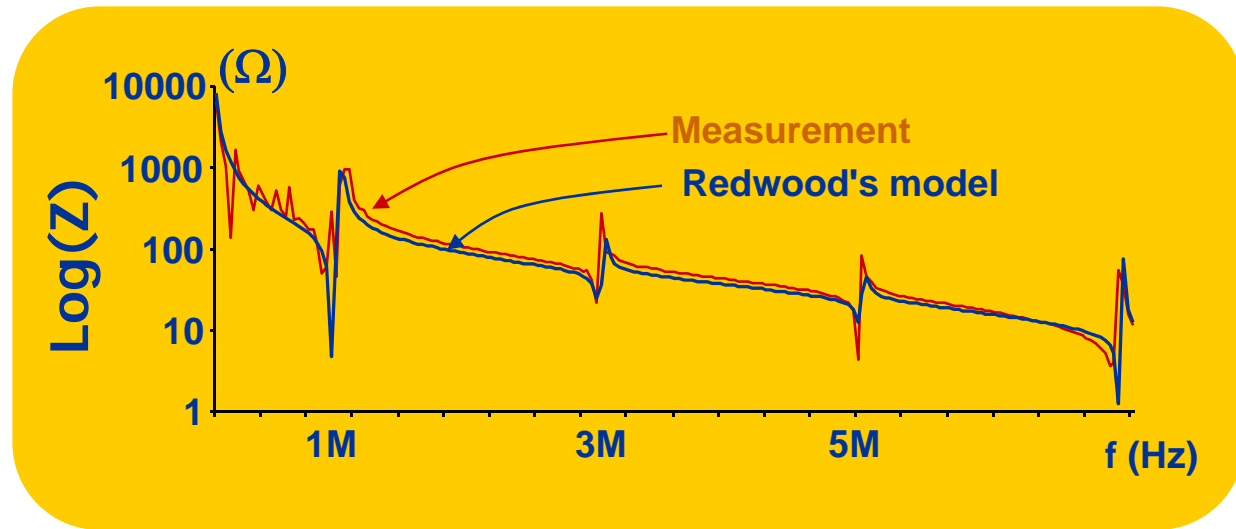
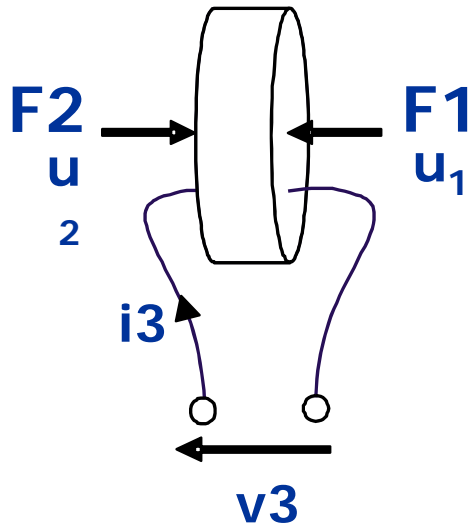
Redwood's Model





Introduction

Redwood's Model vs Measurement



➔ A new model is needed



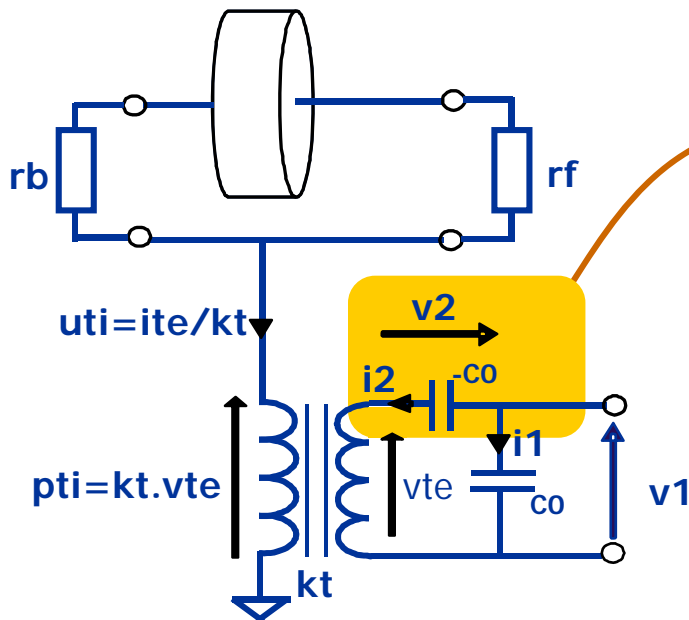
- **Introduction**
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Behavioral Models

Redwood's Model

VHDL-AMS Model



architecture bhv of redwood is

begin

```
i1 == C0 * v1'dot;
```

```
i2 == -C0 * v2'dot;
```

```
pti == kt * vte;
```

```
uti == ite/kt;
```

```
ceramic : entity work.acousticlayer
```

```
generic map (Z0=>Z0, td=>td)
```

```
port map (p1=>t11,m1=>km,p2=>t22,m2=>km);
```

```
rf : entity WORK.resistance
```

```
generic map (rnom=>0.08)
```

```
port map (plus=>t11 , moins=>t1 );
```

```
rb : entity WORK.resistance
```

```
generic map (rnom=>0.08)
```

```
port map (plus=>t22 , moins=>t1 );
```

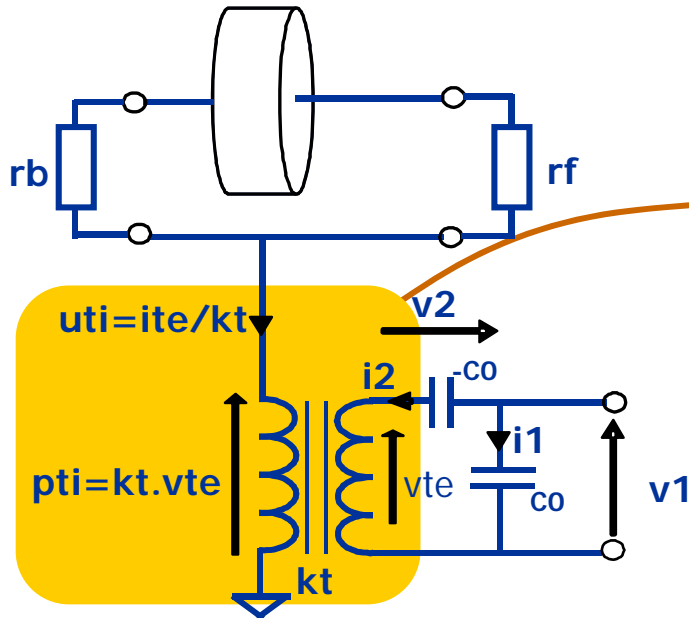
```
end architecture bhv;
```



Behavioral Models

Redwood's Model

VHDL-AMS Model



Ideal transformer

architecture bhv of redwood is

begin

$i_1 == C_0 * v_1 \text{'dot};$

$i_2 == -C_0 * v_2 \text{'dot};$

$pti == kt * v_2;$

$uti == i_2 / kt;$

ceramic : entity work.acousticlayer

generic map (Z0=>Z0, td=>td)

port map (p1=>t11,m1=>km,p2=>t22,m2=>km);

rf : entity WORK.resistance

generic map (rnom=>0.08)

port map (plus=>t11 , moins=>t1);

rb : entity WORK.resistance

generic map (rnom=>0.08)

port map (plus=>t22 , moins=>t1);

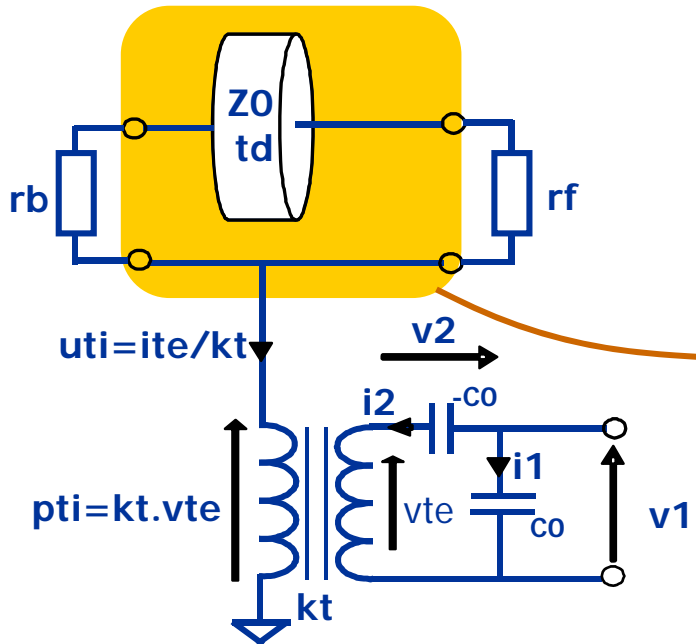
end architecture bhv;



Behavioral Models

Redwood's Model

VHDL-AMS Model



Transmission line

architecture bhv of redwood is

begin

$i1 == C0 * v1'.dot;$

$i2 == -C0 * v2'.dot;$

$pti == kt * vte;$

$uti == ite/kt;$

```
ceramic : entity work.acousticlayer
  generic map (Z0=>Z0, td=>td)
  port map (p1=>t11,m1=>km,p2=>t22,m2=>km);
```

```
rf : entity WORK.resistance
  generic map (rnom=>0.08)
  port map (plus=>t11 , moins=>t1 );
```

```
rb : entity WORK.resistance
  generic map (rnom=>0.08)
  port map (plus=>t22 , moins=>t1 );
```

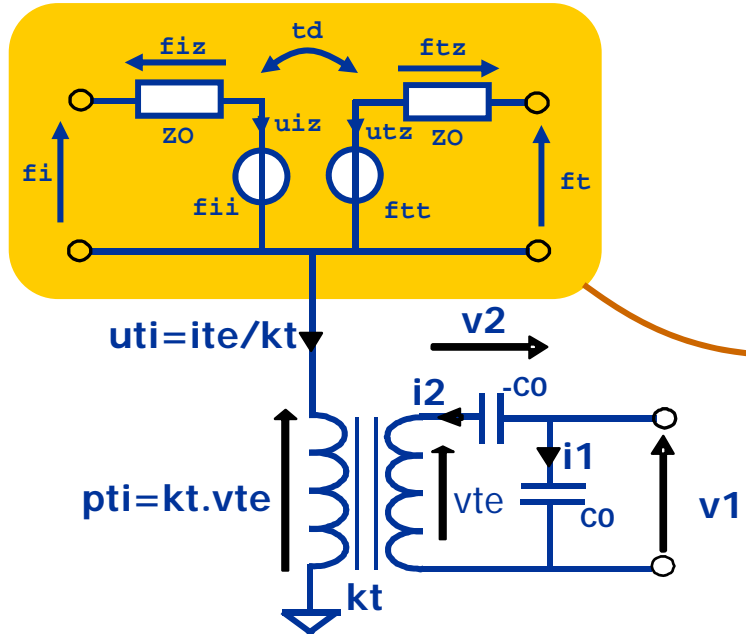
end architecture bhv;



Behavioral Models

Redwood's Model

VHDL-AMS Model



architecture bhv of redwood is

begin

```
i1 == C0 * v1'dot;
```

```
i2 == -C0 * v2'dot;
```

architecture bhva of acousticlayer is

begin

```
ftt == fi'DELAYED(td) - ftz;
```

```
fii == ft'DELAYED(td) - fiz;
```

```
fiz == (uiz + utz'DELAYED(td))*ZO/2.0;
```

```
ftz == (utz + uiz'DELAYED(td))*ZO/2.0;
```

```
end architecture bhva;
```

```
generic map (rnom=>0.08)
```

```
port map (plus=>t22 , moins=>t1 );
```

```
end architecture bhv;
```

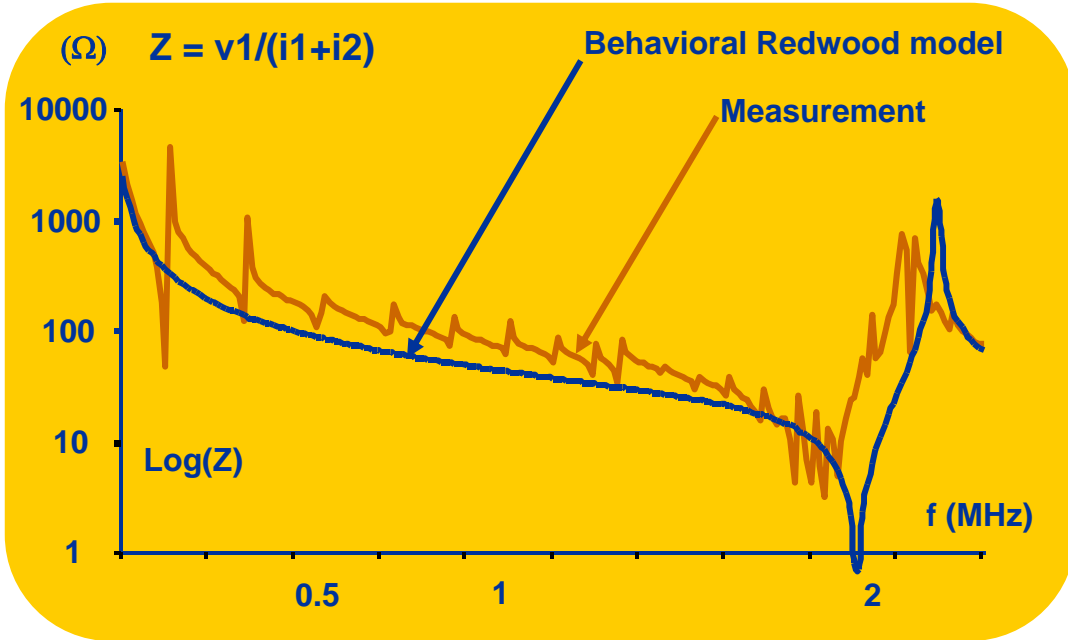
F. Branin

"Transient Analysis of Lossless Transmission Lines,"
in proceeding of IEEE



Behavioral Models

VHDL-AMS Model



$\Phi = 16\text{mm}$
1mm thick

architecture bhv of redwood is

begin

i1 == C0 * v1'dot;

i2 == -C0 * v2'dot;

pti == kt * vte;

uti == ite/kt;

ceramic : entity work.acousticlayer

generic map (Z0=>Z0, td=>td)

port map (p1=>t11,m1=>km,p2=>t22,m2=>km);

rf : entity WORK.resistance

generic map (rnom=>0.08)

port map (plus=>t11 , moins=>t1);

rb : entity WORK.resistance

generic map (rnom=>0.08)

port map (plus=>t22 , moins=>t1);

end architecture bhv;



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New Unified Model

Anisotropic material : not behave in the same way in all directions

A. Iula et al.,
IEEE Trans. On Ultrasonics, Ferroelectrics and Frequency Control, 1998

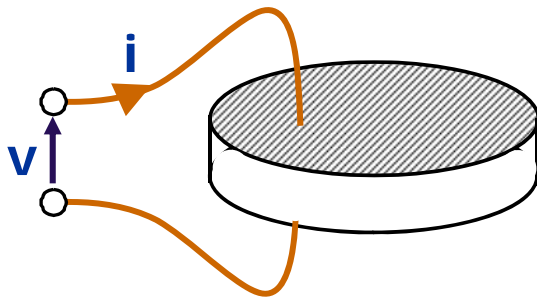
$$v = \frac{h_{33}}{j\omega} (u_1 + u_2) + \frac{kh_{31}}{j\omega} (u_3 + u_4) + \frac{i}{j\omega C_0}$$

with

$$k = 2t/r$$

h : piezoelectric constant

u : particle velocity

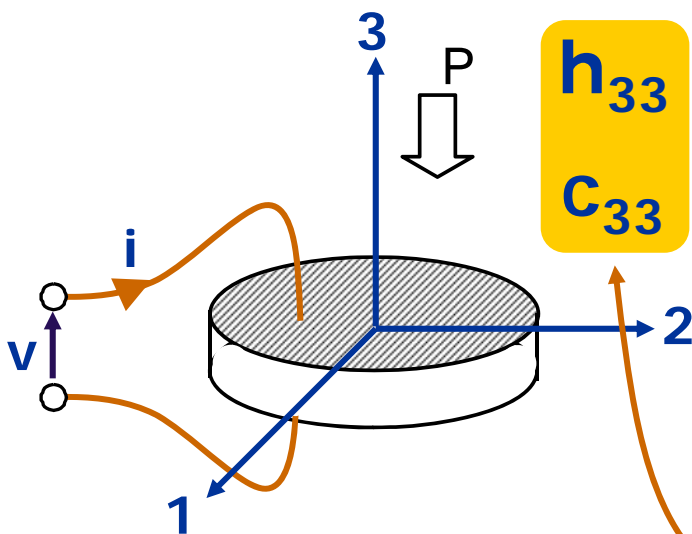




New Unified Model

thickness

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



with

$$k = 2t/r$$

h : piezoelectric constant

u : particle velocity

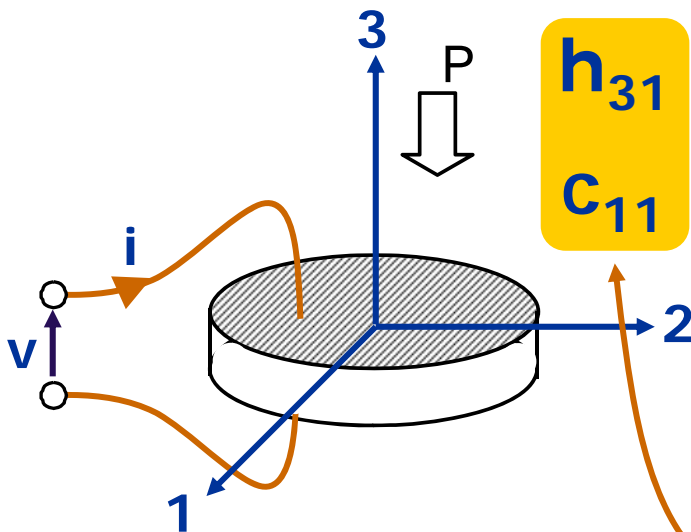
$$u = (c/\rho)^{1/2}$$

c : elastic stiffness



New Unified Model

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



with

$$k = 2t/r$$

h : piezoelectric constant

u : particle velocity

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

c : elastic stiffness

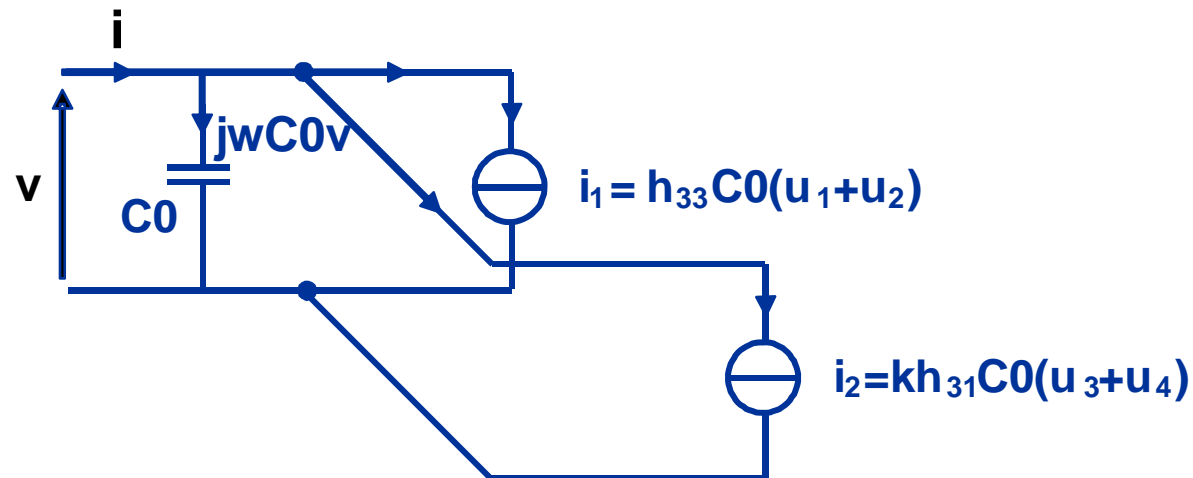


New Unified Model

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

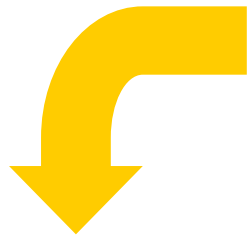


$$i = j\omega C_0 v - h_{33} C_0 (u_1 + u_2) - kh_{31} C_0 (u_3 + u_4)$$





New Unified Model



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

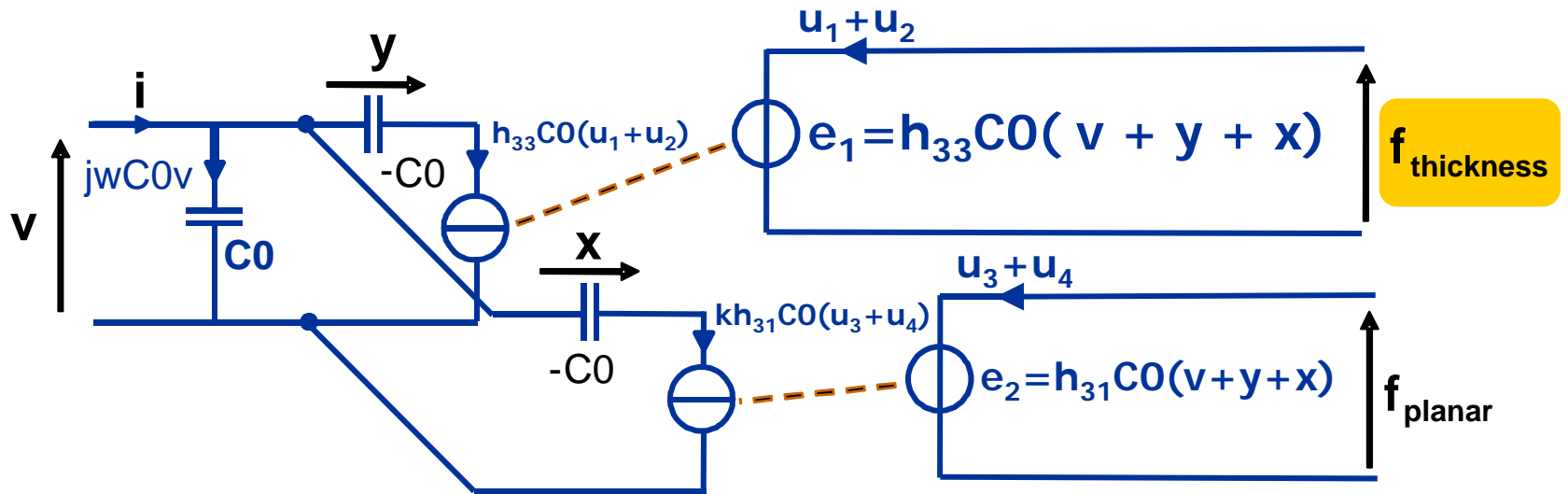
$$f_{\text{thickness}} = h_{33} C_0 \left[v - \frac{1}{j\omega C_0} h_{33} C_0 (u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31} C_0 (u_3 + u_4) \right]$$

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



New Unified Model

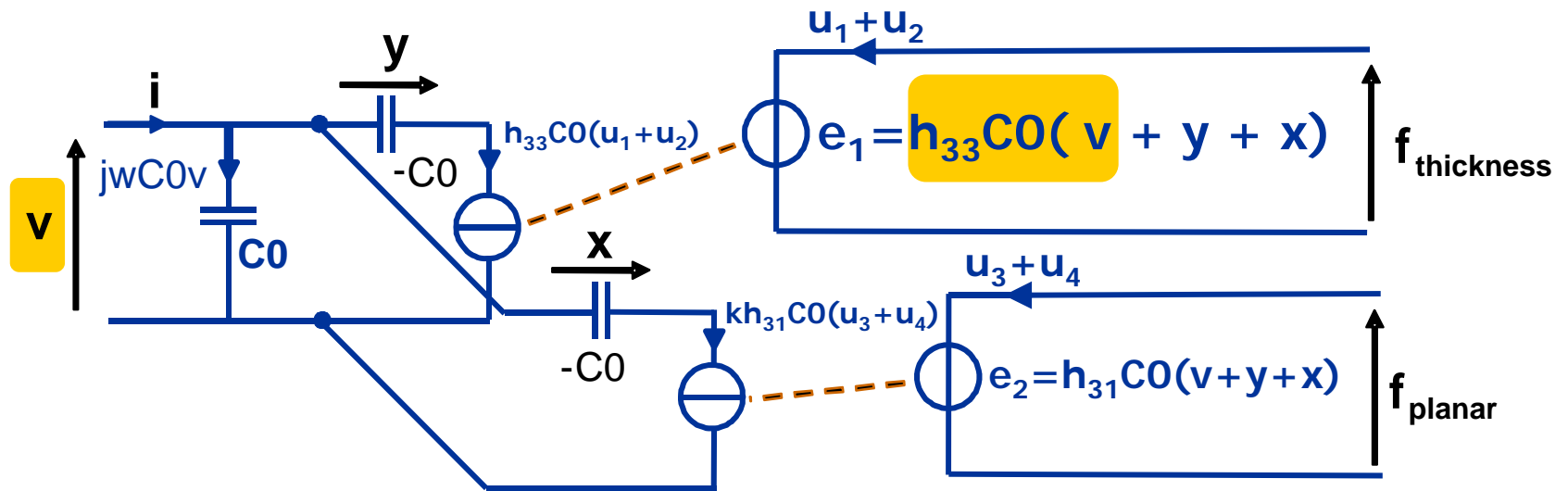
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





New Unified Model

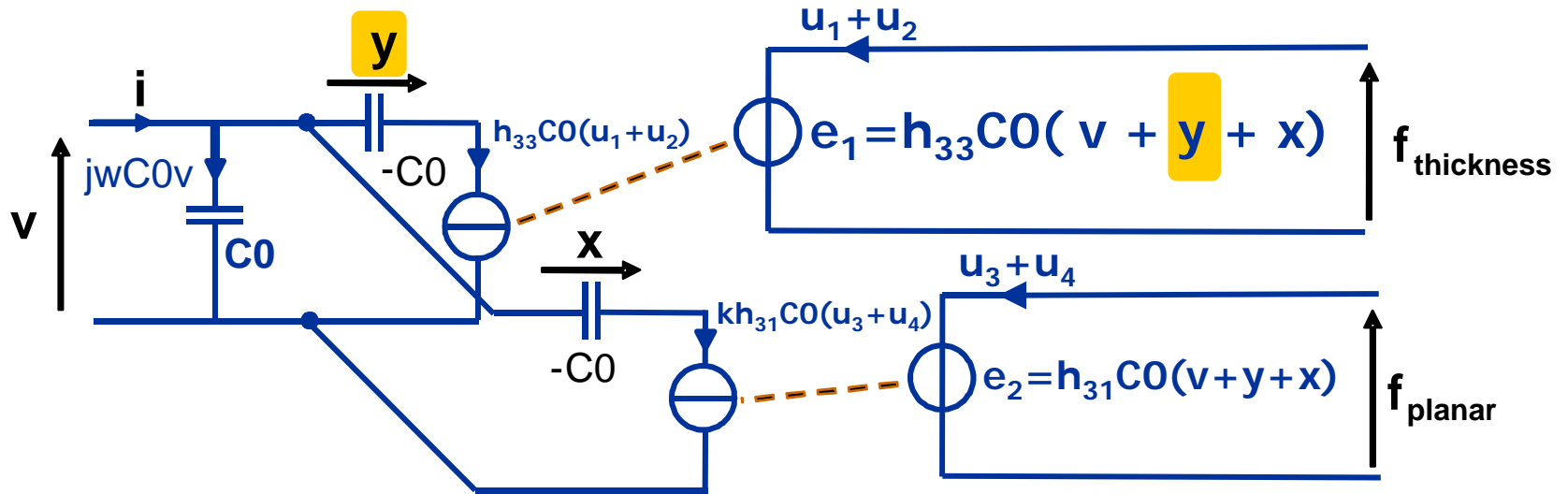
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





New Unified Model

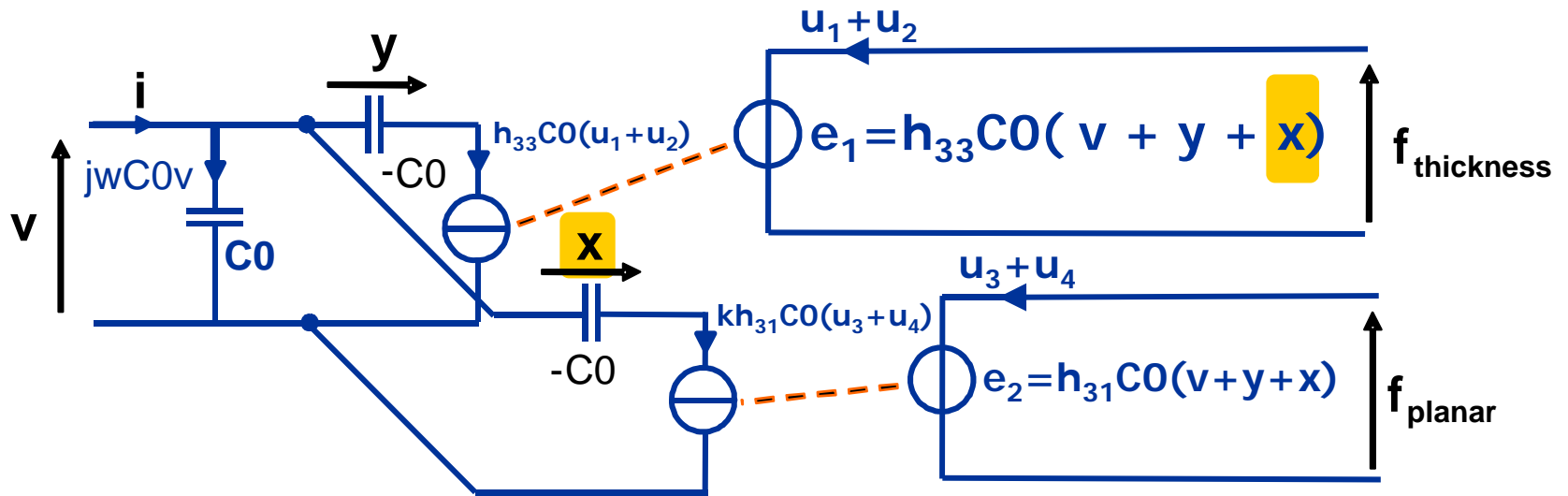
$$f_{\text{thickness}} = h_{33}C_0 \left[v - \frac{1}{j\omega C_0} h_{33}C_0(u_1 + u_2) - \frac{1}{j\omega C_0} kh_{31}C_0(u_3 + u_4) \right]$$





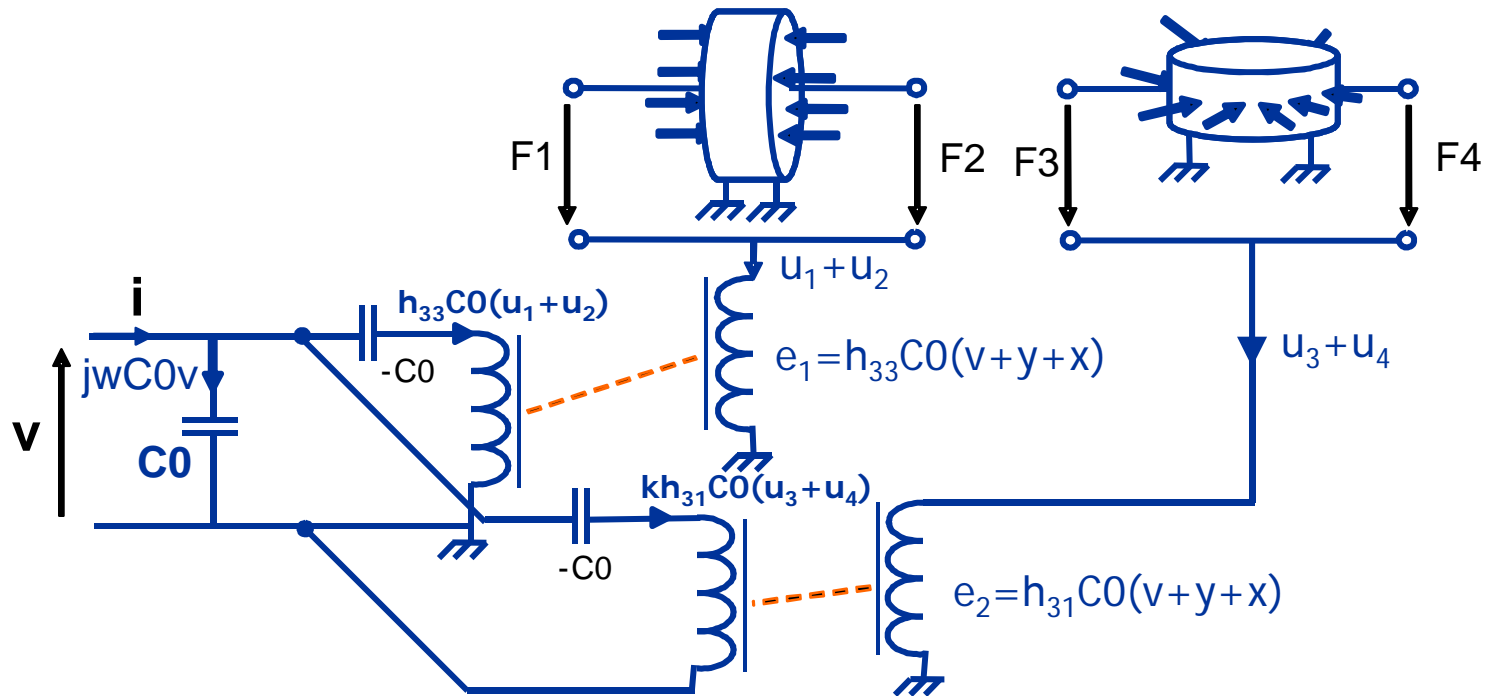
New Unified Model

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





New Unified Model



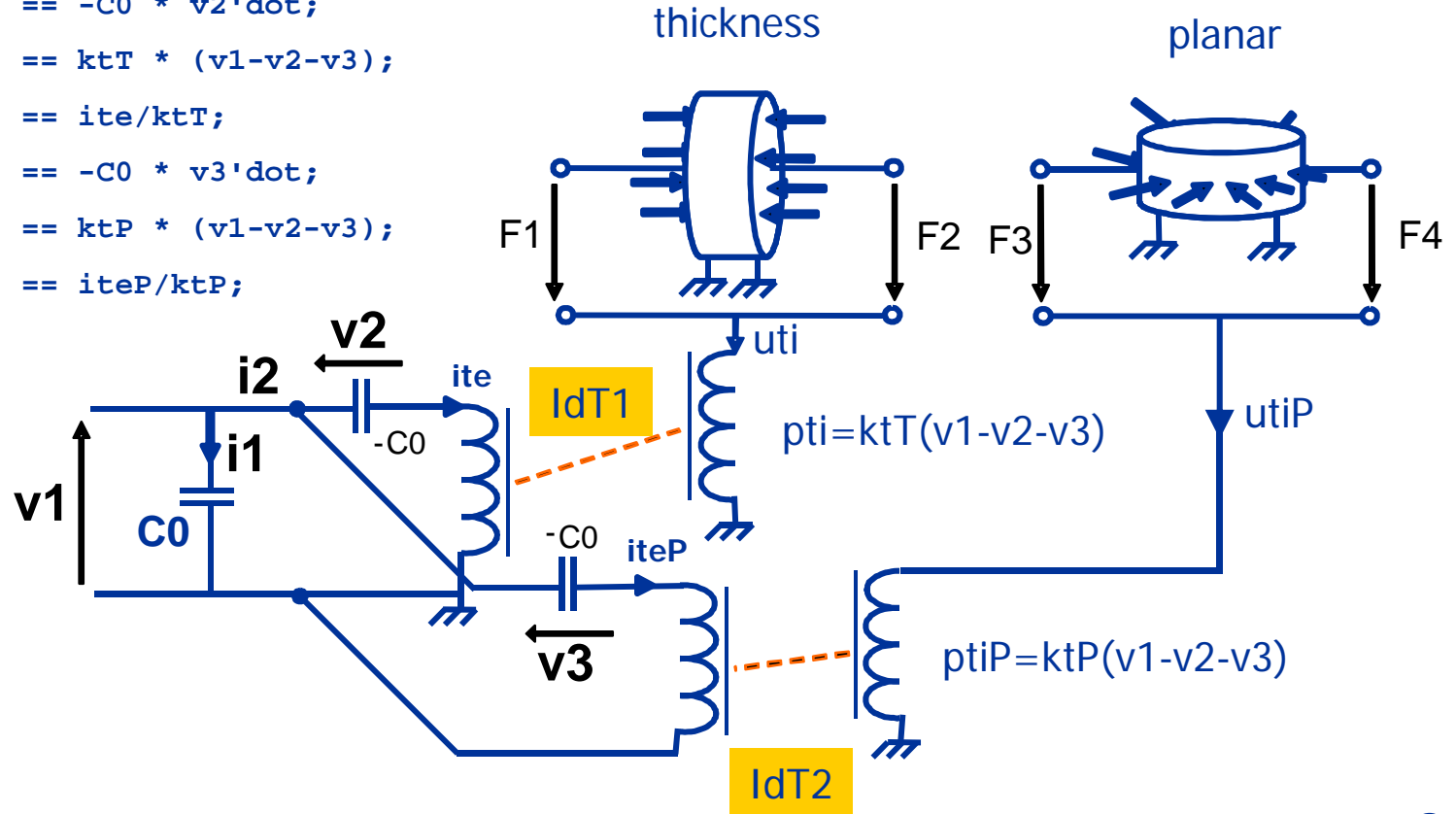


New Unified Model

architecture bhvugp of ugp is
begin

```

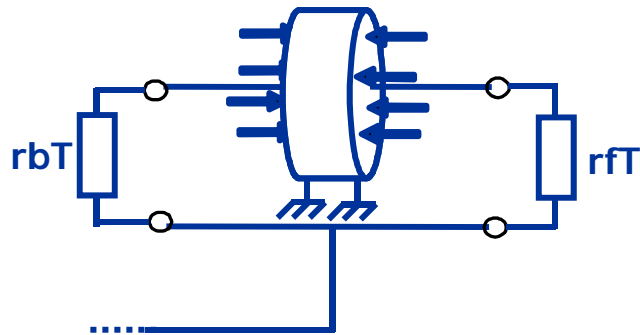
i1      == C0 * v1'dot;
i2      == -C0 * v2'dot;
IdT1 {  pti      == ktT * (v1-v2-v3);
        uti      == ite/ktT;
        i3      == -C0 * v3'dot;
IdT2 {  ptiP     == ktP * (v1-v2-v3);
        utiP     == iteP/ktP;
        .
        .
        .
    
```



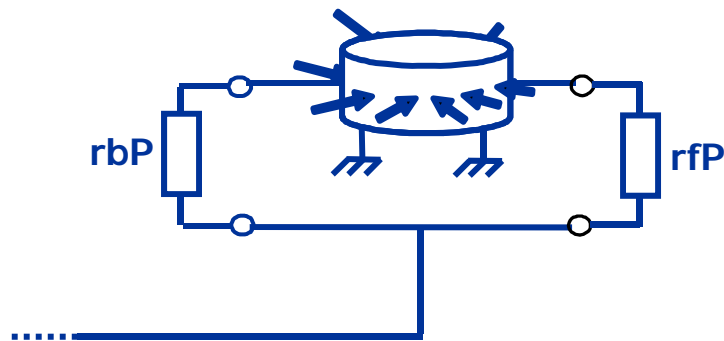


New Unified Model

thickness



planar



```

.
.
.
ceramicT : entity work.acousticlayer
generic map (Z0=>Z0, td=>tdT)
    port map (p1=>t11,m1=>km,p2=>t22,m2=>km);
rfT : entity WORK.resistance
generic map (rnom=>0.08)
    port map (plus=>t11 , moins=>t1 );
rbT : entity WORK.resistance
generic map (rnom=>0.08)
    port map (plus=>t22 , moins=>t1 );

```

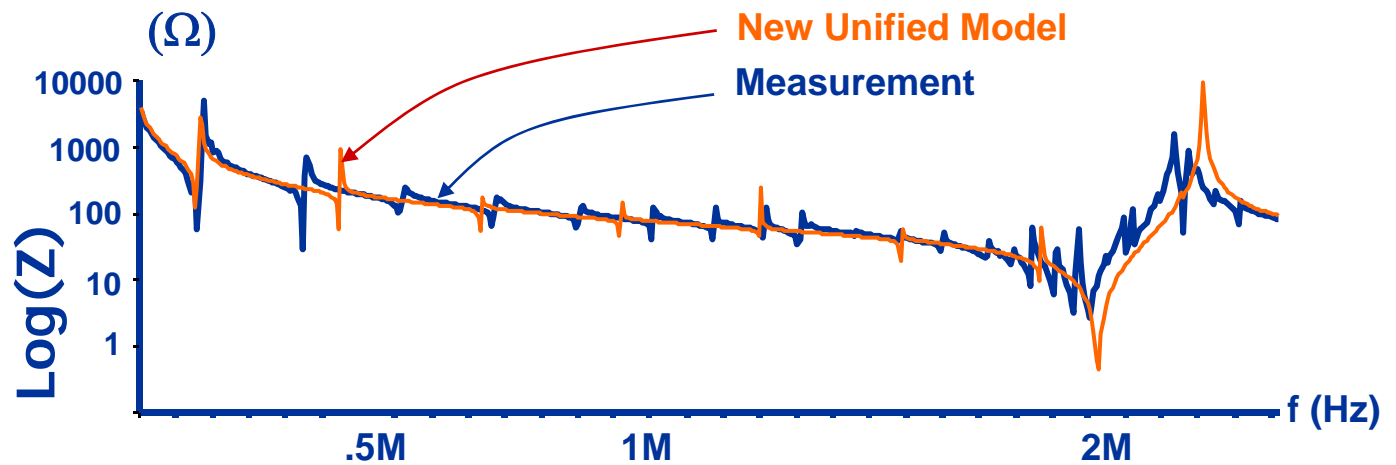
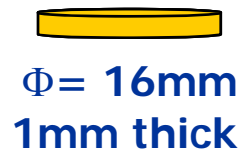
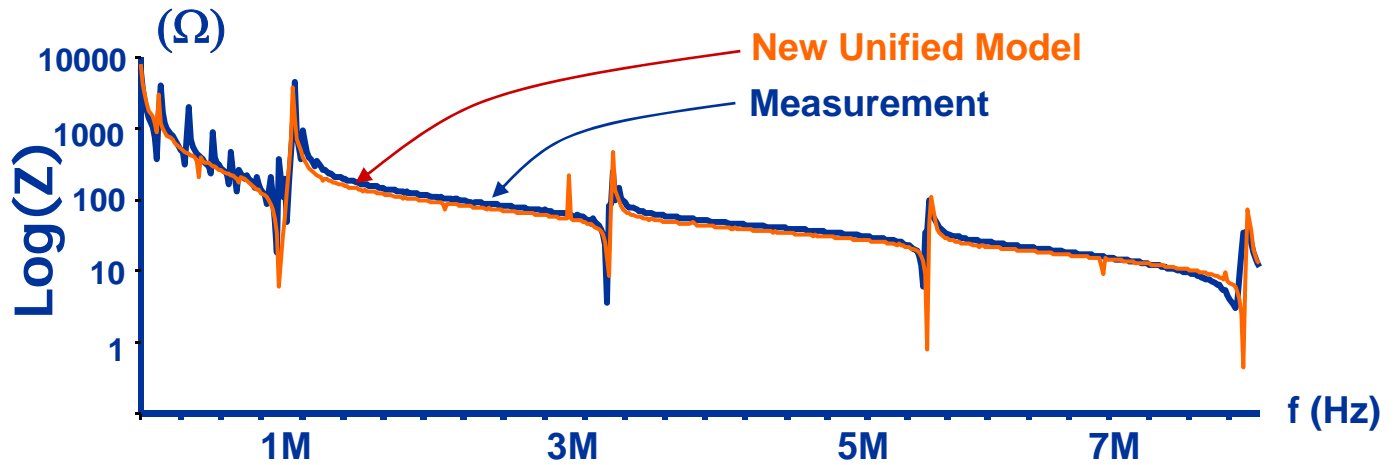
```

ceramicP : entity work.acousticlayer
generic map (Z0=>Z0, td=>tdP)
    port map (p1=>t11P,m1=>km,p2=>t22P,m2=>km);
rfP : entity WORK.resistance
generic map (rnom=>0.08)
    port map (plus=>t11P , moins=>t2 );
rbP : entity WORK.resistance
generic map (rnom=>0.08)
    port map (plus=>t22P , moins=>t2 );
end architecture bhvugp;

```



New Unified Model





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Behavioral Models (Thickness)

New Unified Model

Experimental Validation

Future Works

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