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Breakthrough:

New Solutions to the problem of:

Instantaneous "Resonant Load" Parameters Estimation Operating in "Non-Stationary" Conditions

Real World → Real Operating Conditions

Two broad categories:

- Stationarity, Deterministic, Periodic....
- Non-Stationarity, Time-Evolving (**T-E**), Transient.......

Extensive field tests conducted by known professionals active in the field of ultrasound conclude that:

many of new ultrasonic applications are highly non-stationary!

There is a need for "Easily Implementable Signal Processing Tools" capable to accurately estimate "Load Parameters" in **"Real-Time"**

The proposed solution is based on:

Trigonometric properties of band-limited signals represented in their ***analytical forms***

It can be shown that “Short-Time” Estimations are easily obtainable for the following "Time-Evolving Parameters":

*Magnitude of **“Short-Time”** Load Impedance*

*Argument of **“Short-Time”** Load Impedance* haute école neuchâtel berne jura **arc** ingénierie saint-imier le locle porrentruy

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*“**Short-Time**” Active/Reactive Power of "**Short-Time**” Load Impedance″*

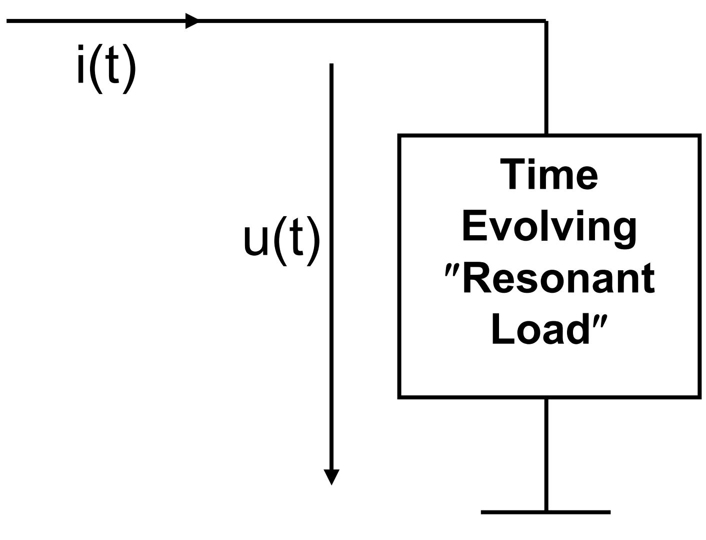
*Instantaneous Frequency of “**Time-Evolving**” Load Voltage or Load Current"*

Basic theoretical analysis

$$i(t) = \hat{I}(t)\ \cos(2\cdot\pi\cdot f_o(t)\cdot t + \phi_i(t))$$

$$u(t) = \hat{U}(t)\ \cos(2\cdot\pi\cdot f_o(t)\cdot t + \phi_u(t))$$

Basic structure bloc diagram



$\hat{I}(t)$: Instantaneous current envelope

$\phi_i(t)$: Instantaneous current phase

$\hat{U}(t)$: Instantaneous voltage envelope

$\phi_u(t)$: Instantaneous voltage phase

$f_o(t)$: Instantaneous driving signal frequency

Then, i(t) and u(t) can be represented in their respective analytical forms:

$$i(t) \rightarrow i_{analytic}(t) = i(t) + j \cdot \tilde{i}(t)$$

$$u(t) \rightarrow u_{analytic}(t) = u(t) + j \cdot \tilde{u}(t)$$

With:

$$\tilde{i}(t) = \hat{I}(t) \cdot \sin(2 \cdot \pi \cdot f_o(t) \cdot t + \phi_i(t))$$

$$\tilde{u}(t) = \hat{U}(t) \cdot \sin(2 \cdot \pi \cdot f_o(t) \cdot t + \phi_u(t))$$

$u(t) \rightarrow$ Hilbert Transformation $\rightarrow \tilde{u}(t)$

$i(t) \rightarrow$ Hilbert Transformation $\rightarrow \tilde{i}(t)$

$$\mathcal{H}\{x(t)\} = x_{HT}(t) \quad ; \quad x_{HT}(t) = \frac{1}{\pi} \cdot \int_{-\infty}^{\infty} \frac{x(\tau)}{\tau - t} \, d\tau$$

$\mathcal{H}\{x(t)\}$ properties: $\mathrm{Mod}[\mathcal{H}] = 1$, $\mathrm{Arg}[\mathcal{H}] = -\pi/2$

➔ The Hilbert Transformer is a **90 degrees** phase-shifter!

From trigonometric properties, the following relationships can be derived:

$$\hat{I}(t) = \sqrt{i(t)^2 + \tilde{i}(t)^2}$$

Instantaneous current envelope

$$fo(t) = \frac{1}{2\cdot\pi}\cdot\frac{i(t)\cdot\frac{d}{dt}\tilde{i}(t) - \tilde{i}(t)\cdot\frac{d}{dt}i(t)}{\hat{I}(t)^2}$$

Instantaneous current frequency

$$M_{stZ}(t) = \frac{\sqrt{u(t)^2 + \tilde{u}(t)^2}}{\sqrt{i(t)^2 + \tilde{i}(t)^2}}$$

Short - Time Magnitude of the Load Impedance

$$\sin\left(\phi_u(t) - \phi_i(t)\right) = \frac{i(t)\cdot\tilde{u}(t) - \tilde{i}(t)\cdot u(t)}{\sqrt{i(t)^2 + \tilde{i}(t)^2}\cdot\sqrt{u(t)^2 + \tilde{u}(t)^2}}$$

Short - Time Argument Sinus of the Load Impedance

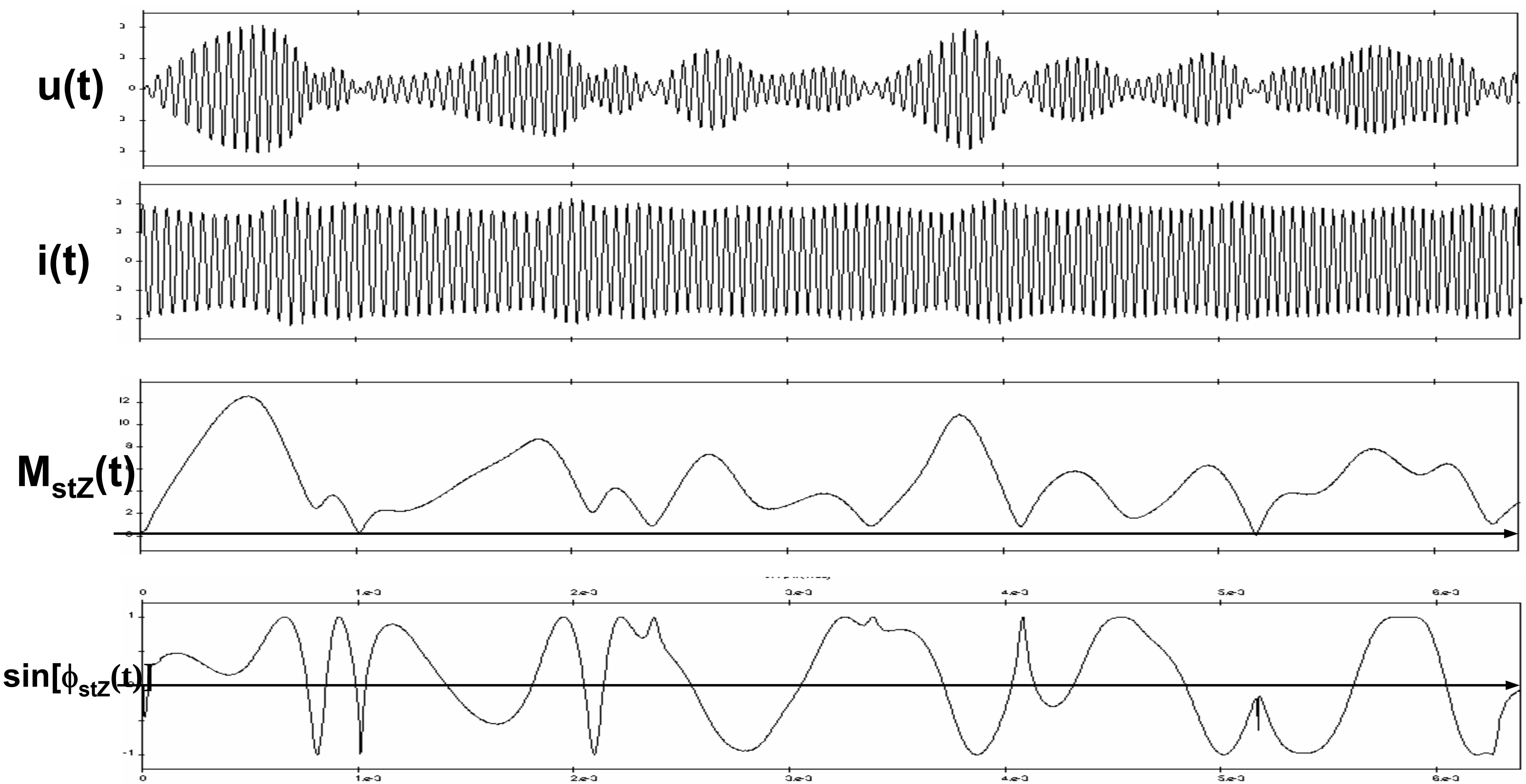
Let us define the **"Short-Time"** Active Power as follows:

$$P_{active}(t) = \frac{1}{2} \cdot \hat{U}(t) \cdot \hat{I}(t) \cdot \cos\left[\phi_{dyn}(t) \right]$$

Then:

$$P_{active}(t) = \frac{i(t) \cdot u(t) + \tilde{i}(t) \cdot \tilde{u}(t)}{2}$$

Computer Simulation Example



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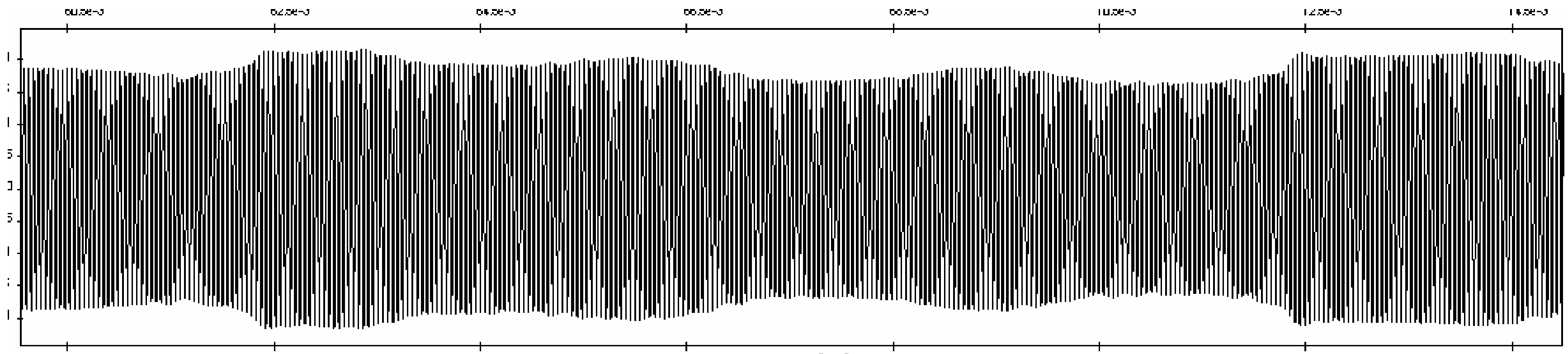
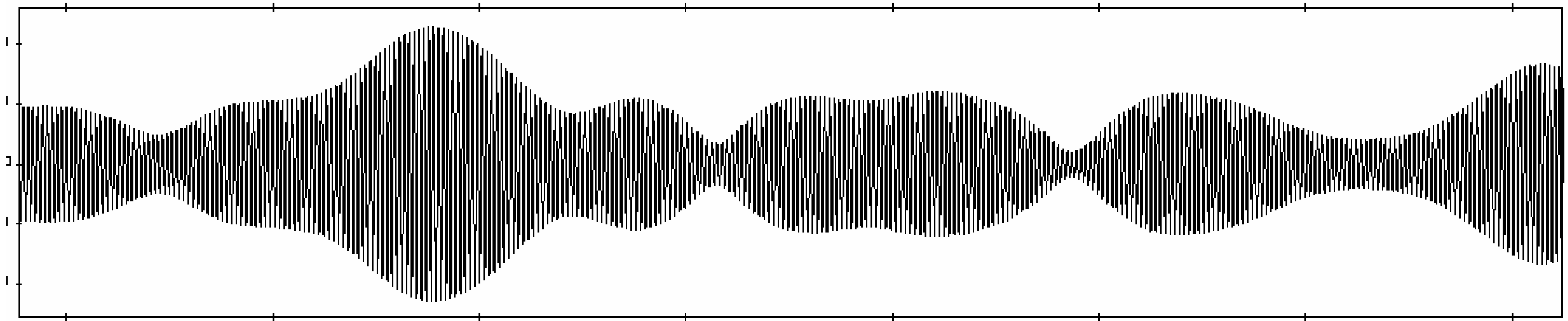
Field Test Measurements (from MMM ultrasonic system)



u(t)



i(t)

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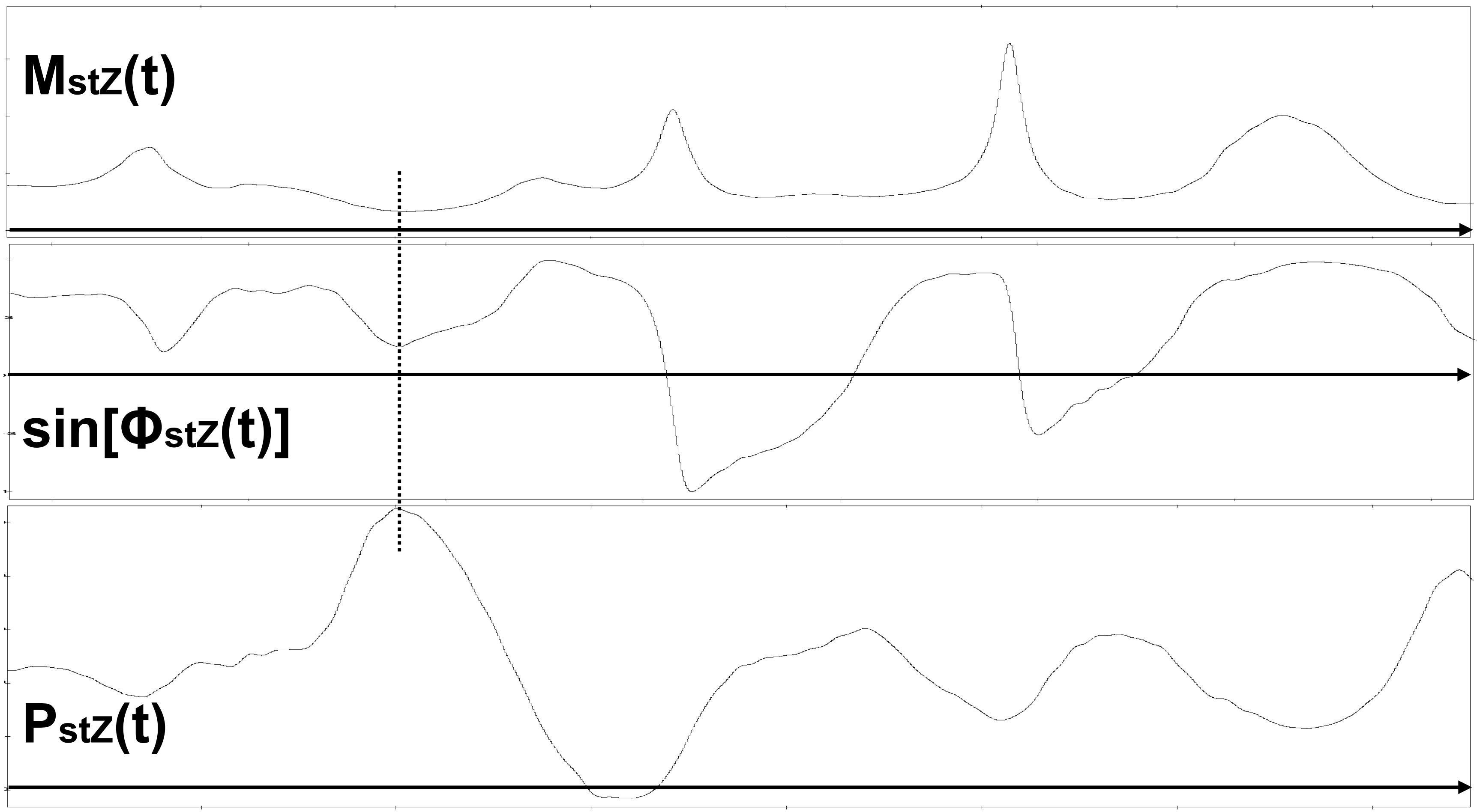
Computed **"Short-Time"** Magnitude, Argument, Active Power of the Load



Conclusion

*Many Processes with fast changing load conditions can greatly benefit from "**real-time**" load parameters estimations*

This can also dramatically enhance the global performances of some industrial processes.