Abstract: Performance characteristics of Electrically Small Antennas are limited by fundamental physics. Using Non-Foster elements into antennas structures appears like an opportunity to overshoot those limits. In this paper, a Negative Impedance Converter circuit is designed for antenna applications at 868 MHz. These active circuits, that produce Non-Foster negative capacitance or inductance, are known as sensitive circuits due to their nonlinearities that can produce instabilities. Thus, designing Negative Impedance Converters at Ultra High Frequency bands becomes quite challenging. Accurate design is strongly recommended to predict the final behavior of the circuit. The Negative Impedance Converter sensitivity is investigated with respect to Printed Circuit Board design through both simulation and measurement results.

Keywords: Negative Impedance Converter, Non-Foster elements, negative impedance, electrically small antennas.

References


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Sensitivity of Negative Impedance Converter circuit with respect to PCB design effects

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• **Motivations:** Improve compact antennas performances for directivity applications
  - Innovative antennas for Internet of Things.
  - Directive antennas issues.
  - State of the art: negative impedances.
  - Practical achievement of Non-Foster for antennas.

• **Negative impedance converter sensitivity analysis**
  - Theoretical aspects and preliminary investigations.
    - NIC architecture.
    - Schematic Simulations.
  - Practical and relevant studies.
    - Full EM Co-Simulation.
    - Measurement Results.

• **Conclusion and future works**
MOTIVATIONS:
IMPROVE COMPACT ANTENNAS PERFORMANCES FOR DIRECTIVITY APPLICATIONS.
Compact and directive antennas for smart objects:
→ Focus the radiation in useful directions.
→ Spatial selectivity.

Control what you point at.
DIRECTIVE ANTENNAS ISSUES

- Usual techniques to enhance antennas’ directivity:
  → Reflectors, directors, arrays, lenses.

- Classical techniques that lead to:
  → Larger antennas.
  → Limited bandwidth.

Trade-off: Directivity and antenna size.
STATE OF THE ART : NEGATIVE IMPEDANCES

- Non-Foster elements are classically used to enhance compact antennas’ impedance matching bandwidth.

- Negative impedance used here as an opportunity to enhance compact and directive antennas performances:
  - Negative resistive elements $\rightarrow$ Superdirectivity [1].
  - Non-Foster elements $\rightarrow$ Directivity bandwidth of compact antennas [1].

Solution: Negative impedance elements

PRACTICAL ACHIEVEMENT OF NON-FOSTER FOR ANTENNAS

- Non-Foster elements are achieved with Negative Impedance Converters circuits (NIC).
  - Active and complex RF circuits.
  - Few practical realizations.
  - Often designed for VHF bands frequencies.
  - Suffer from difficulties with instability.

Sensitivity issues at UHF band and above
NEGATIVE IMPEDANCE CONVERTER SENSITIVITY ANALYSIS
NIC architecture

NIC converts a passive load $Z_L$ to a negative impedance $Z_{NIC}$.

- Two cross-coupled Bipolar Junction Transistors (BJT).
- Load ($Z_L$) inside the feedback loop.
- Differential negative impedance ($Z_{NIC}$).
- Easy to connect at balanced port of an antenna (e.g. dipole).

Analytical transfer function:

$$Z_{NIC} = -Z_L \frac{\beta - 1}{\beta + 1} + \frac{2h_{11}}{\beta + 1}$$

$h_{11}$ : BJT’s input resistance.

$\beta$ : BJT’s current gain.

Implementation difficulties and sensitivity issues.
THEORETICAL ASPECTS AND PRELIMINARY INVESTIGATIONS

Schematic Simulations (1/2)

- An extra microstrip line $L_1$ is introduced in different branches of the NIC’s ideal model.
- Identification of the critical lines and the more sensitive area: feedback loop.
- Sensitivity study to transmission lines and substrate nature for a capacitive load $Z_L=10\text{pF}$ in the feedback loop.
Schematic Simulations (2/2)

Sensitivity study to transmission lines and substrate nature for a capacitive load $Z_L=10\text{pF}$.

- Effect of microstrip lines’ length $L_1$:

- $L_1$ substrate nature impact:

NIC behavior is significantly impacted by substrate nature and transmission line lengths especially in the feedback loop.
PRACTICAL AND RELEVANT STUDIES

Full EM Co-Simulation (1/2)

- Accurate model of the NIC with a full EM simulation of the PCB.
- Three PCB configurations to check the preliminary investigations on RO4350B™:
  - RF ports location.
  - Transmission line lengths.
  - Physical dimensions.
  - Coupling effects.
PRACTICAL AND RELEVANT STUDIES

Full EM Co-Simulation (2/2)

- Different results compared with preliminary investigations.
- The shortest NIC (1) has the closest behavior to the NIC’s ideal model.

Full EM co-simulation is required for an accurate NIC model. NIC miniaturization leads to a better control of its behavior.
PRACTICAL AND RELEVANT STUDIES

Measurement Results

- Measurement of RF circuits (1) and (3).
- Stability ensured during measurement using a Spectrum analyzer.

Good agreements between full EM co-simulations and measurements considering the negative capacitance value.
A sensitivity investigation to physical PCB effects on the NIC behavior is studied from ideal schematic to full EM co-simulations and measurements.

Significant impact of the PCB is observed on the NIC’s Non-Foster response: feedback loop.

Good agreements of measurement results with EM co-simulation but not with theory:

→ A full EM co-simulation is strongly required to tune Non-Foster component PCB design.

Negative capacitance measured with a good agreement at UHF band: circuit candidate for compact antennas applications

**Future work:**

NIC circuit integration with compact antennas co-design for UHF band applications.

Innovative compact and superdirective antennas with Non-Foster elements.