IEEE Radio and Wireless Symposium
San Diego, CA Jan 09

CLASS E RF/MICROWAVE POWER AMPLIFIERS

Class E broadband amplifier with C-LC shunt network

Basic theory, simulation and prototype

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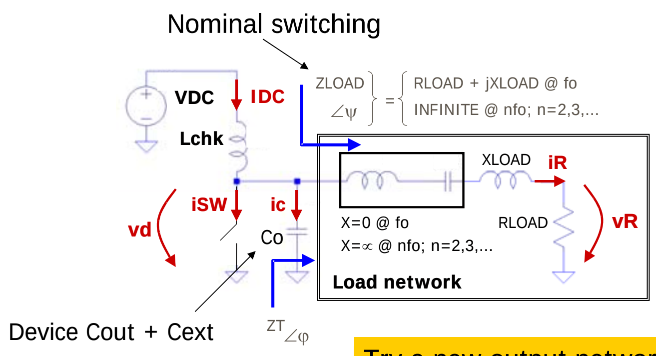
IEEE Topical Symposium on Power Amplifiers for Wireless Communications

Motivation: Class E and broadband

- **Class E amps very interesting in modern communication systems** ...
  - Large number of channels for a long period from a small-size battery.
  - Power amplifier is a main consumer of dc power from a battery.
  - Class E offers high operating efficiency near 100 % for ideal case.
- **Class E amplifiers are narrowband by concept.**
  - Output network tuned to one frequency.
  - Nominal operation if switch "see" a nominal impedance at fo and harmonics.
  - Published results for broadband operation: Grebennikov, Raab, Al-Shahrani, Gudimetla, Qin, Quach, Tat Hung, Tayrani, Everard, Pajic, etc.
- **Design of a broadband class E UHF amplifier ...**
  - With choke in drain to supply,
  - With C parallel with device (or more) included in output network

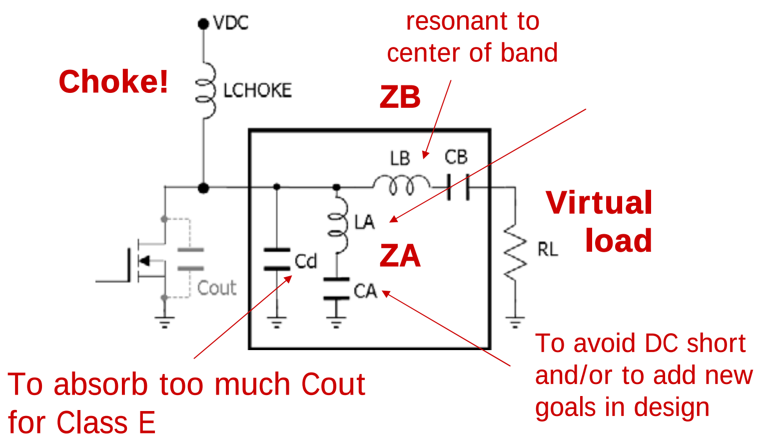
Bandwidth: 403-470MHz **Rated power**: 4W **Load**: 50Ω
Efficiency: 75% @ Pout=5W **Power supply**: 7.5V
Harmonic spectrum: Aditional filter for harmonic rejection.

Class E: basics of the idea



Try a new output network designed to show almost ZLOAD for the complete broadband, 400-470MHz.

Broadband: output network



Analysis was done with similar method as Raab'76.

Broadband: equations for the design (1)

Considering: i) the ZLOAD to show to device at fo; ii) the angle of ZLOAD to show to device (49º); iii) the slope of that angle =0 for broadband design; iv) the resonant frequency of LB-CB must be fo and v) the CA value must be a low impedance versus LA impedance.

$$LBx(\omega x, \psi x, Cx, Cdx, Nratiox) := \frac{8.0\ 10^{-4}}{\omega x^2\ Cx^2\ (Nratiox - 1.)} \left[\begin{array}{l} 175.\ \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}\ Cx\ \tan(\psi x) + \blacksquare \ldots \\ + 175.\ \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}\ Cx\ Nratiox\ \tan(\psi x) + \blacksquare \ldots \\ + 98.\ Cdx\ Nratiox + 98.\ Cdx\ Nratiox\ \tan(\psi x)^2 \end{array} \right]$$

$$CBx(\omega x, \psi x, Cx, Cdx, Nratiox) := 1250.\ Cx^2\ \frac{Nratiox - 1.}{\begin{array}{l} 175.\ \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}\ Cx\ \tan(\psi x) + \blacksquare \ldots \\ + 175.\ \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}\ Cx\ Nratiox\ \tan(\psi x) + \blacksquare \ldots \\ + 98.\ Cdx\ Nratiox + 98.\ Cdx\ Nratiox\ \tan(\psi x)^2 \end{array}}$$

Analysis was done with similar method as Raab'76.

Broadband: equations for the design (2)

$$LAx(\omega x, \psi x, Cx, Cdx, Nratiox) := 7\ Nratiox\ \frac{\left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}}{\omega x^2 \left[\begin{array}{l} 25.\ \tan(\psi x)\ Nratiox\ Cx - 25.\ \tan(\psi x)\ Cx + \blacksquare \ldots \\ + 7\ Cdx\ Nratiox \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}} - 7.\ Cdx \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}} \end{array} \right]}$$

$$Rx(\omega x, \psi x, Cx, Cdx, Nratiox) := .28\ \frac{\left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}}{Cx\ \omega x}$$

$$CAx(\omega x, \psi x, Cx, Cdx, Nratiox) := \left(2\ 10^{-2}\ Nratiox - 2\ 10^{-2}\right) \frac{\begin{array}{l} 49.\ Cdx\ \tan(\psi x)^2 + 49.\ Cdx + \blacksquare \ldots \\ + 175.\ \left(\tan(\psi x)^2 + 1\right)^{\frac{1}{2}}\ Cx\ \tan(\psi x) \end{array}}{\tan(\psi x)^2 + 1.}$$

Analysis was done with similar method as Raab'76.

The design: using the equations ...

Transistor RD07MVS1(Mitsubishi): Nominal **Ron=0.18R Cout=60pF**

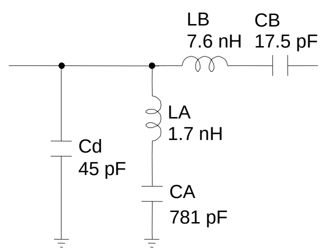
From classical narrowband class E theory:

Co = 16.8pF @ 403MHz, 15.5pF @ fo ; 14.4pF @ 470MHz

Using equations:

$Cx := 15.5 \cdot pF$ $fx := 436.5 \cdot MHz$ $\psi x := 49 \cdot deg$

$\omega x := 2 \cdot \pi \cdot fx$ $Cdx := 45 \cdot pF$ $Nratiox := 10$



$Cx := 15.5 \cdot pF$ $fx := 436.5 \cdot MHz$ $\psi x := 49 \cdot deg$

$\omega x := 2 \cdot \pi \cdot fx$ $Cdx := 45 \cdot pF$ $Nratiox := 10$

$LBx(\omega x, \psi x, Cx, Cdx, Nratiox) = 7.613\,nH$

$CBx(\omega x, \psi x, Cx, Cdx, Nratiox) = 17.462\,pF$

$LAx(\omega x, \psi x, Cx, Cdx, Nratiox) = 1.702\,nH$

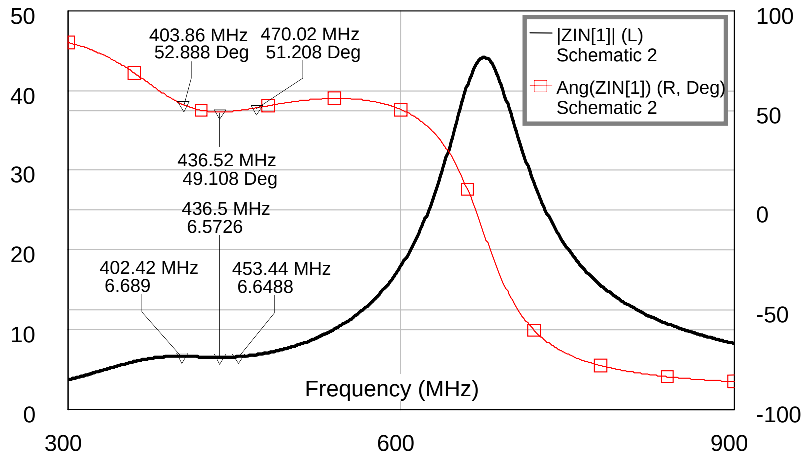
$Rx(\omega x, \psi x, Cx, Cdx, Nratiox) = 10.04\,\Omega$

$CAx(\omega x, \psi x, Cx, Cdx, Nratiox) = 781.007\,pF$

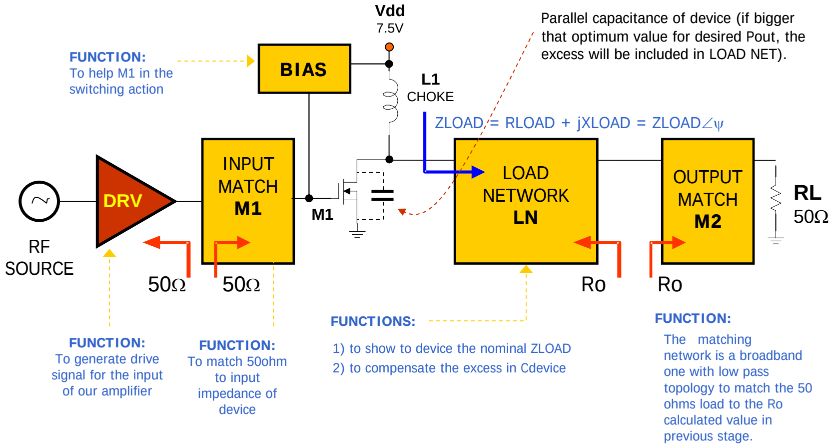
$ZLOAD(fx, Cx) = 4.321 + 4.971j\,\Omega$

$|ZLOAD(fx, Cx)| = 6.587\,\Omega$

The design: output network simulation



The design: block diagram



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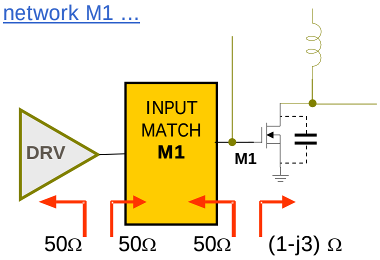
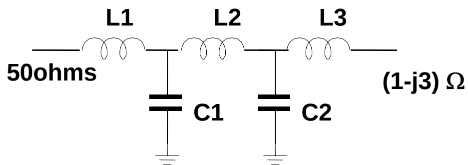
The design: matching driver

About the input matching network M1 ...



- ZIN = 1Ω -j3Ω @ 430MHz [123pF]
- Broadband
- Lowpass response.
- Maximum saturated gain in PA

Topology ...



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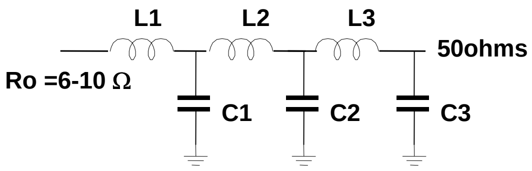
The design: output matching

Simple (low parts count) and ladder L topology for broadband.

Theoretical design ...



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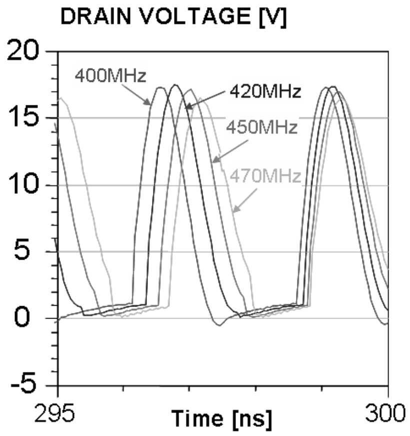
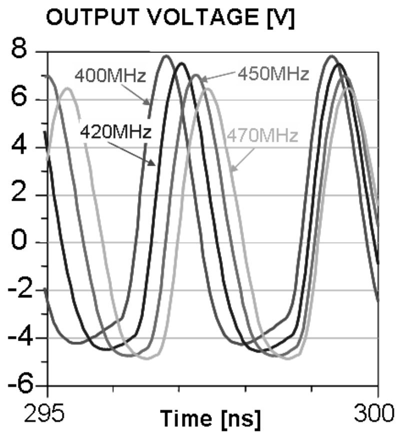
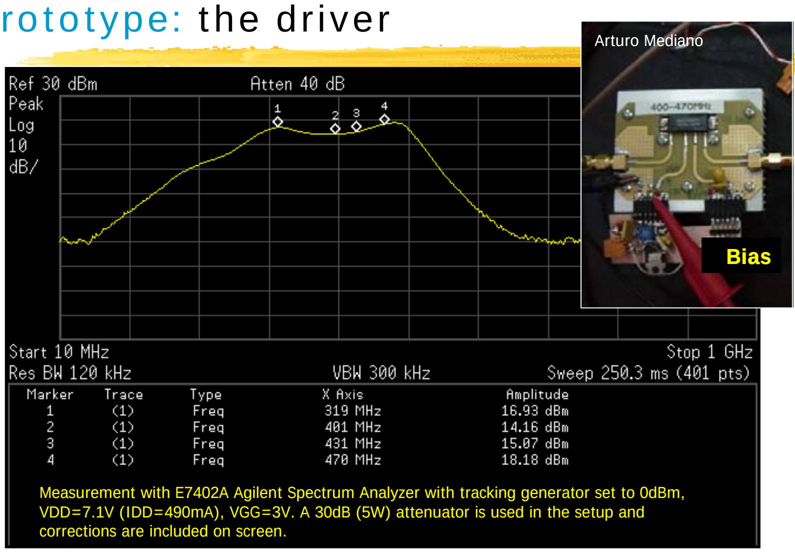
The design: simulation (time domain)





Prototype: the driver



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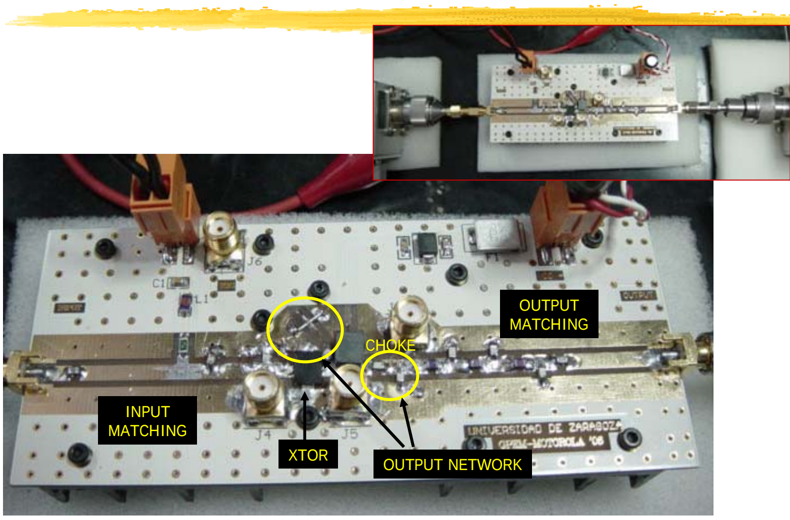
Prototype: the class E PCB



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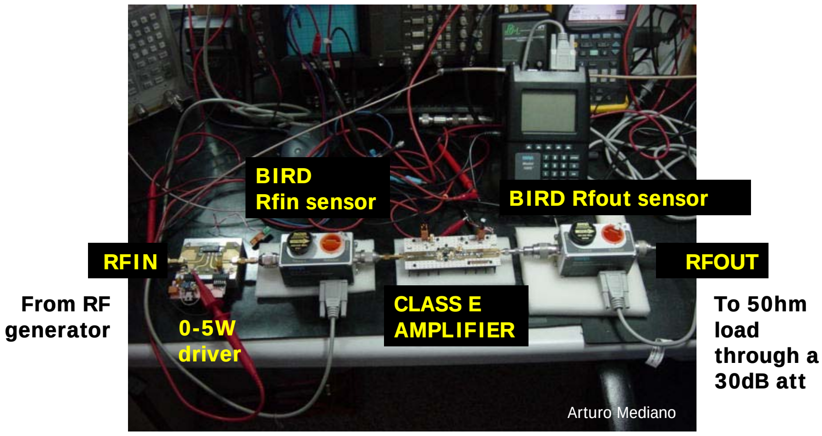
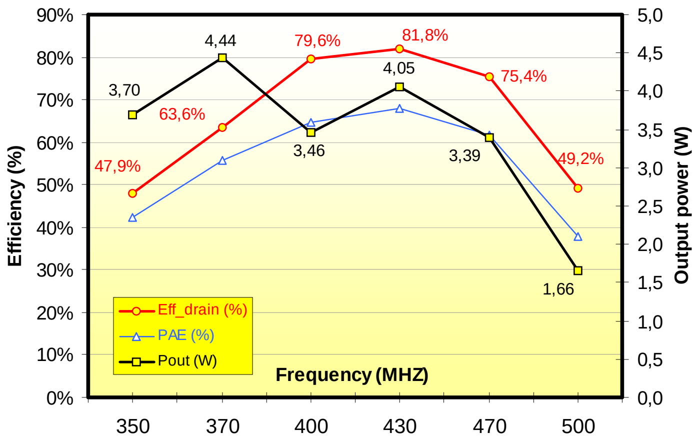
Prototype: characterization setup



Prototype: measurements



Conclusions

- **Analytical expresions** for a class E design with a **C-LC output network** for broadband, with choke in drain and excess in device output capacitance compensation-absortion were shown.
- An UHF amplifier was **designed**, **simulated and optimized** with real world components and prototype parasitics with good results.
- A big transistor with excess in Cout was used for the design.
- **A prototype has been built** to work in broadband.
- Main problems were found in the model of transistor as a switch and the output inductance of device.
- This exploration has lead to the conclusion that the C-LC series output branch in the Class E amplifier is an attractive solution for radios where operation over a large number of channels for a long period and from a small size battery is typical.

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Thanks for your attention...

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