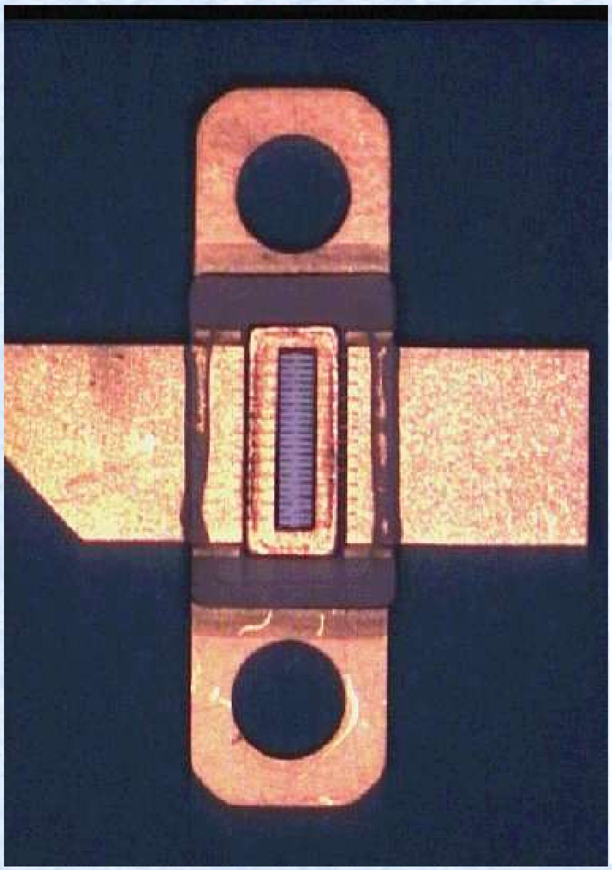
The Bodger's Guide to Solid State QRO

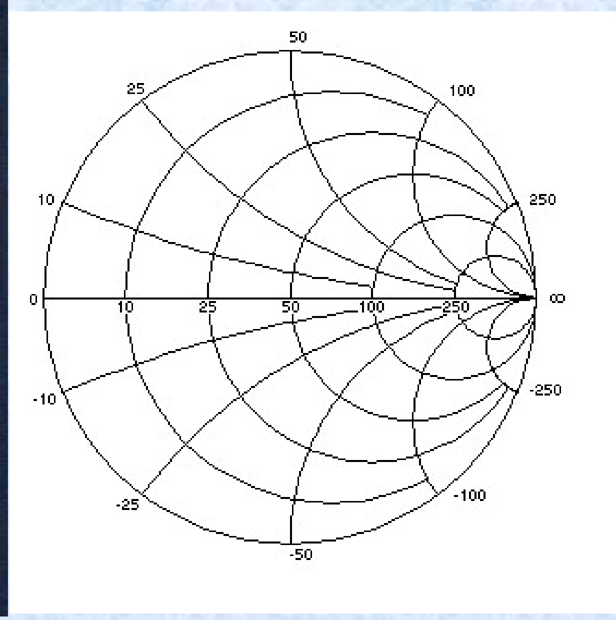
or

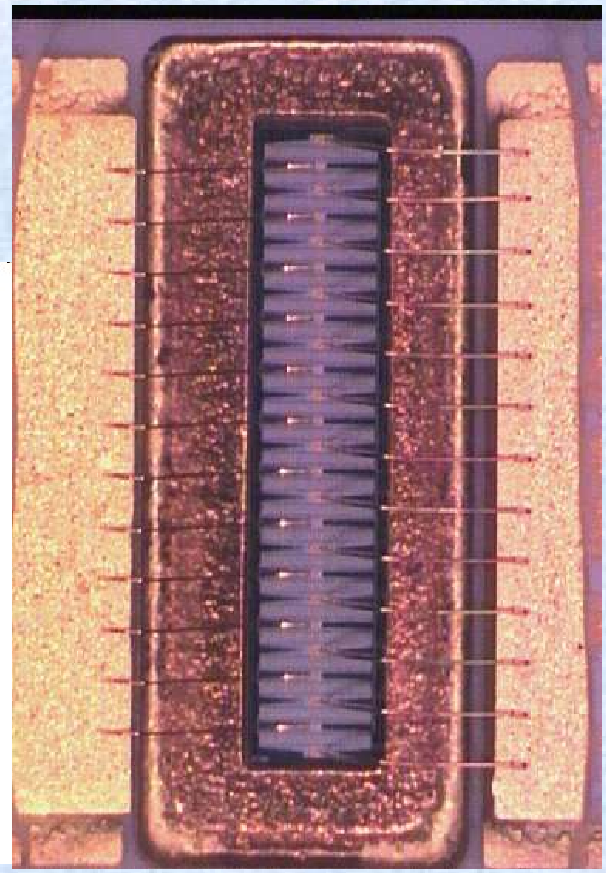
How to get serious power without potential electrocution!

John Worsnop G4BAO



Laterally Diffused Metal
Oxide Semiconductor



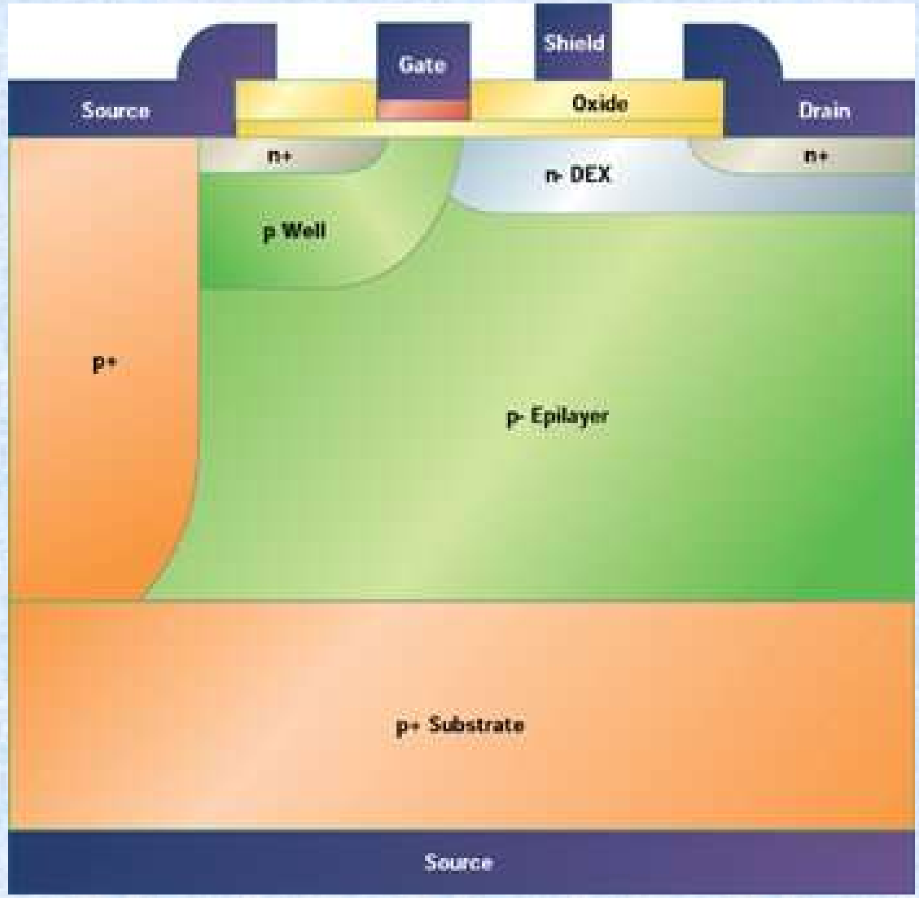


- Bodger – (noun)
  - A highly skilled itinerant wood-turner, who worked in the beech woods on the chalk hills of the Chilterns, in England

- Bodging (Br. Slang)
  - an inexpertly or roughly done job, typically in the field of DIY.

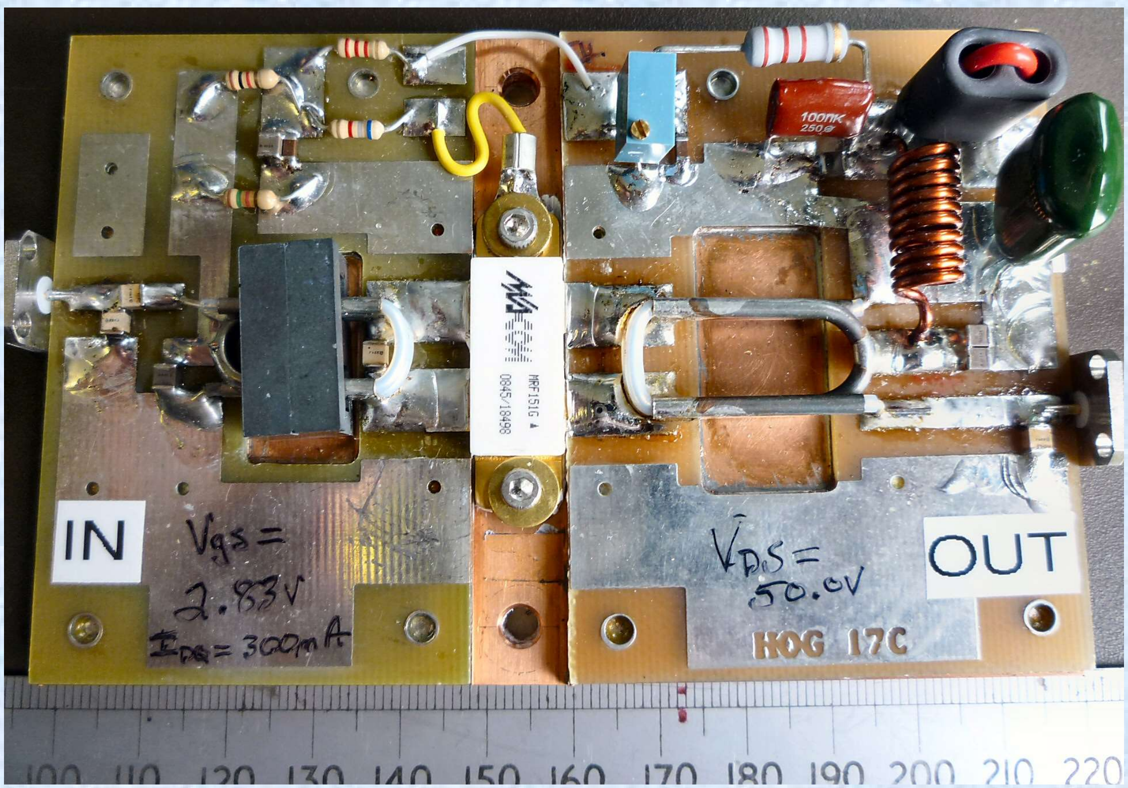
LDMOS for Bodgers

- Modified N-channel MOSFET.
- Three terminals of the transistor are accessible from the top of the chip.
- and source is at the bottom allowing direct connection to ground.
- No nasty beryllium oxide insulator needed.
- matching circuitry can be added within the transistor package.
- Devices that operate up to about 4GHz
- Vdd typically 28 or 50V.
- 150 Watt plus devices at 2GHz
- 1kW plus devices at VHF
- Simple positive gate bias circuitry.
- Hard to destroy in development.



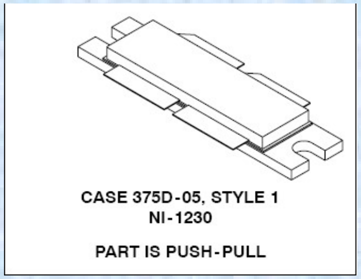
Devices- The previous generation

- The legendary MRF151G "Gemini" device
  - 300Watts out 15dB Gain to 144MHz VSWR 5:1
    - Some surplus amplifiers available



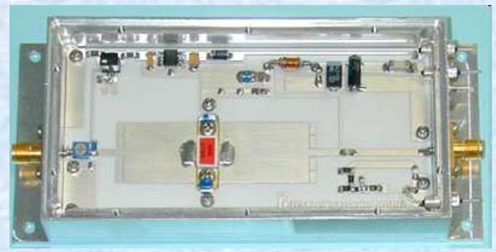
Devices- What's state of the art now?

- Freescale
  - Single ended
    - MRF6V2300 – 300 Watts 24dB gain 10-600MHz - $83
    - MRF7S35120HSR3 - 3.4GHz 120W Pulsed -$250
  - "Gemini"
    - MRFE6VP6k125 1.8-600MHz; 1250 watt
    - MRF6VP121KH? - 965-1215 MHz, 1kW (23cms?)

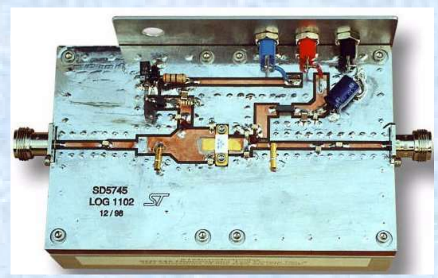


Amplifier Choices for Amateurs

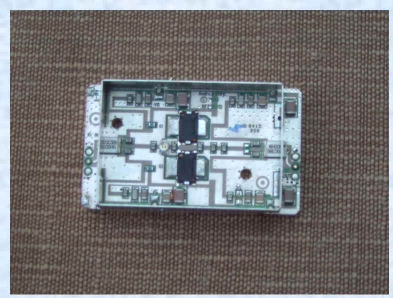
- **Buy one (£££)!**
  - » **image © DB6NT**



- **"Grow your own"**
  - » **Various kits available**

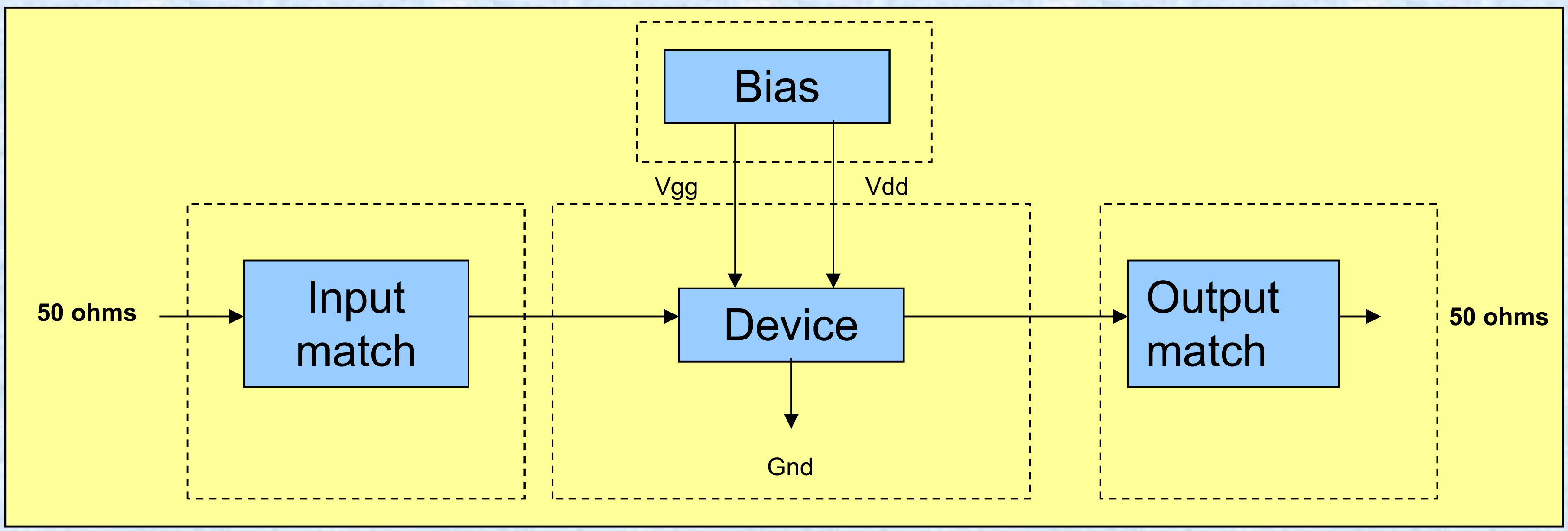


- **Modify surplus**
  - » **The Bodger's choice**



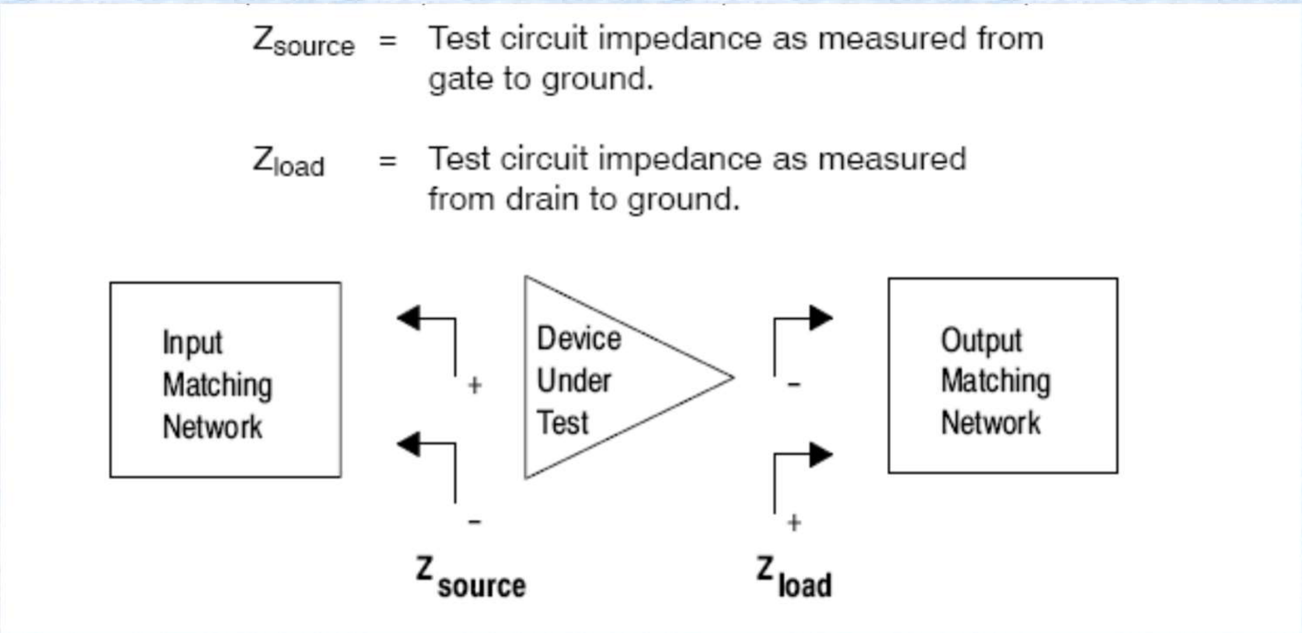
It's the impedances, stupid!

- Power transistors are low impedance devices.
- Typically less than 5ohm, resistive and reactive
- You have to match them to 50ohms
- Matching circuits have a bandwidth



It's the impedances, stupid!

- So the (Bodger's) design process is:
  - Make the device input look like 50 ohms by transforming its input impedance over the required bandwidth.
  - Make sure the device "sees" the correct impedance load for the power level
  - Make sure the impedance matching doesn't make the amplifier unstable at other frequencies.



So we need the device datasheets, right?

- **WRONG!**
  - Fine if data is available for the frequency you need
- Much LDMOS is designed for cellular or broadcast
- 88-108MHz, 225MHz, 890 -1215 MHz

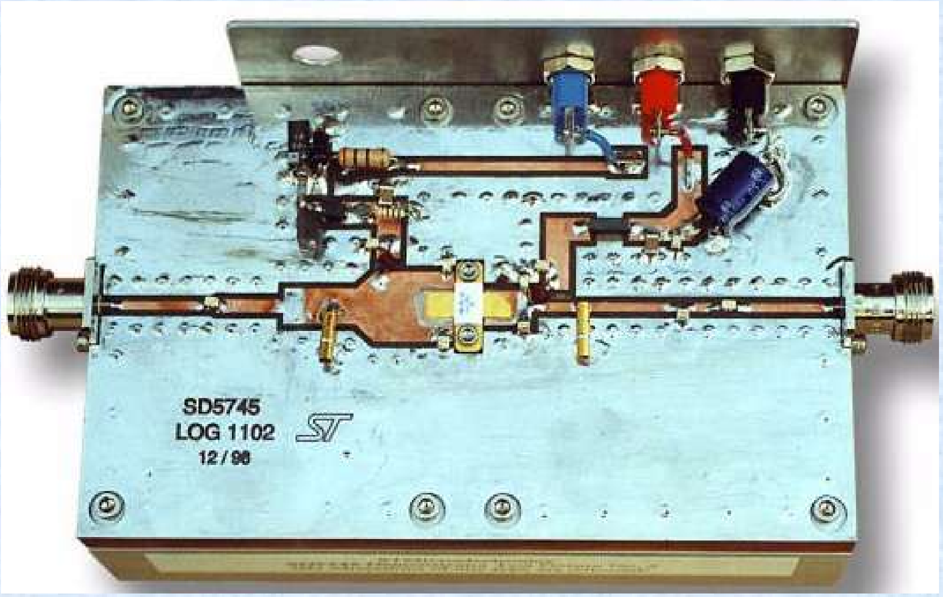
So we're stuck?

- Amateurs don't have the technology to measure device impedances.
- So let's call upon………………….

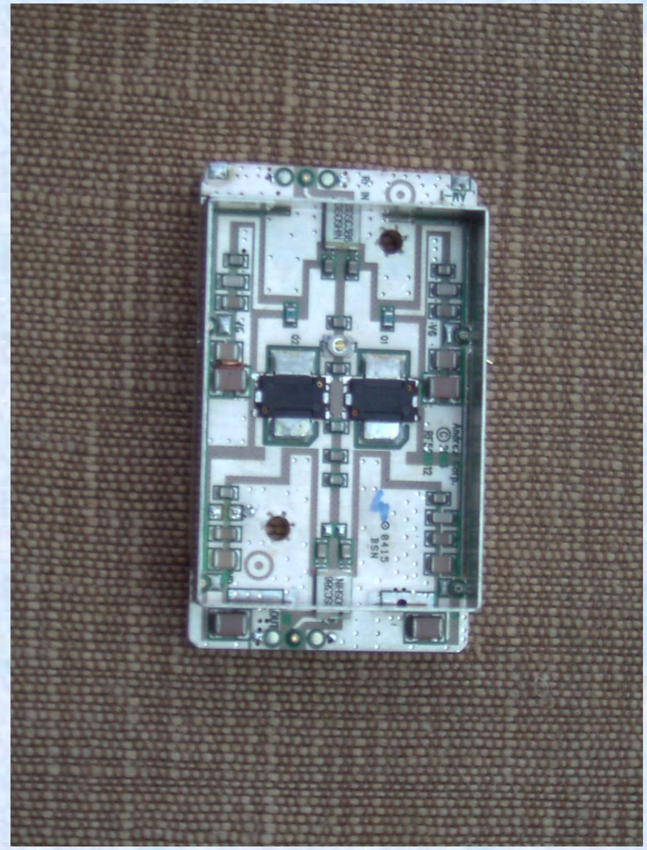
The Bodger's subroutine!

Applicable to a "new" design or retuning surplus

```
make intelligent stab at what
   you think might work
then
 repeat
        cut
        try
        optimise
 until working satisfactorily
end
```



The LDMOS Bodger's toolkit



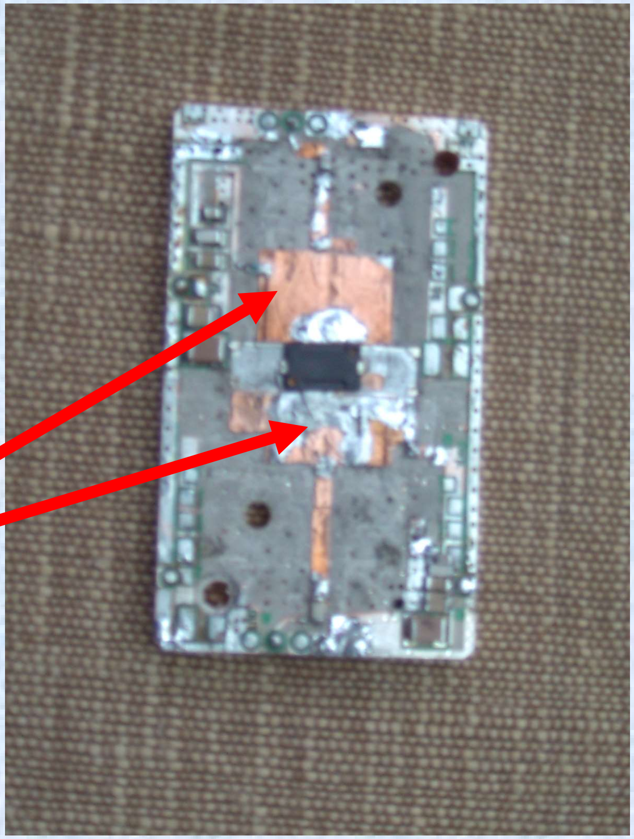
- Along with a soldering iron, the basic tools are:

- pair of cheap vernier callipers
- a roll of adhesive copper tape
- a sharp scalpel
- a roll of plastic insulation tape
- a Smith Chart program
- "Appcad" program
- QUCS: Quite Universal Circuit Simulator

and of course, something to bodge

Something to Bodge for 23cms

- 900MHz Cellular base station amplifiers
- Look at the device datasheet.
  - Avoid devices that are internally matched.
  - Really high power ones tend to be.
- Using the Bodger’s subroutine, either:
  - strip off all matching and try again from scratch using sticky copper foil.
    - Use a “T” step from very wide down to typically 7 -9 ohm line on input.
    - 5-7 ohm line on output, and trim length starting at 0.25λ
- or
  - Use existing lines and try to move input match then Pout up in freq in stages by changing capacitor values.



Reverse Engineer the existing input circuit

- Determine the board thickness and material
  - Find a 50ohm line and measure its width (say 1.8mm)
  - Use Appcad to work out εr
- Measure Ls, Cs and microstrip lines
  - Scale line lengths by 1296/900
- Plot on your Smith Chart
  - Assume that Zin increases from 900-1296 and see which way the final match goes
- Iterative process
  - Change a C based on above see if amp matches better at 1296.

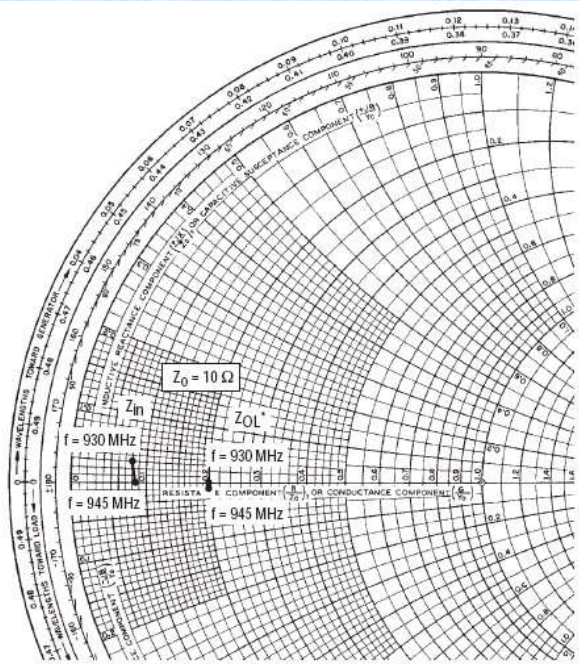
Reverse Engineer the existing input circuit

Example 1.7+j1 at 900MHz from datasheet

- Matched with 0.131λ 12Ω, series, 10pF shunt, 10pF series

- 0.131λ = 0.188λ at 1296
- Assume Zin changes to 3+j3 and see what C will have to do to rematch

Freescale MRF9045



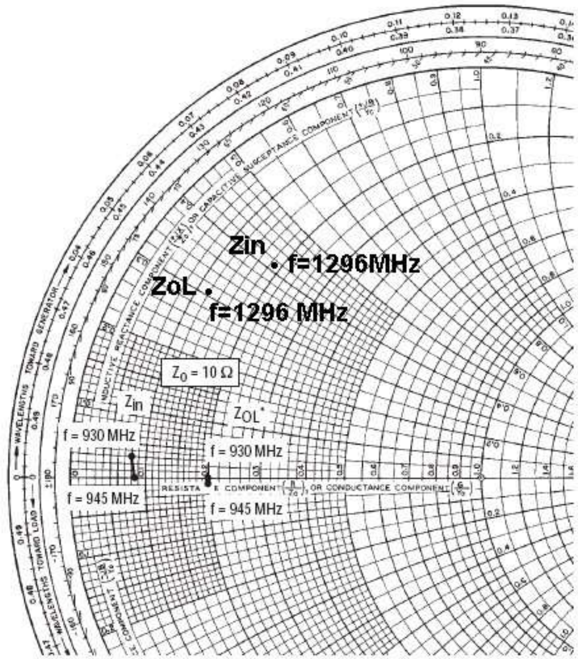
V_{DD} = 28 V, I_{DQ} = 350 mA, P_{out} = 45 W (PEP)

f MHz	Z_{in} Ω	Z_{OL}* Ω
930	0.81 + j0.25	2.03 – j0.09
945	0.85 + j0.05	2.03 – j0.28

Z_{in} = Complex conjugate of source impedance.

Z_{OL}* = Complex conjugate of the optimum load impedance at a given output power, voltage, IMD, bias current and frequency.

Freescale MRF9045 1296MHz



“measured” impedances

V_{DD} = 28 V, I_{DQ} = 350 mA, P_{out} = 45 W (PEP)

f MHz	Zin Ω	ZoL* Ω
1296	1.9+j4.1	1.2+j3.1

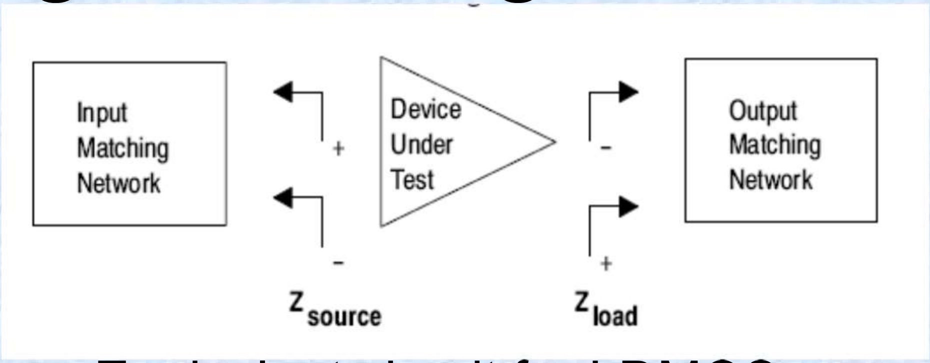
Z_{in} = Complex conjugate of source impedance.

Z_{OL}* = Complex conjugate of the optimum load impedance at a given output power, voltage, IMD, bias current and frequency.

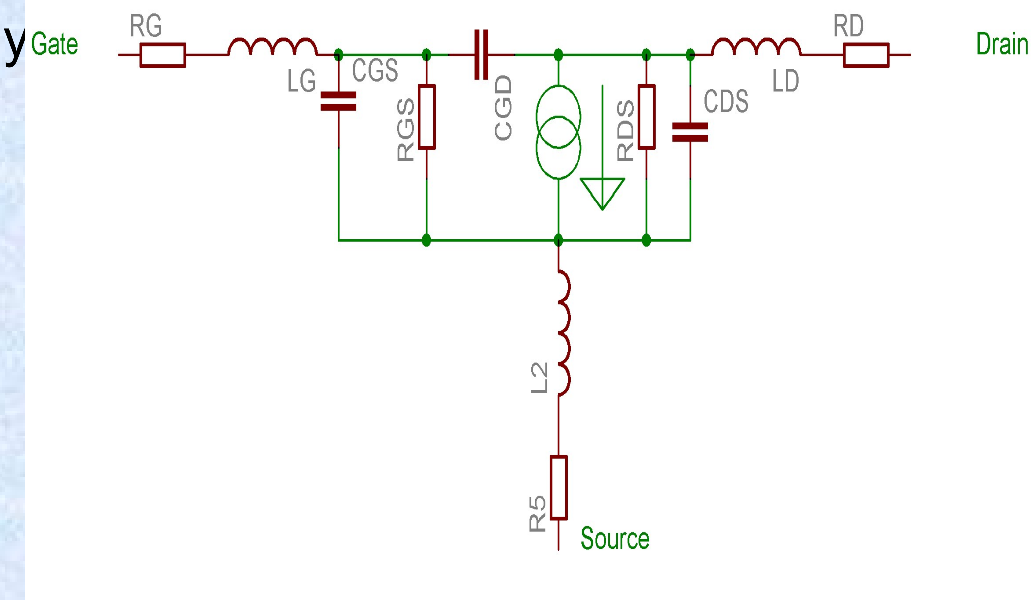
Output matching for Bodgers

- Drain voltage swings from Vdd to Vdd_{on}
- This is approximately 0 to Vdd
- If we assume the waveform is sinusoidal

- Output power is approximately
- $P_{out} = Vdd^2/2R_{Load}$

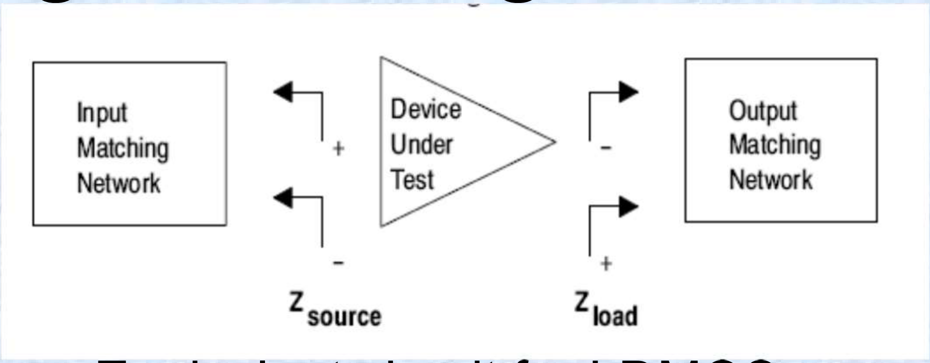


Equivalent circuit for LDMOS

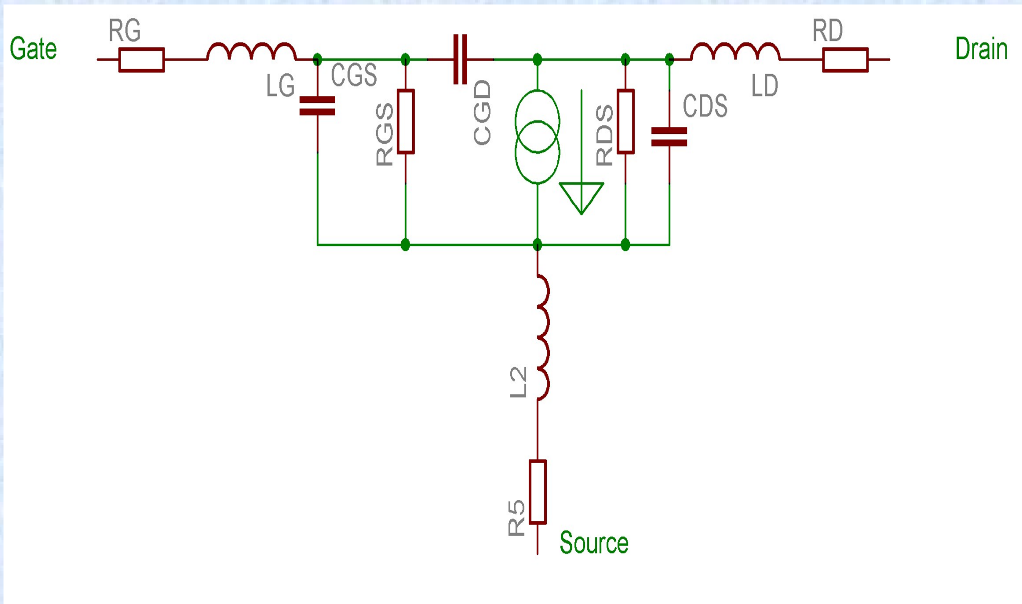


Output matching for Bodgers

- So to deliver the power, the device needs to "see"
- $R_{Load} = Vdd^2/2P_{out}$
- We have C_{DS} in parallel with the device
- So our network must resonate this out as well (conjugate matching)



Equivalent circuit for LDMOS



Output matching for Bodgers

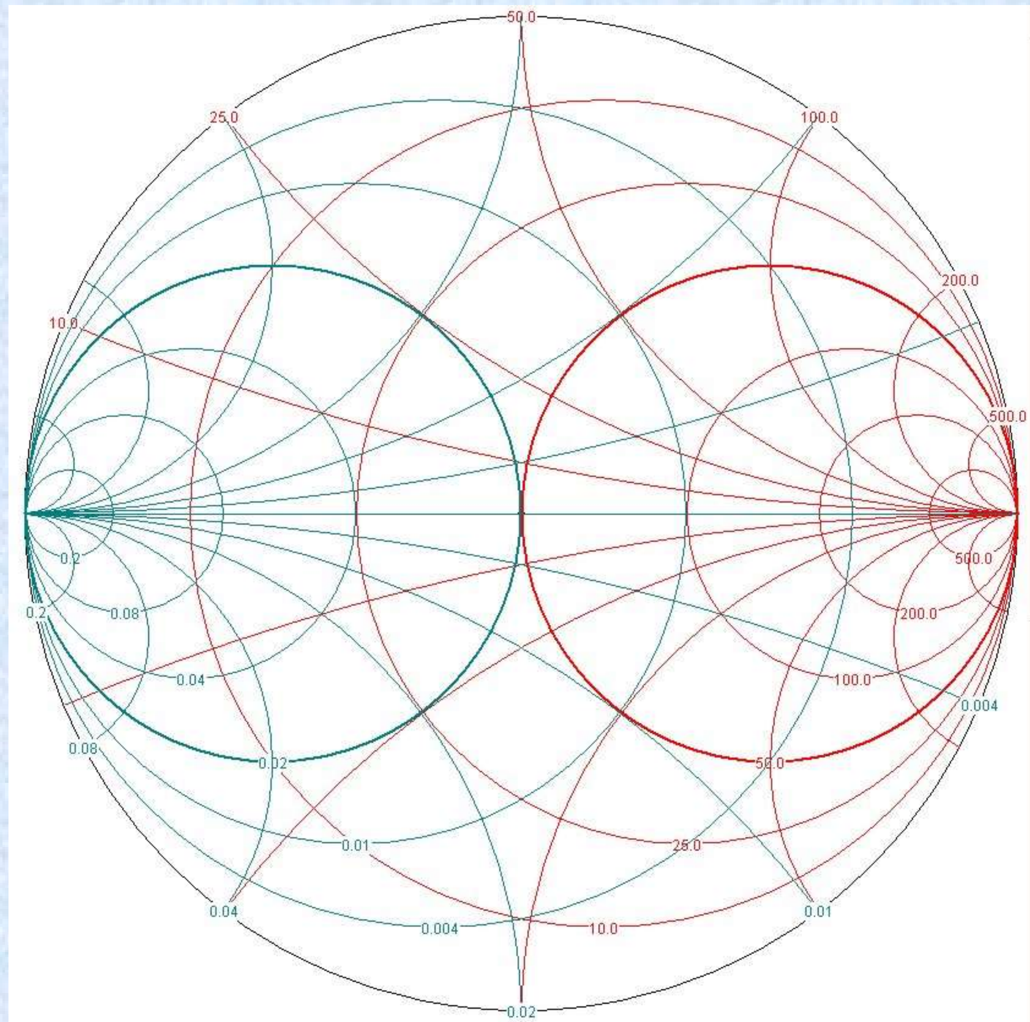
- So we have our output network requirements!
- $R_{Load} = Vdd^2/2P_{out}$
- in parallel with conjugate of C_{DS}
- But I prefer series circuits because impedances add.
- So
- Convert this to a series R+-jX format using Maths or a Smith Chart.

Example 6VP2300H device at Pout = 300Watts, 50 Volts

- This gives R_{Load} = 4.16 ohms in parallel with C_{DS} = 120pF
- Convert this to a series combination and conjugate it.
  - Z_L= 3.2 +j1.76 ohms
- Compare this to the datasheet value of 2.7 +j2.2 ohms
- Close enough?
- Time to get out the Smith Chart

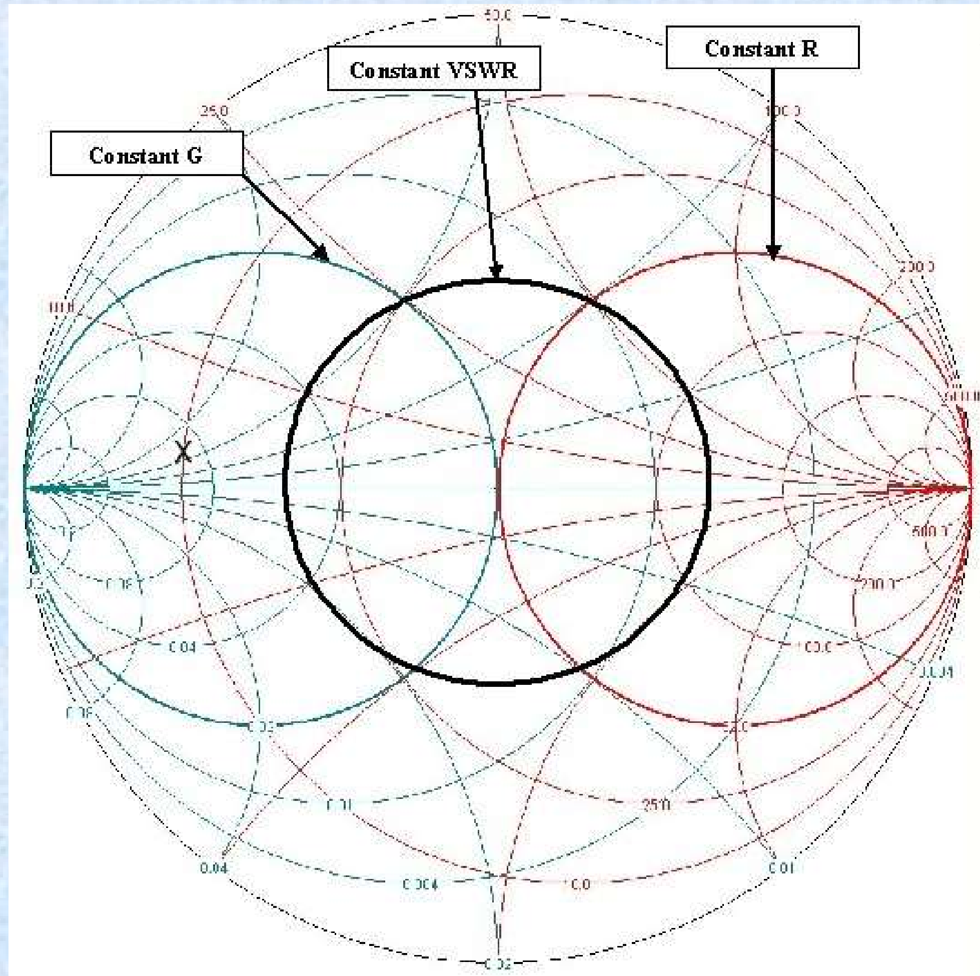
A brief aside on the Smith Chart

- **"Immittance" Chart**
- A whole day could be given over to its usage
- It allows you to plot complex impedances, admittances and line lengths.



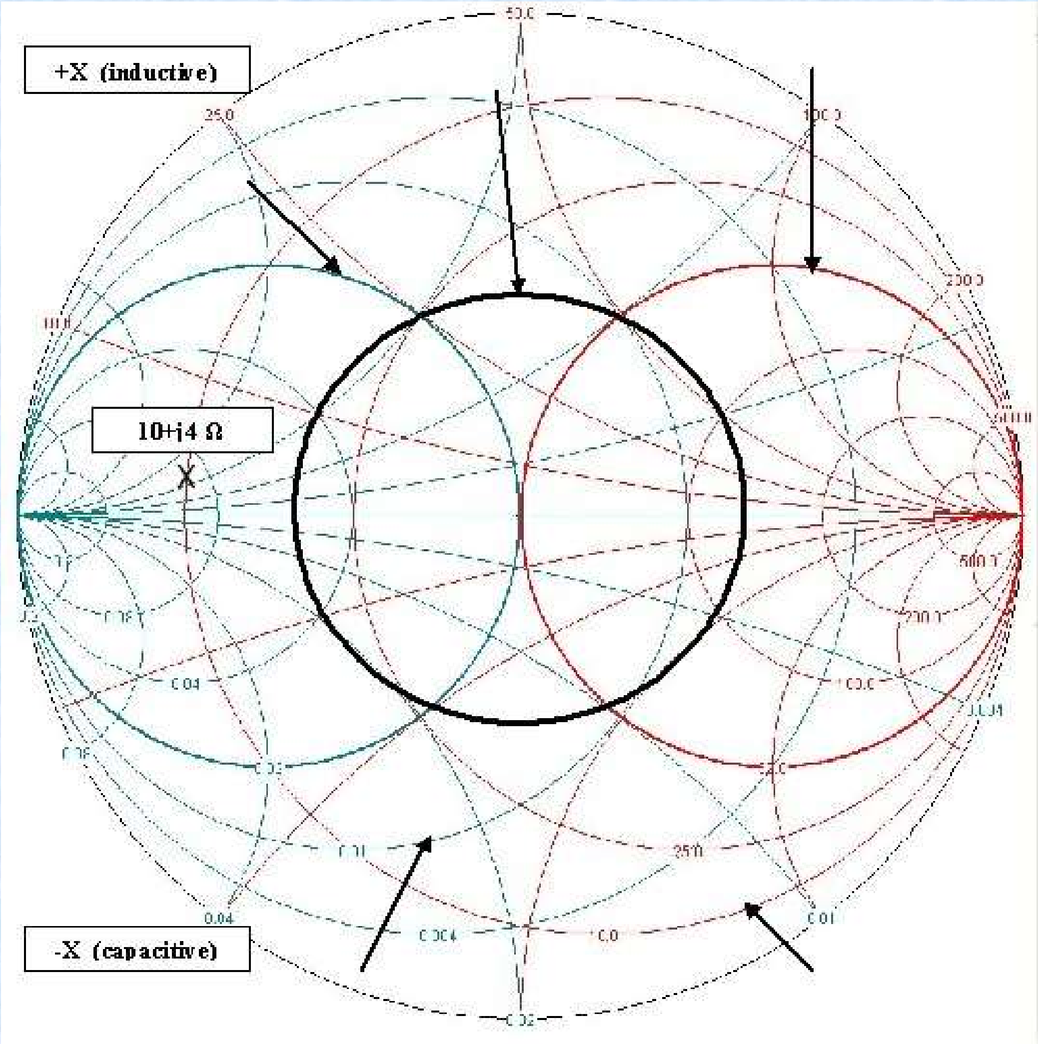
A brief aside on the Smith Chart

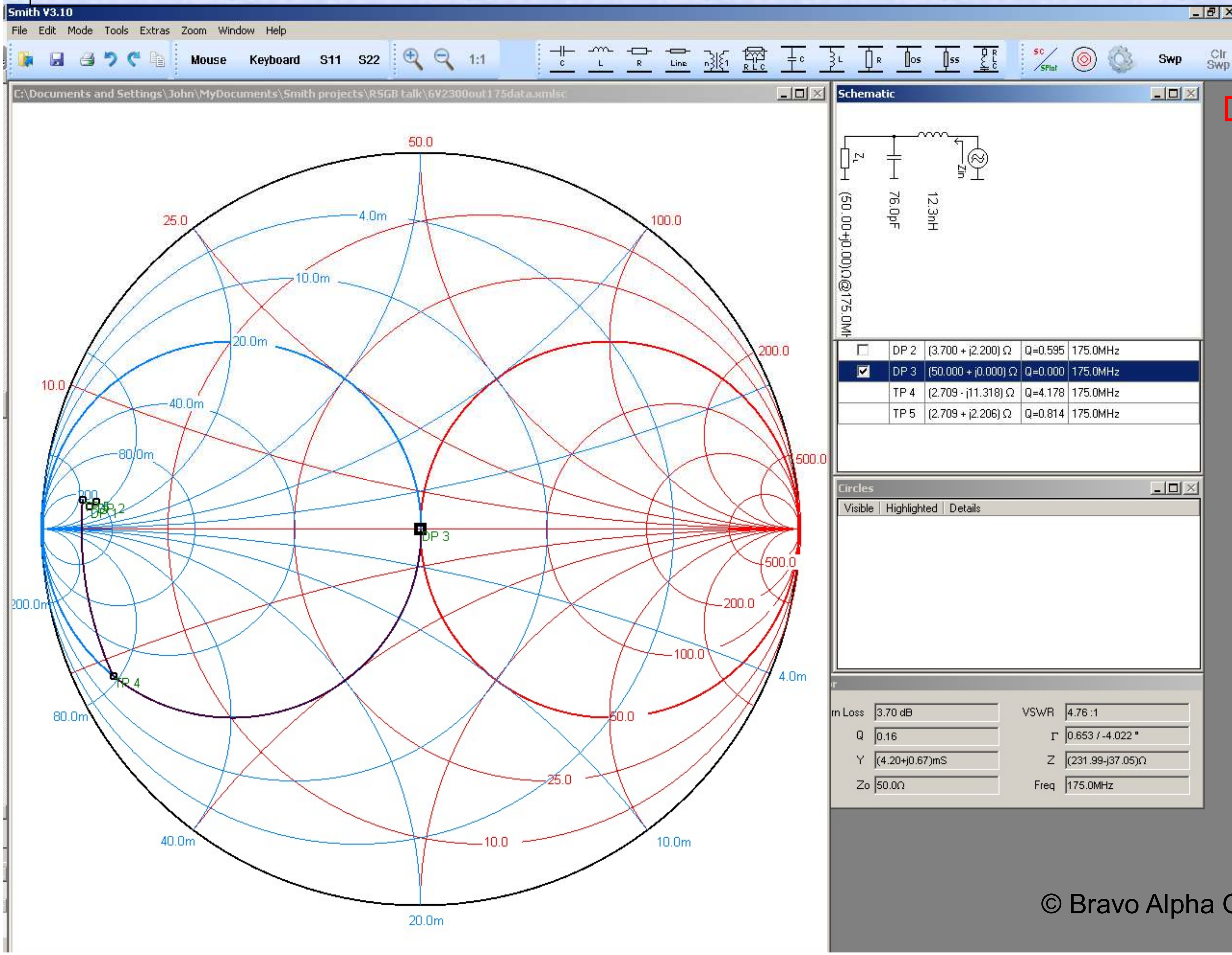
- Series L or C moves you along constant R circle
- Shunt C or L moves you along constant G circle.



A brief aside on the Smith Chart

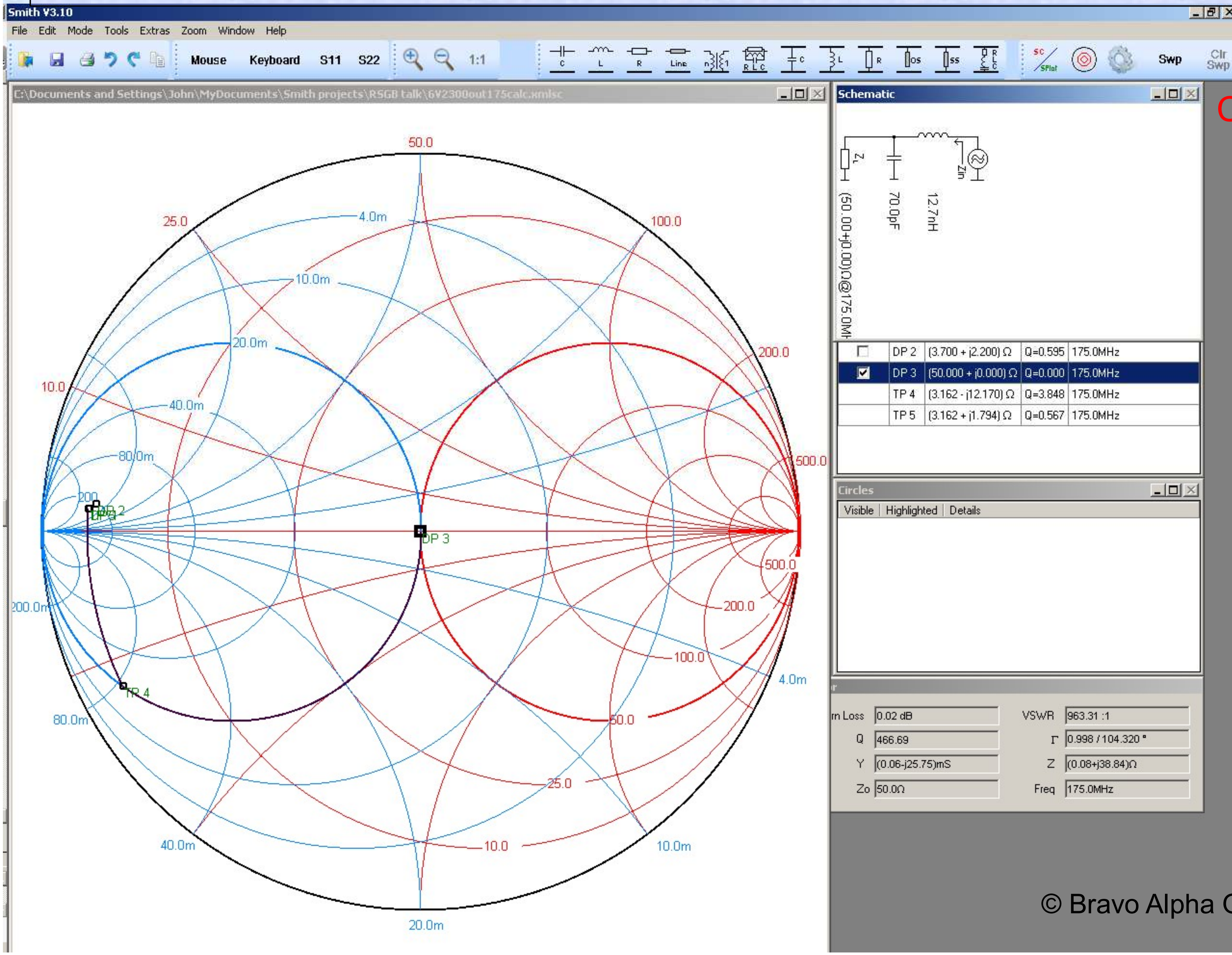
- Usually use "normalised" impedances,
  - i.e (actual Z)/Zo
- Positive reactances (Inductive) are in the upper half of the chart
- Negative reactances (Capacitive) are in the lower half of the chart
- Impedance can be plotted directly





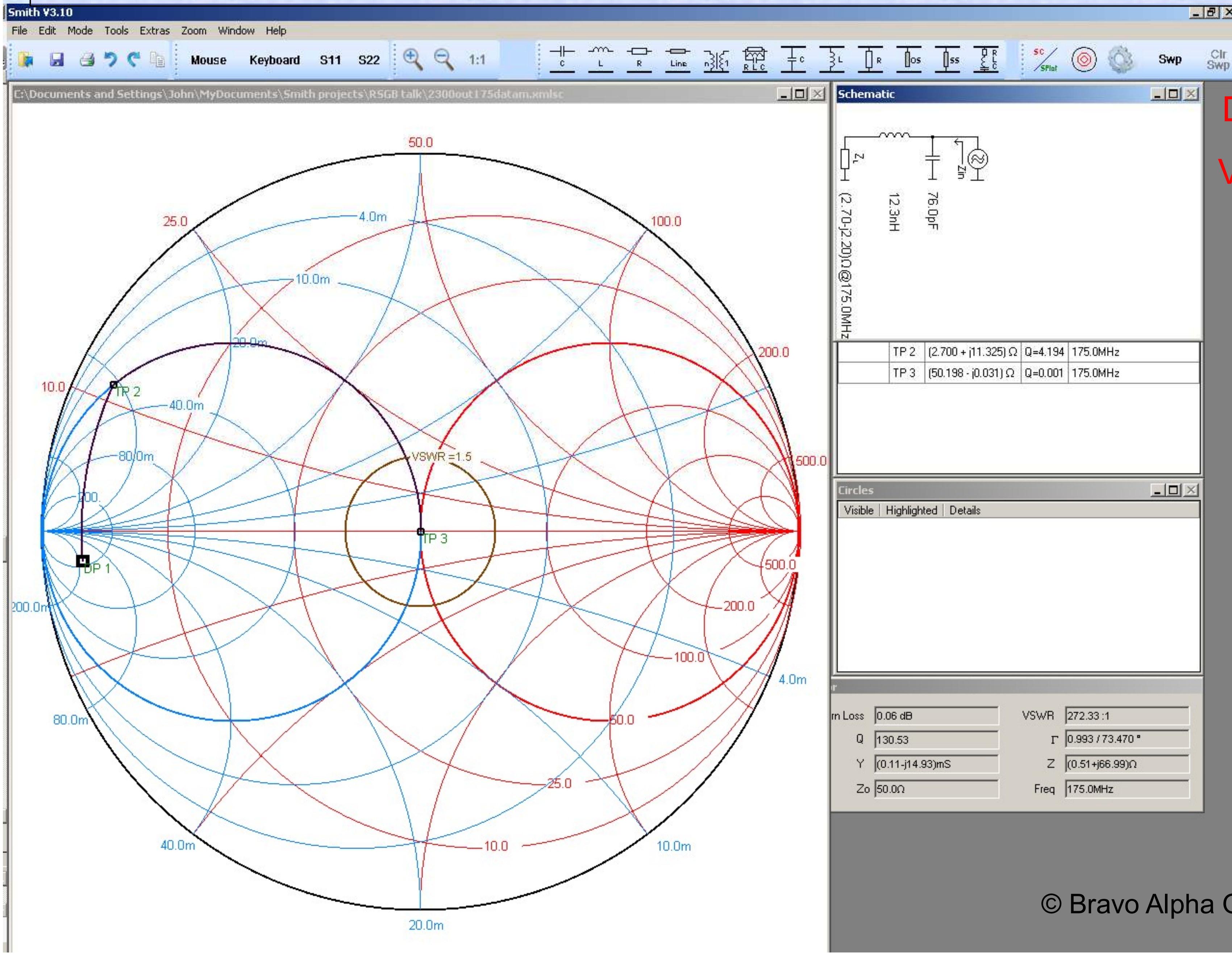
Datasheet

12.3nH
76pF



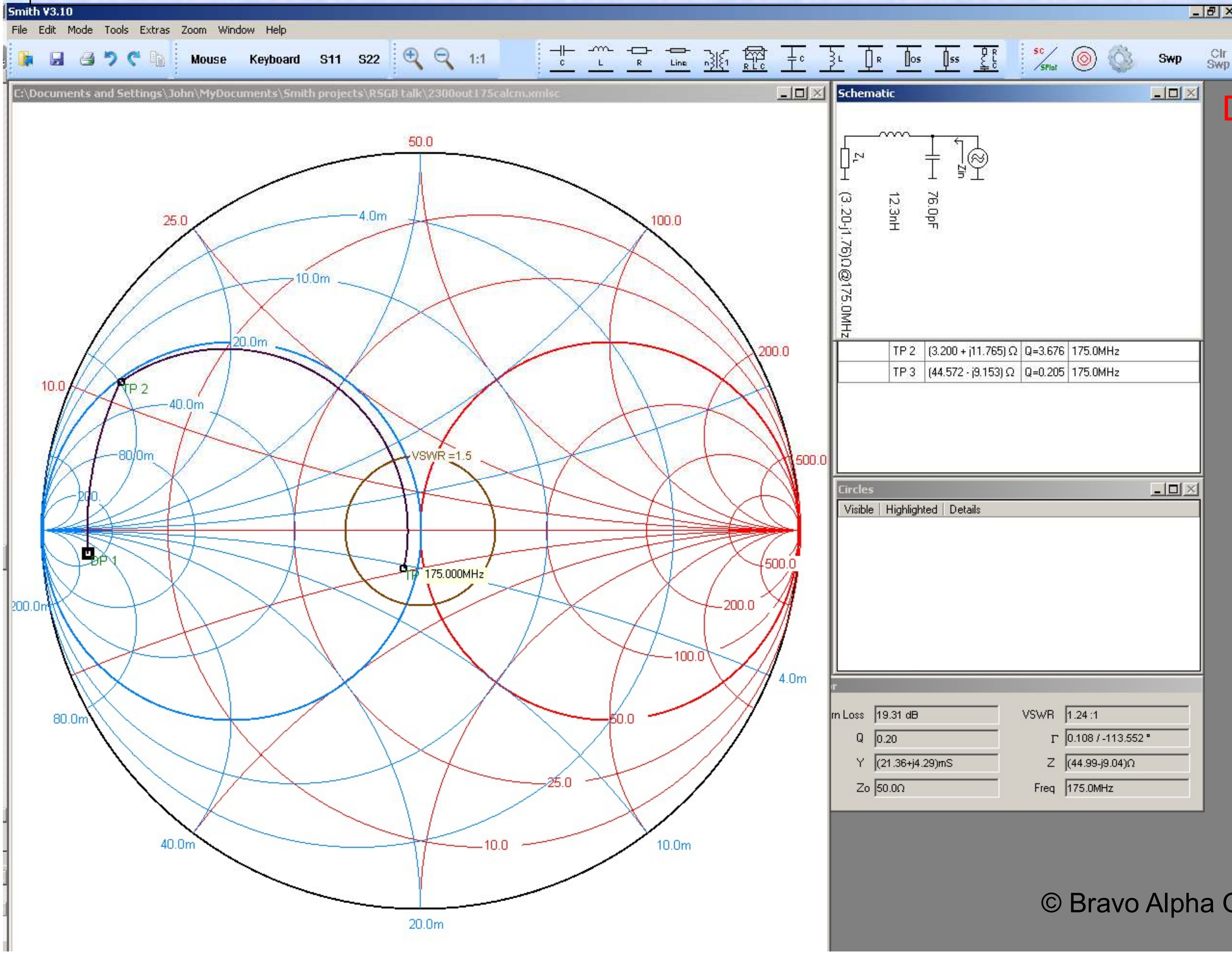
Calculated

12.7nH
70pF



Datasheet

VSWR 1:1

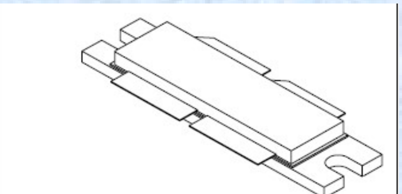


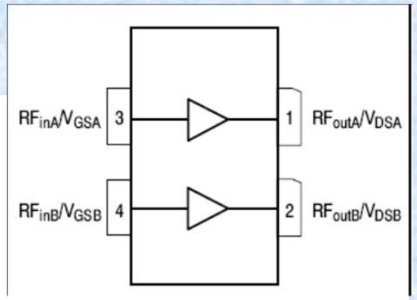
Datasheet

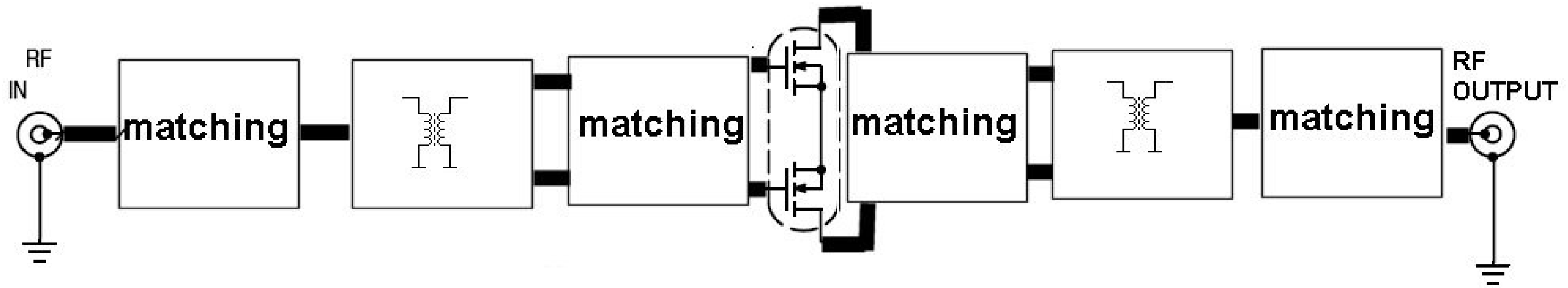
VSWR 1.24:1

Gemini Devices - Transformer matching

- Gemini devices are two devices in one package
- Designed for Push-pull operation
- Transformers allow balun and impedance transformation







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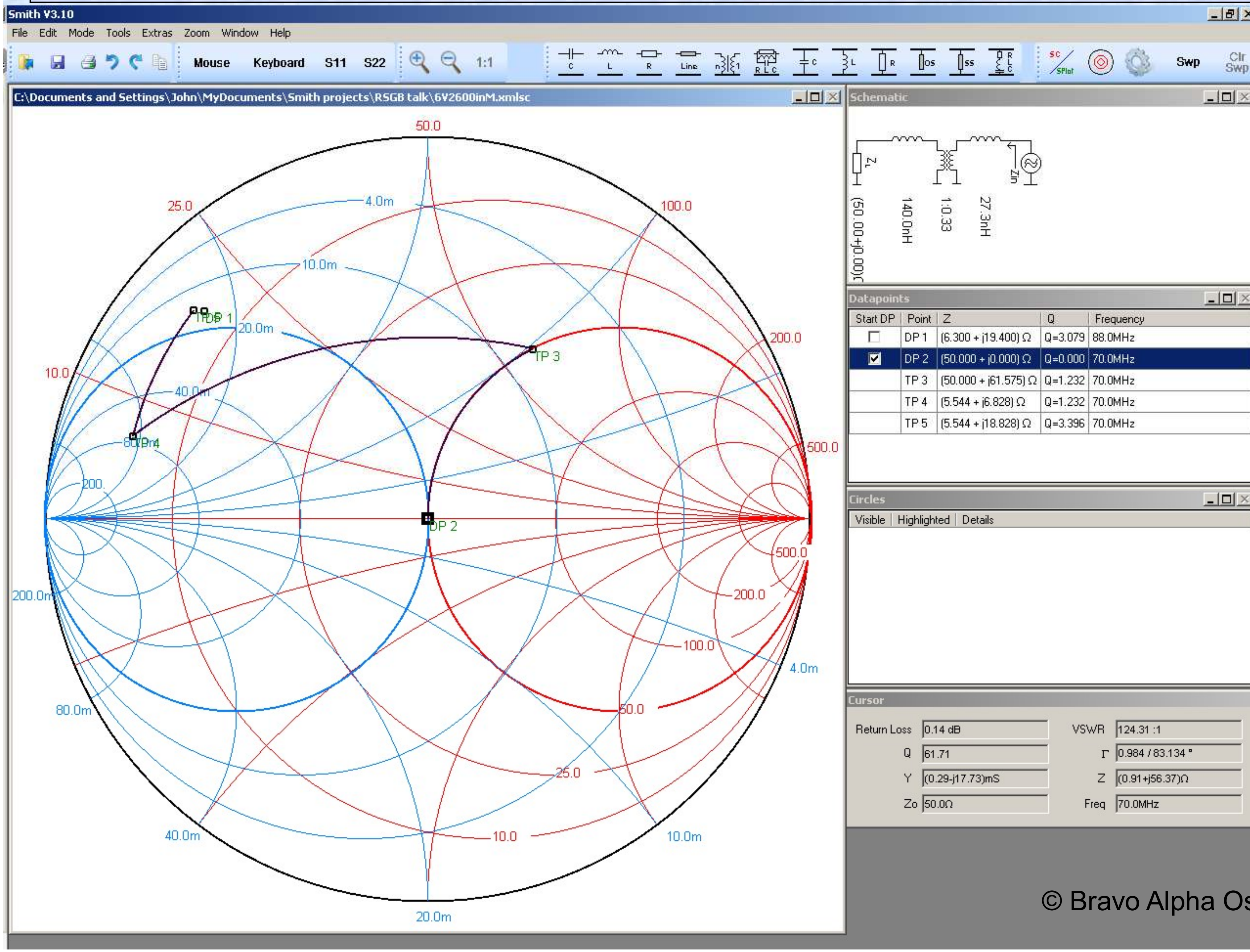
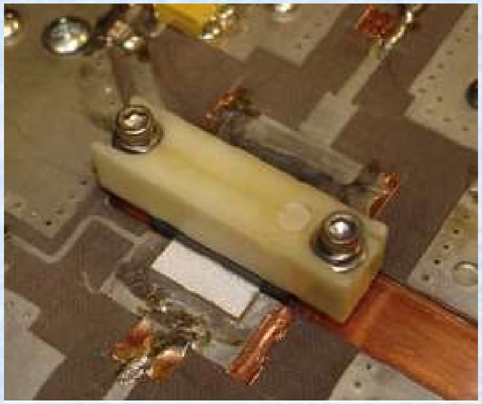


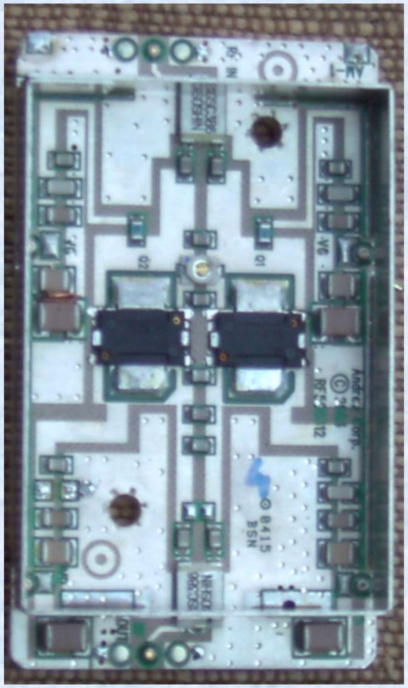
Device mounting -The choices

Bolt

Clamp



Solder



Device mounting - clamping vs bolting

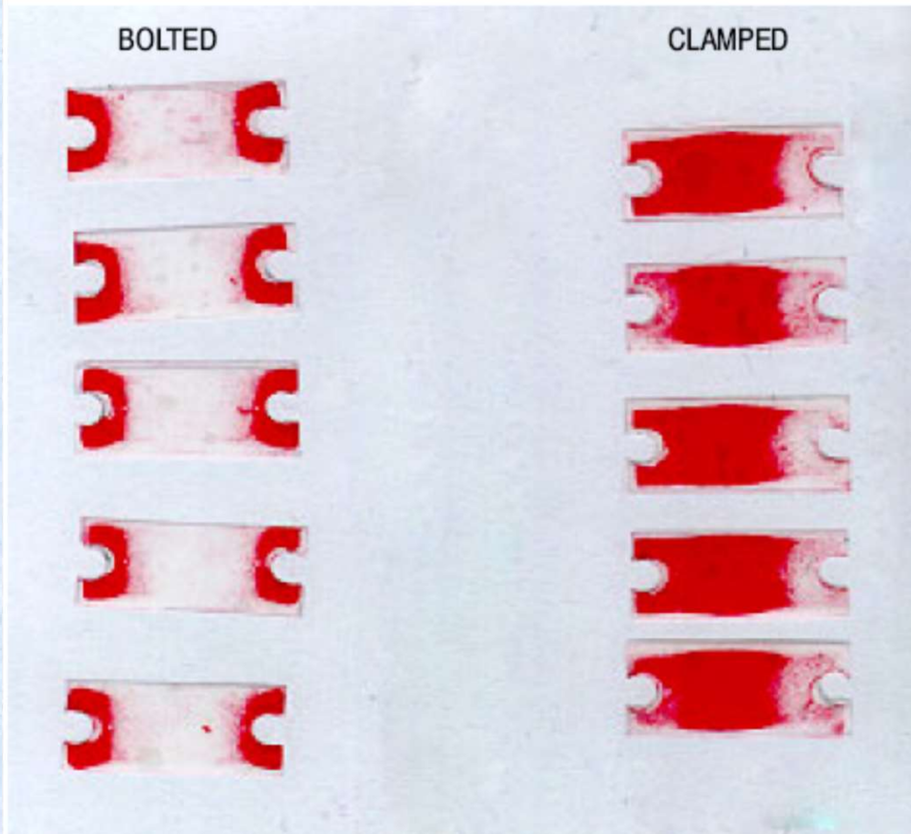
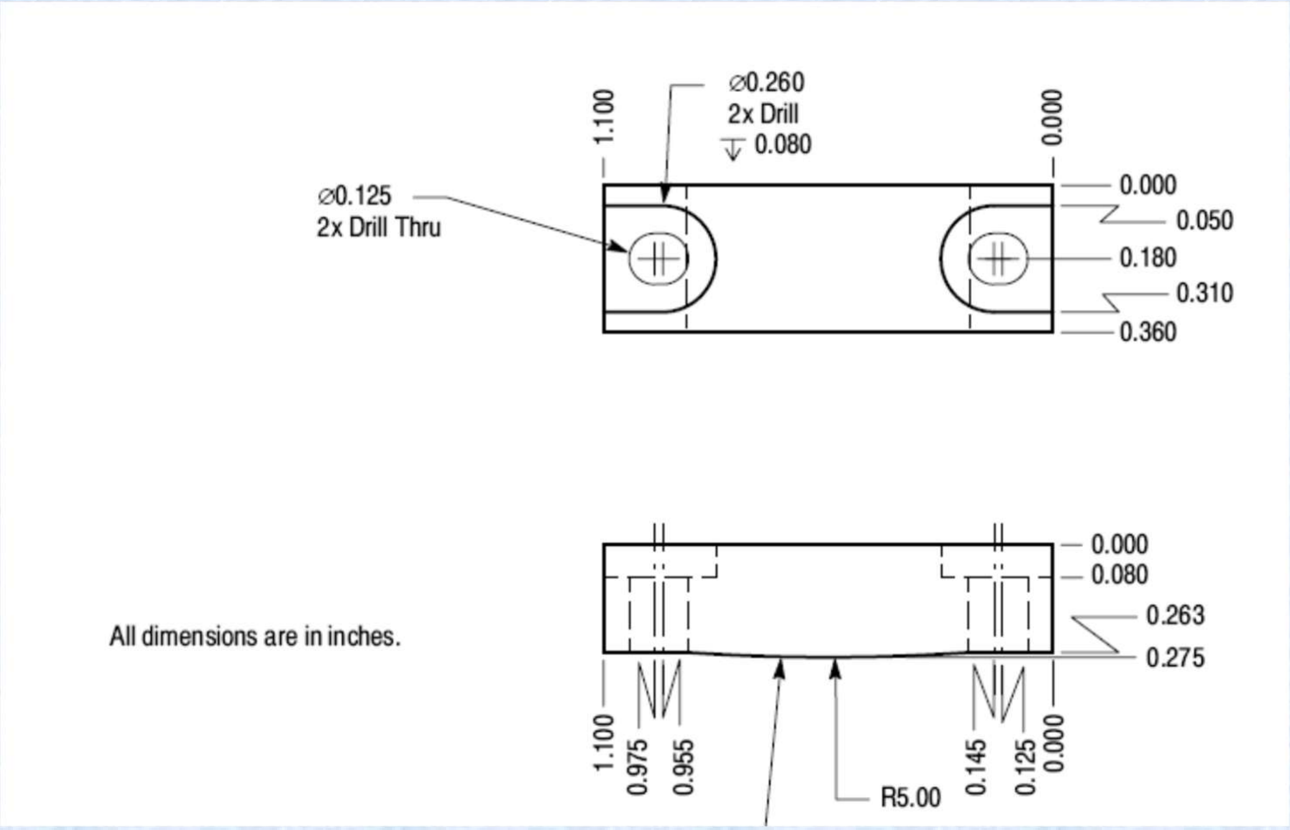


Figure 7. Pressure Paper Test Results for Five TO-272WB Packages with #4-40 Screws at a Mounting Torque of 4.0 in-lb

Source Freescale AN-3789

Device mounting – Typical clamp design

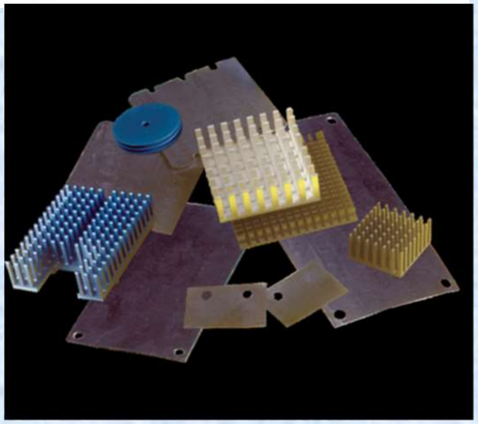


Source Freescale AN-3789

Device mounting – Getting the heat away

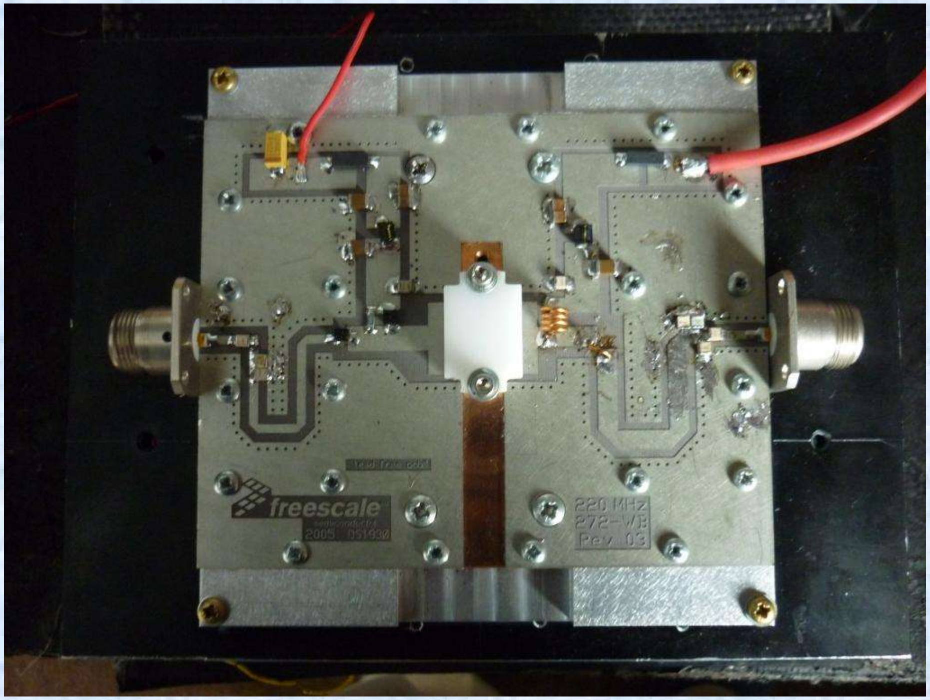
- Use a copper heat spreader!!
- Interface material
  - Nothing when clamping, if the copper heat spreader is flat enough
  - Conductive grease (RS)

  - 0.125mm T-GON805 (graphite sheet)
  - (Mouser)



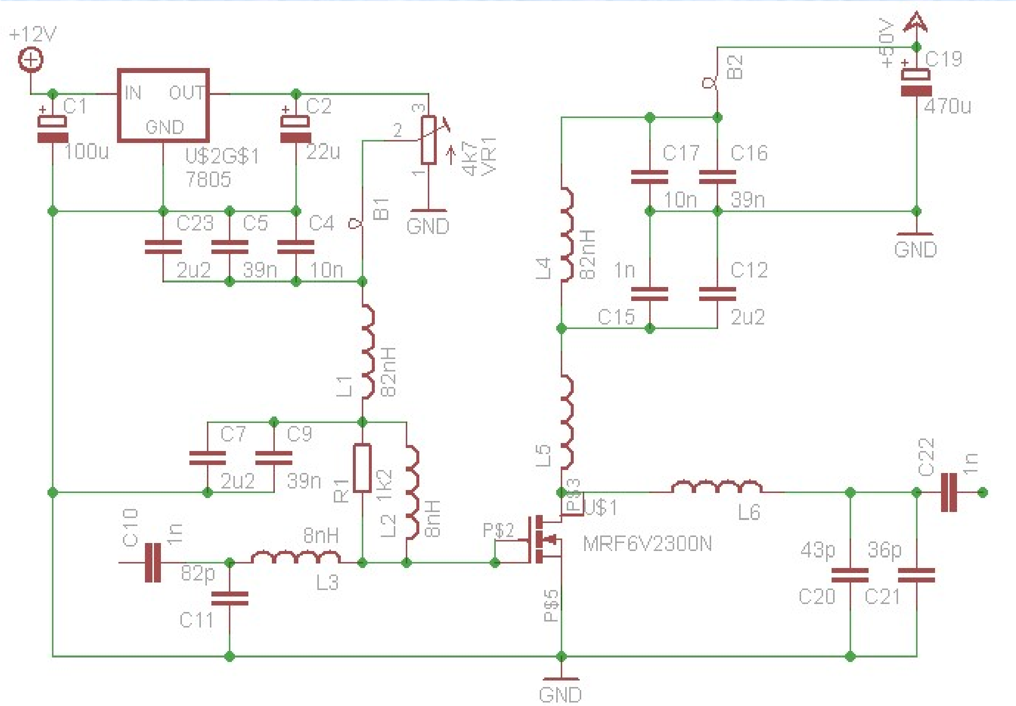
A 144MHz design with the 6V2300

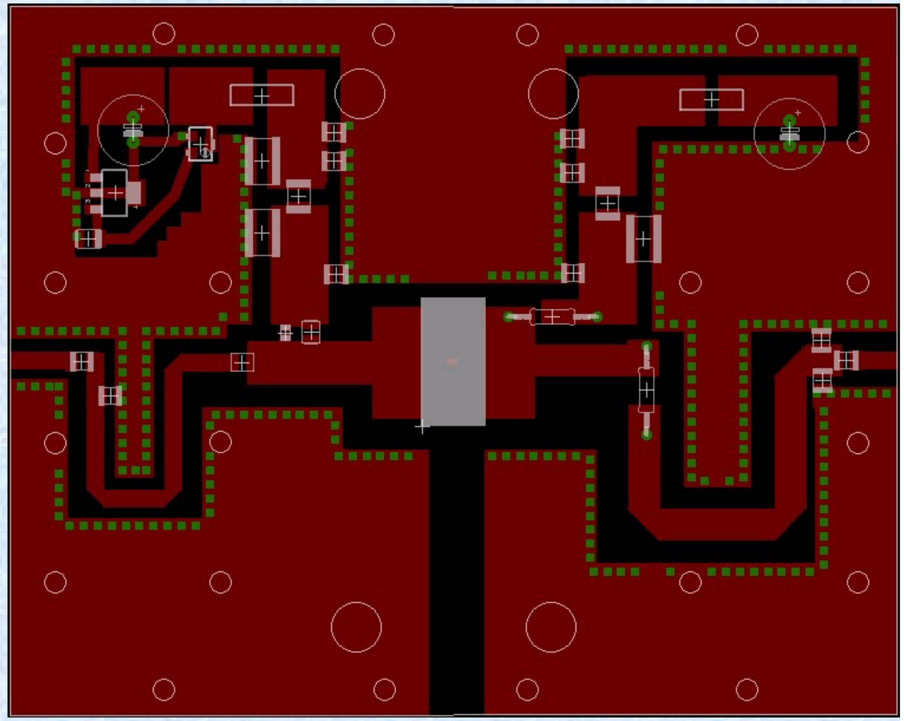
- Measured 270 Watts on 2m for 800mW drive.
- Flangeless device clamped down with PTFE clamp.
- Narrow band matching – but no trimmers.
- Currently on Freescale test board.
- Eagle PC design done with bias regulator.



A 144MHz design with the 6V2300

- Eagle PC design done with bias regulator.





The G4BAO 23cm design with the MRF9045

- RadCom June 2007
- Proven Design
- Low loss Teflon PCB

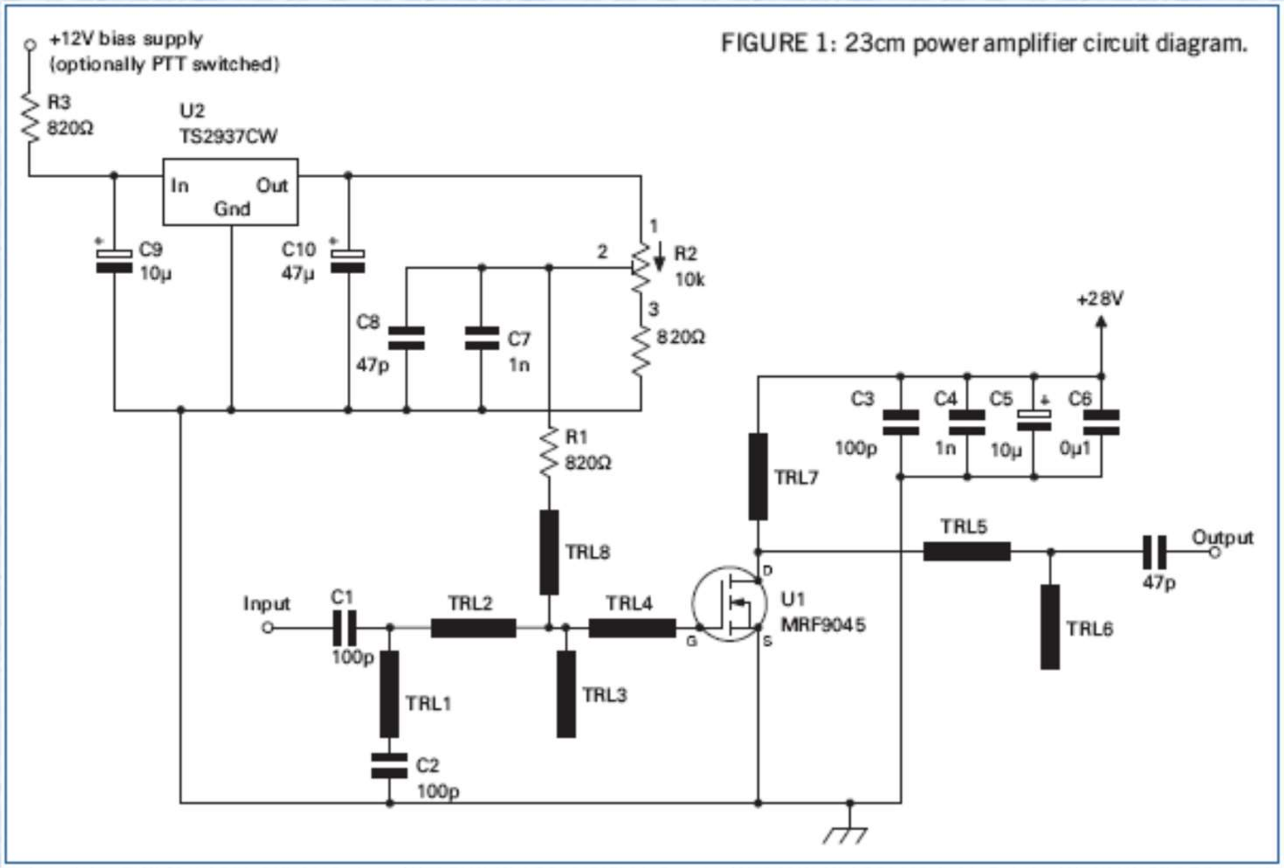


FIGURE 1: 23cm power amplifier circuit diagram.

Do's and don'ts

- Get the heat away quickly!!
- DO Always use a copper heat spreader
- DO try and avoid shunt capacitors (losses)
- DO Watch the output capacitor's rating and type.
  - 100Watts in to 50 ohms means that 1.4 Amperes of RF is flowing.
- DON'T use trimmers except when "bodging".
  - Shunt capacitors have high currents as well
- DON'T put too much gate bias voltage!

Acknowledgements

- F1JRD, GW4DGU, G4HJW, G0MRF for advice and encouragement.
- Freescale Applications Engineering
- LDMOS pictures – ST Microelectronics
- "Smith" program - Prof. Dellsperger HB9APG from the University of Berne
- The writers of QUCS and Appcad