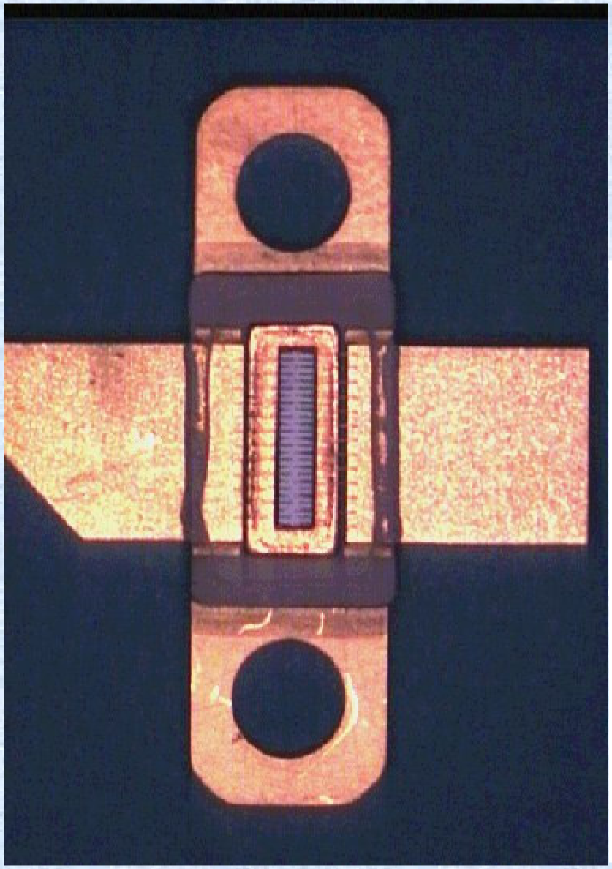
The Bodger's Guide to Solid State QRO at VHF

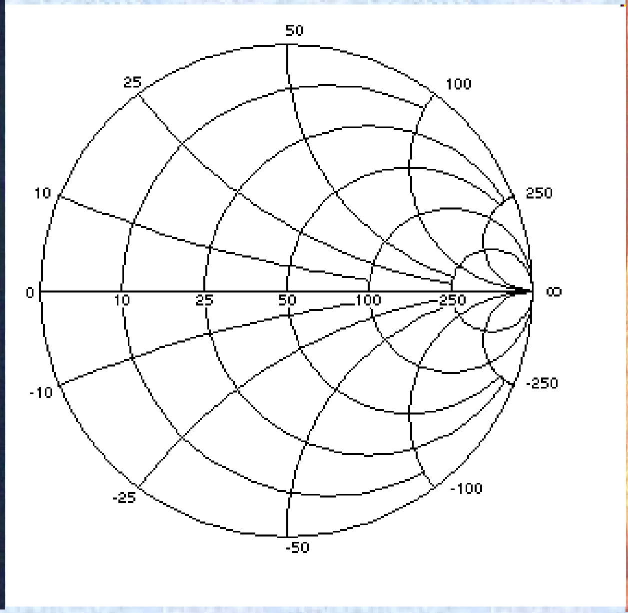
or

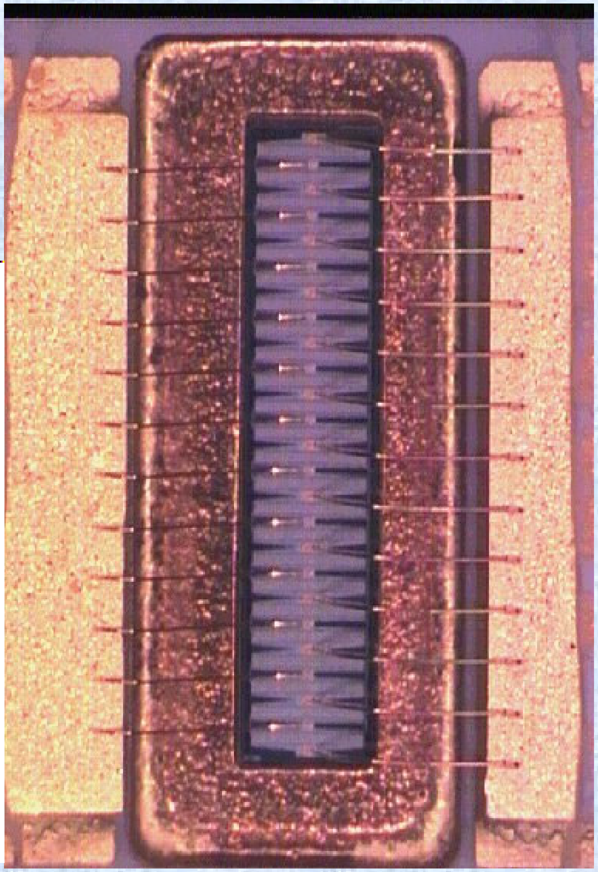
How to get serious VHF power without potential electrocution!

John Worsnop G4BAO



Laterally **D**iffused **M**etal
Oxide **S**emiconductor





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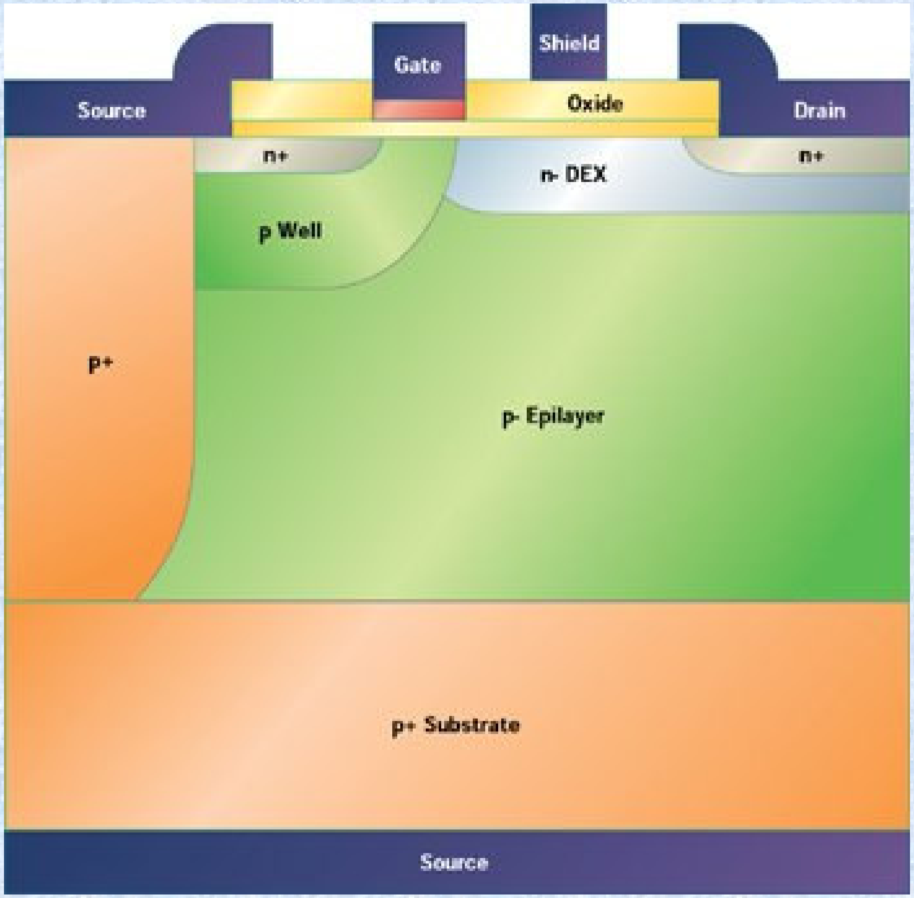
- Bodger – (noun)
  - A highly skilled itinerant wood-turner, who worked in the beech woods on the chalk hills of the Chilterns, in England
- Bodging (Br. Slang)
  - an inexpertly or roughly done job, typically in the field of DIY.

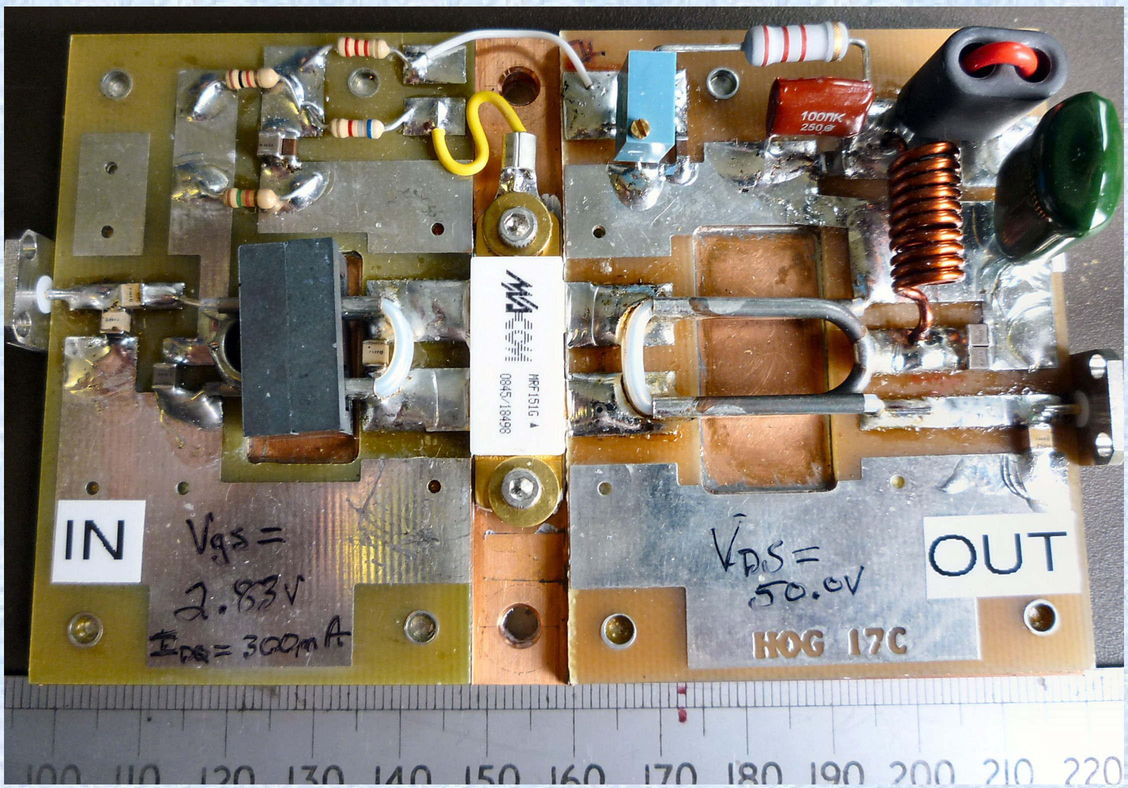
LDMOS for Bodgers

- 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.
- 800 Watt plus devices at VHF
- Simple positive gate bias circuitry.
- Hard to destroy in development.

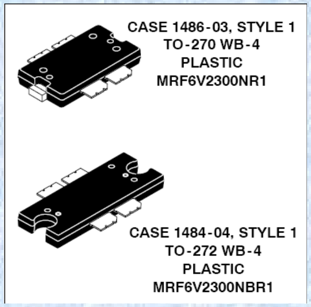


Devices- The previous generation

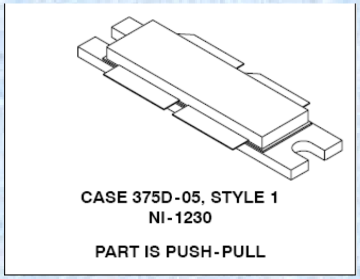
- The legendary MRF151G "Gemini" device
  - 300Watts out 15dB Gain to 144MHz VSWR 5:1
    - Some surplus amplifiers available



Devices- What's available now?

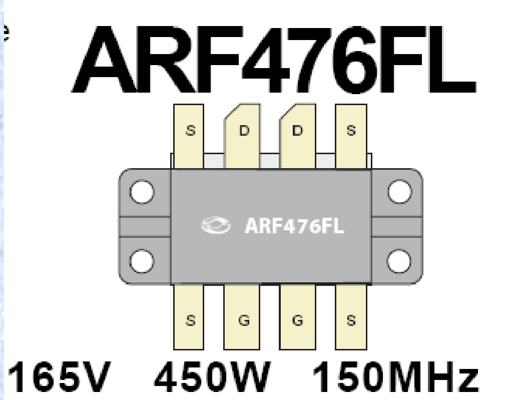


- Freescale
  - Single ended
    - MRF6V2300 – 300 Watts 24dB gain 10-600MHz - $83
  - "Gemini"
    - MRF6VP2600 400 Watts 24dB gain 10-250MHz - $150
    - VSWR 10:1
    - MRF6VP41kH 800 Watts 22dB gain 10-500MHz - $610
    - VSWR 10:1 (DL4XX 800W amp for 2m)
  - And coming soon
    - MRFE6VP6300H 1.8-600MHz; 300 watt CW
    - rated up to 65:1 VSWR in CW!



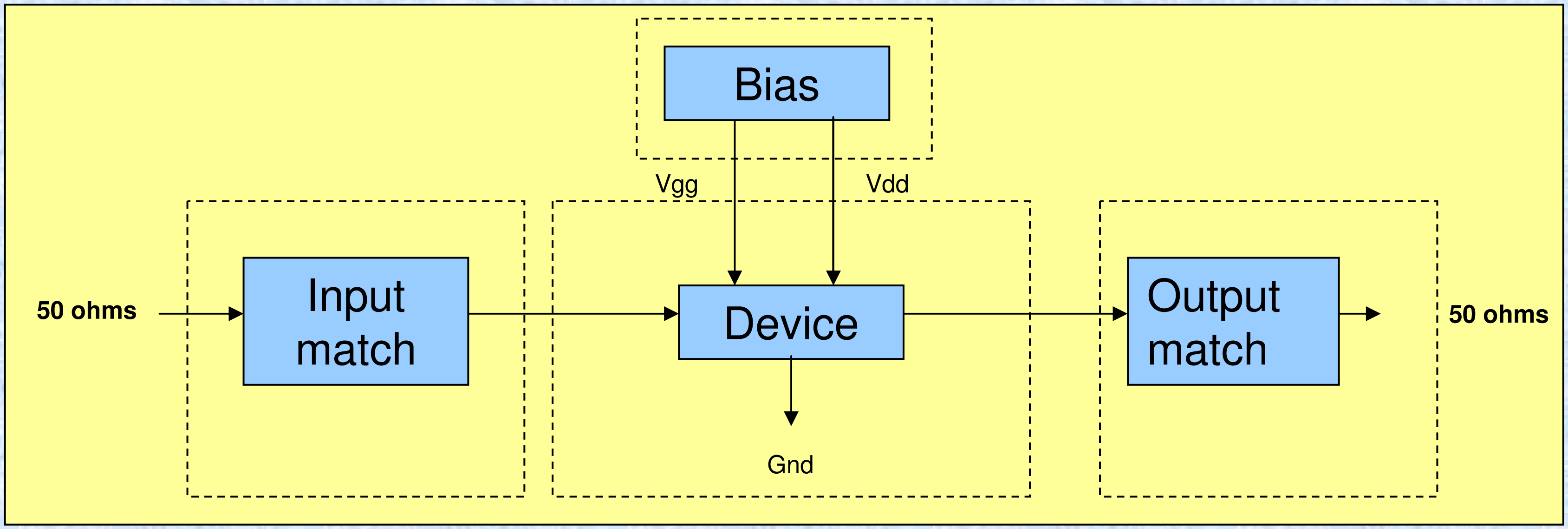
  - All these are 50 Volt devices

- Microsemi
  - ARF467FL
    - Rated for pulsed operation to 900Watts Peak!
    - 150 Volt supply



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

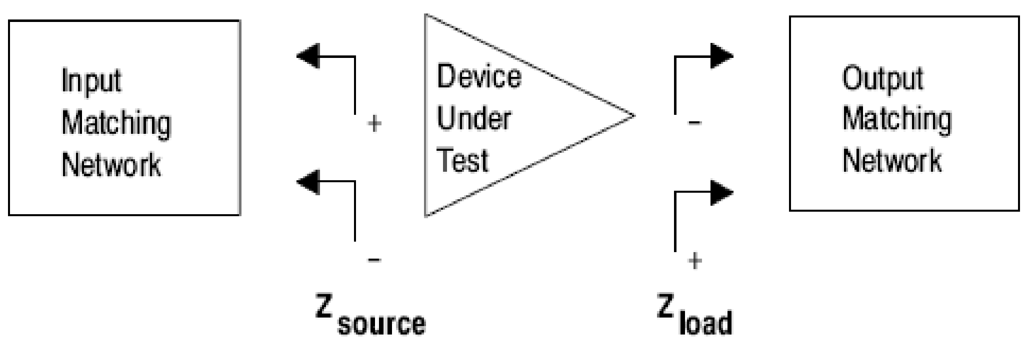


It's the impedances, stupid!

- 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.

Z_{source} = Test circuit impedance as measured from gate to ground.

Z_{load} = Test circuit impedance as measured from drain to ground.



So we need the device datasheets, right?

- **WRONG!**
  - Fine if data is available for the frequency you need
- Much VHF LDMOS is designed for broadcast
- 88-108MHz, 225MHz, 470-860 MHz

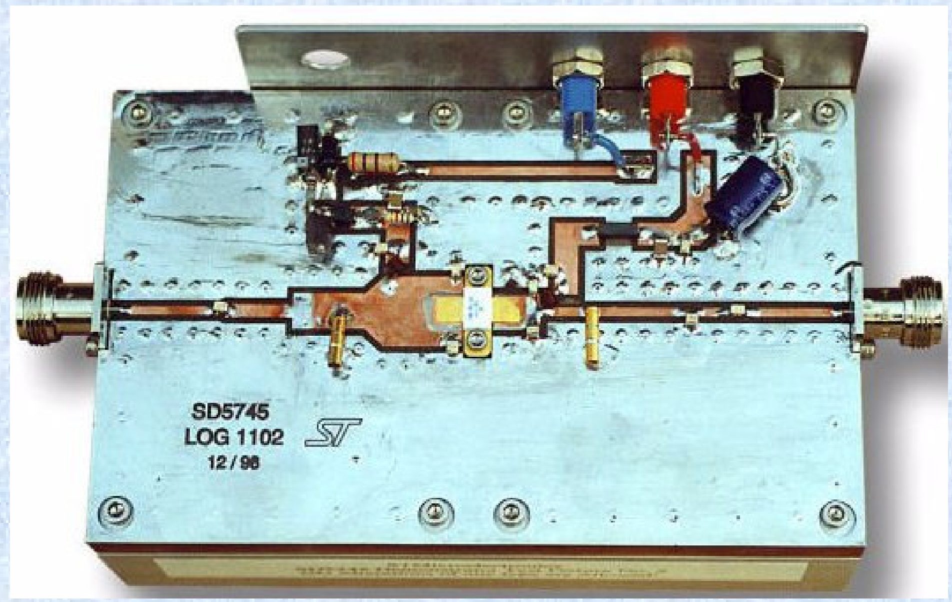
So we're stuck?

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

The Bodger’s subroutine!

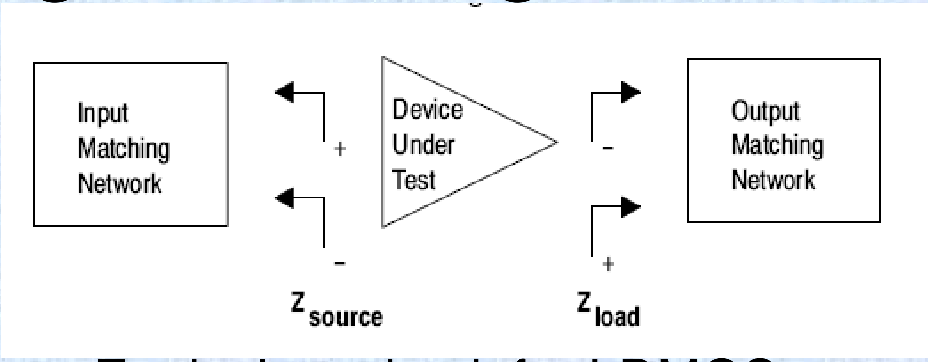
Applicable to a “new” design or retuning surplus

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



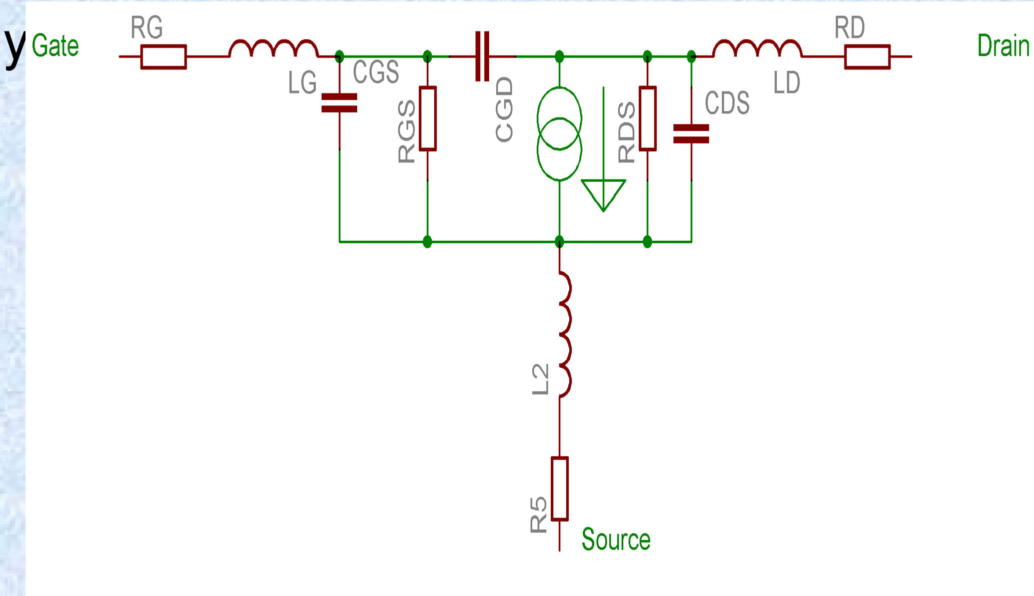
Output matching for Bodgers

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



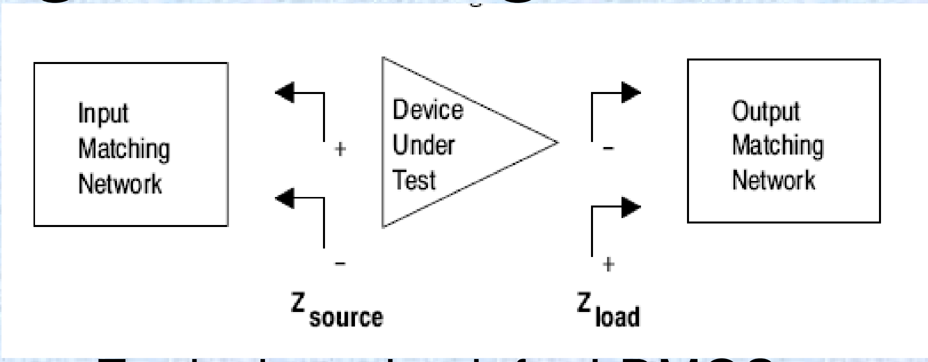
- Output power is approximately
- $P_{out} = Vdd^2/2R_{Load}$

Equivalent circuit for LDMOS

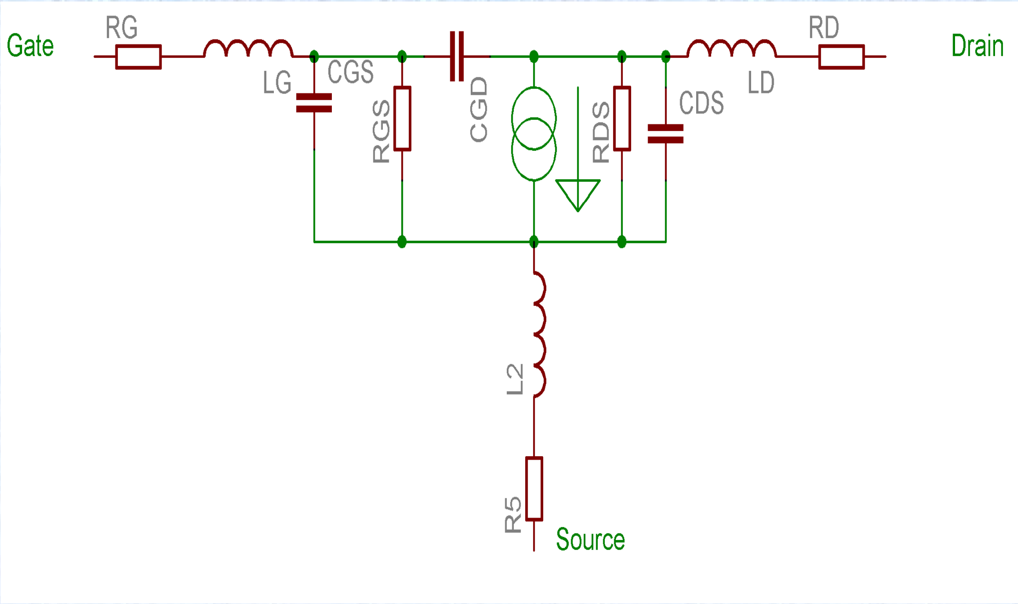


Output matching for Bodgers

- So to deliver the power, the device needs to "see"
- $R_{Load} = Vdd^2/2P_{out}$



Equivalent circuit for LDMOS



- We have C_{DS} in parallel with the device
- So our network must resonate this out as well (conjugate matching)

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

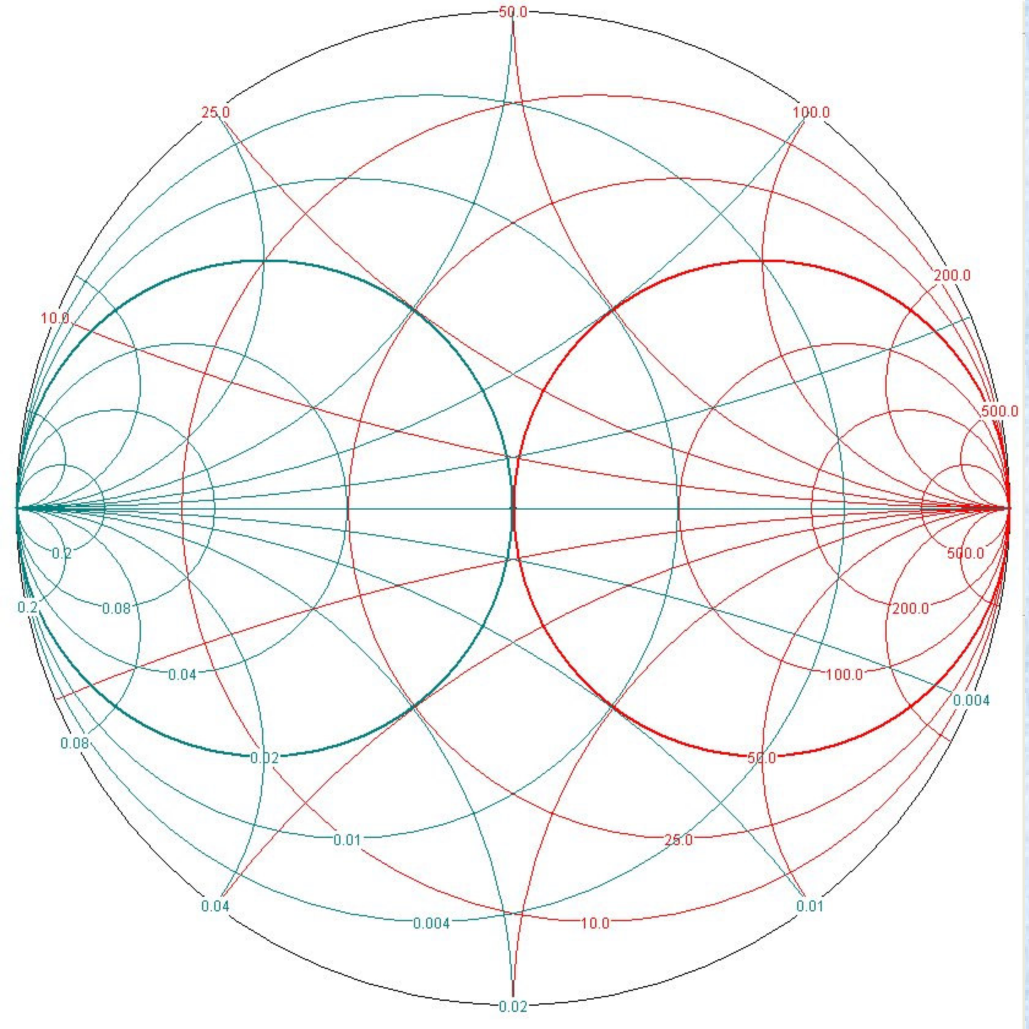
- This gives R_{Load} = 4.16 ohms in parallel with C_{DS} = 120pF
- Convert this to a series combination and conjugate it.

  - 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

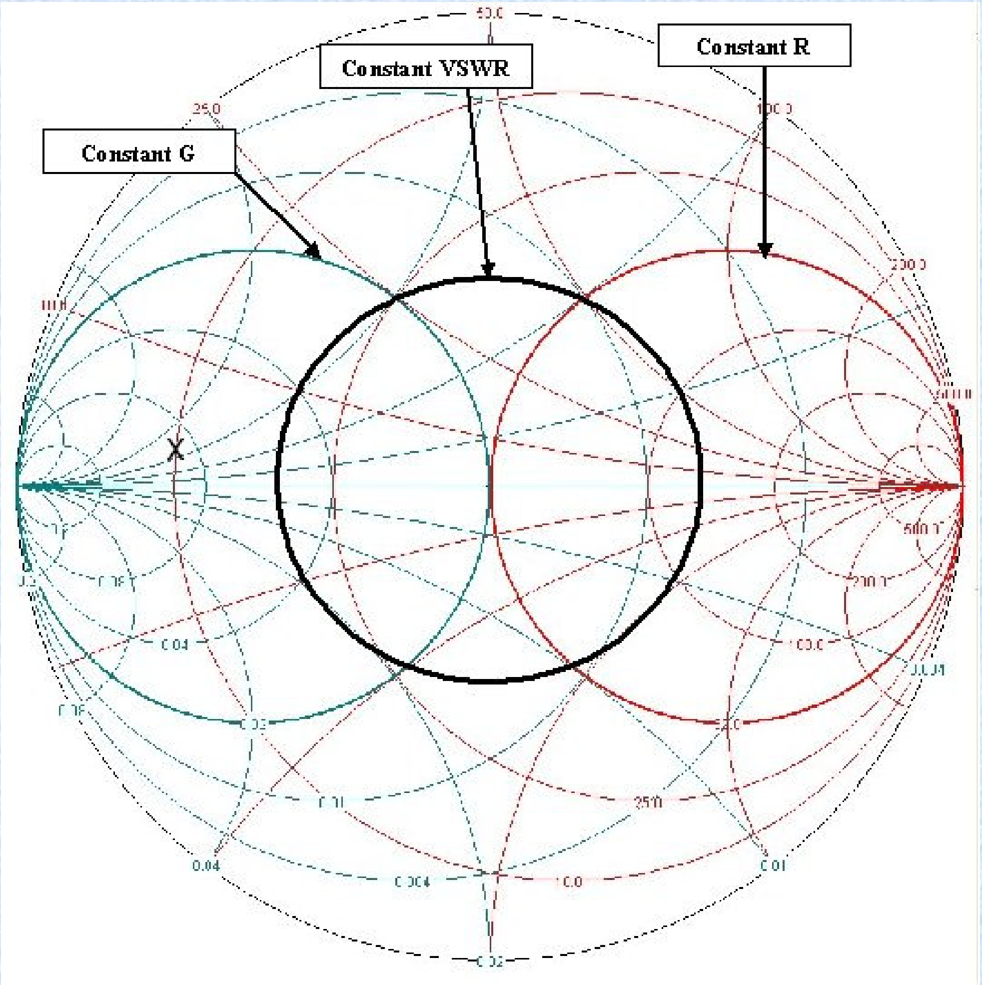
A brief aside on the Smith Chart

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



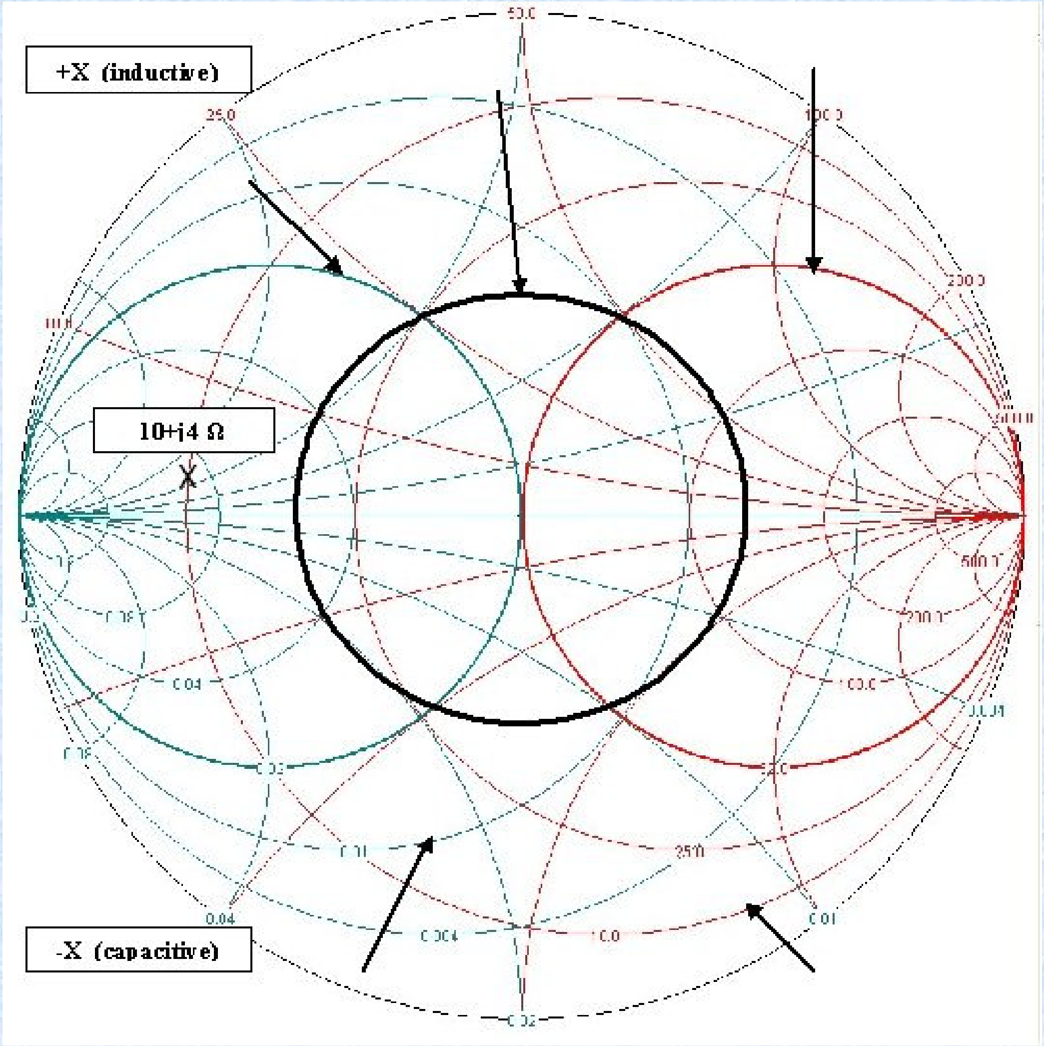
A brief aside on the Smith Chart

- 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



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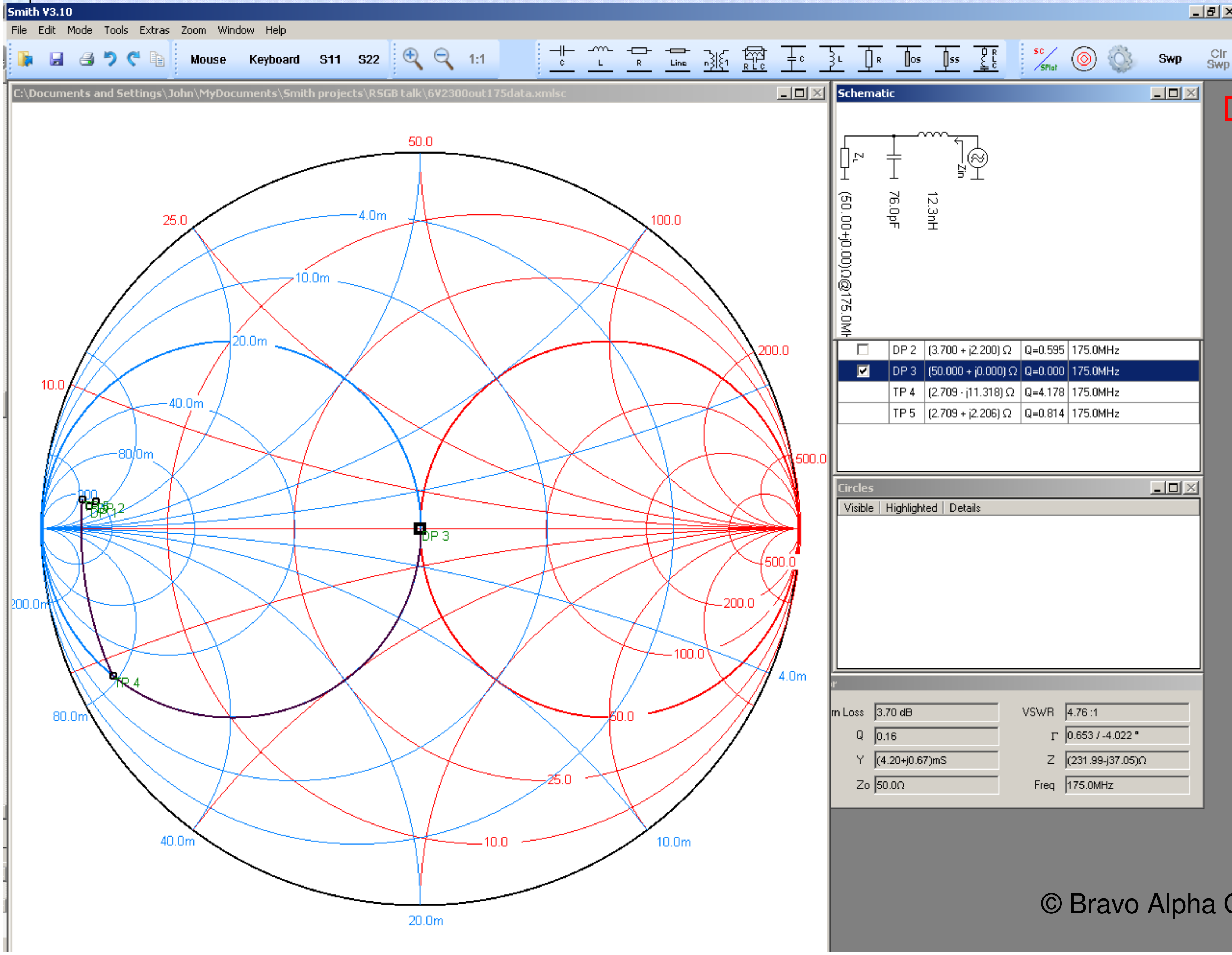

Datasheet

12.3nH
76pF

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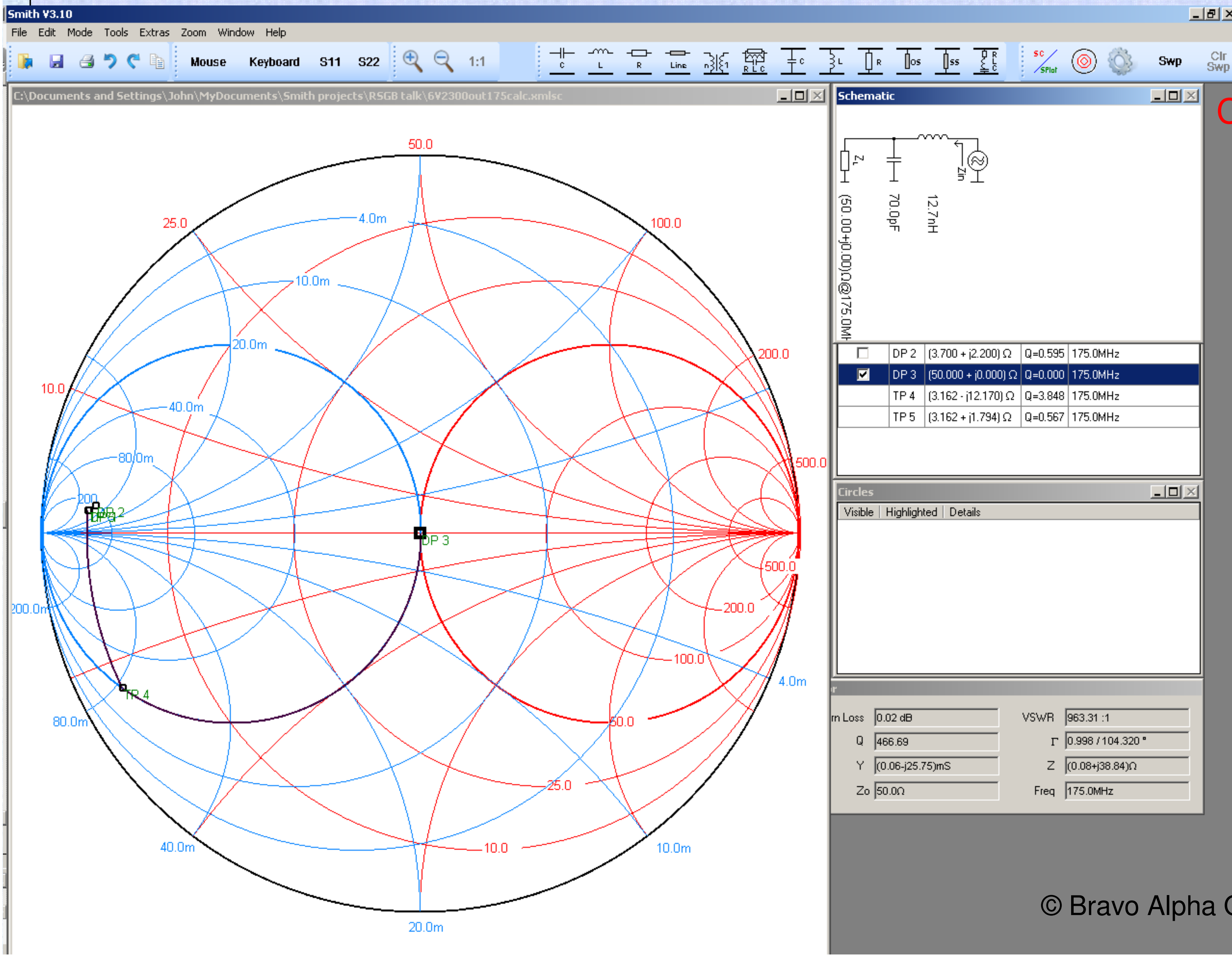

Calculated

12.7nH
70pF

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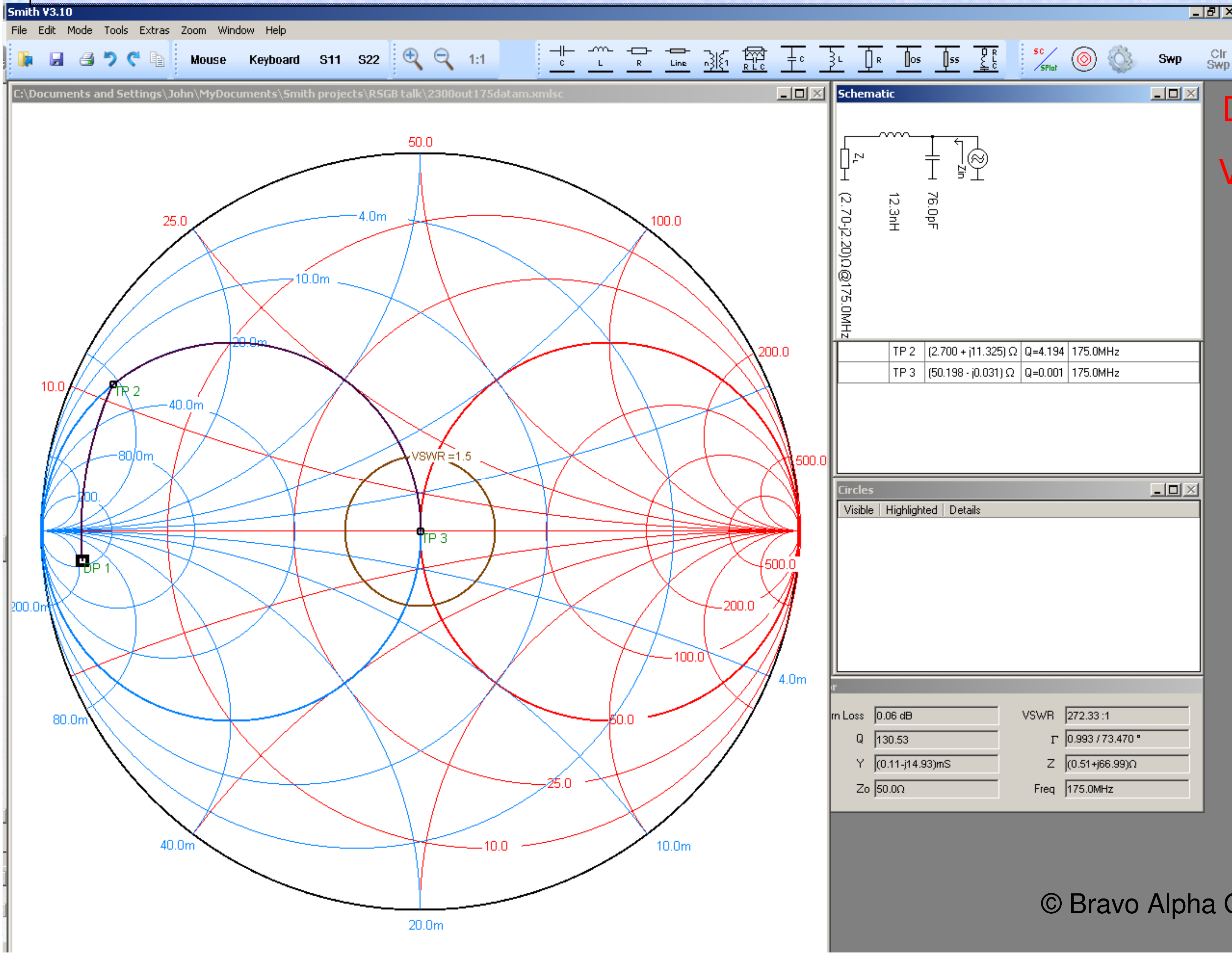

Datasheet

VSWR 1:1

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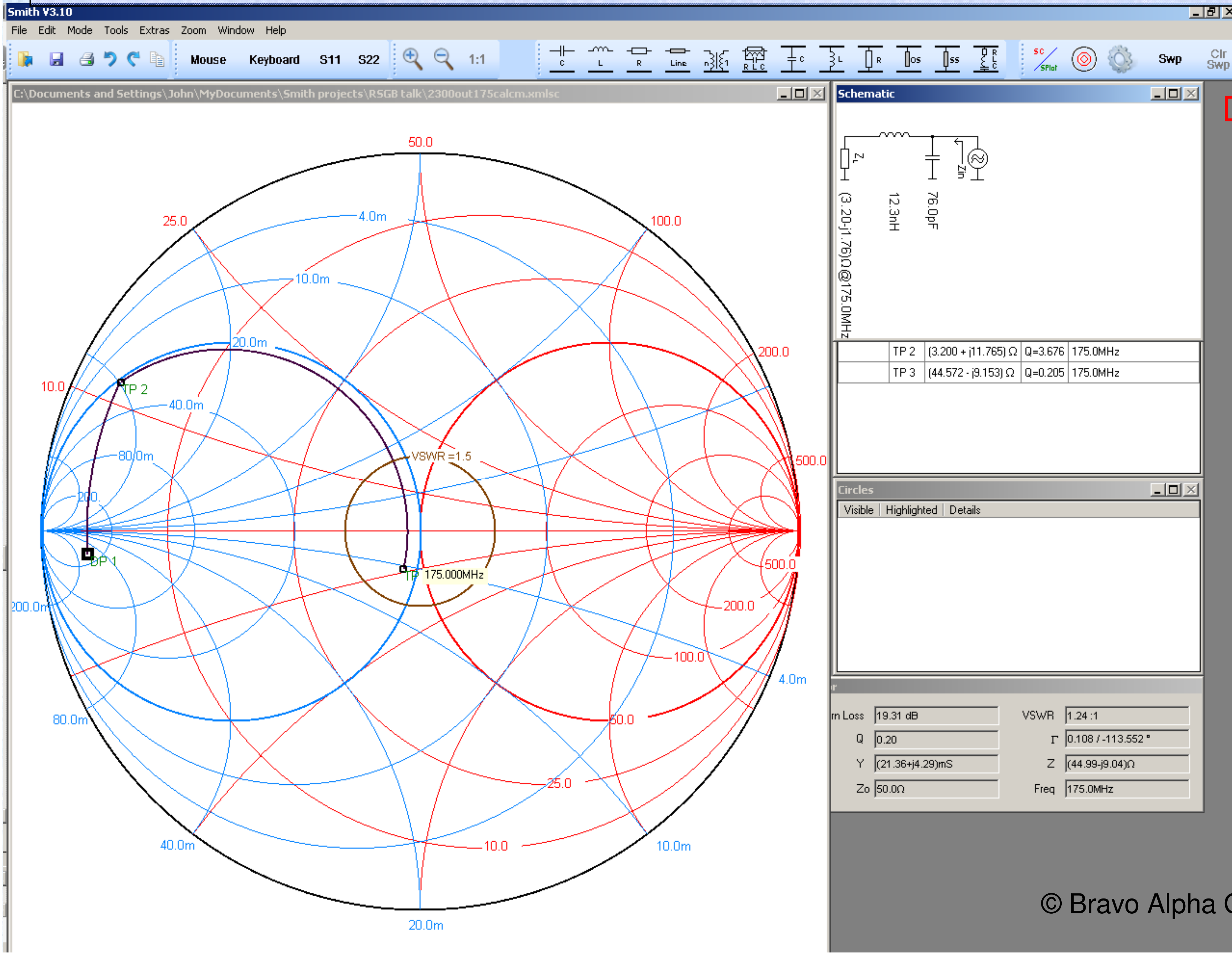
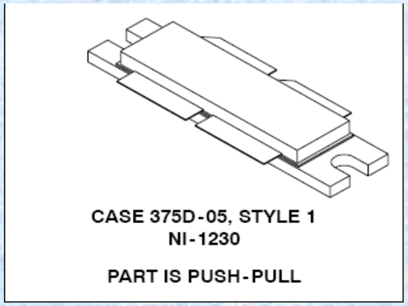


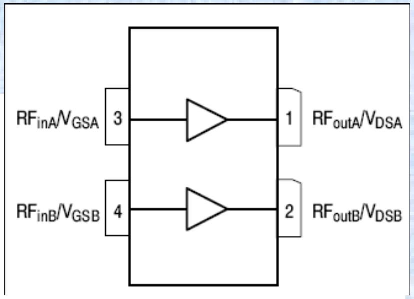
Datasheet

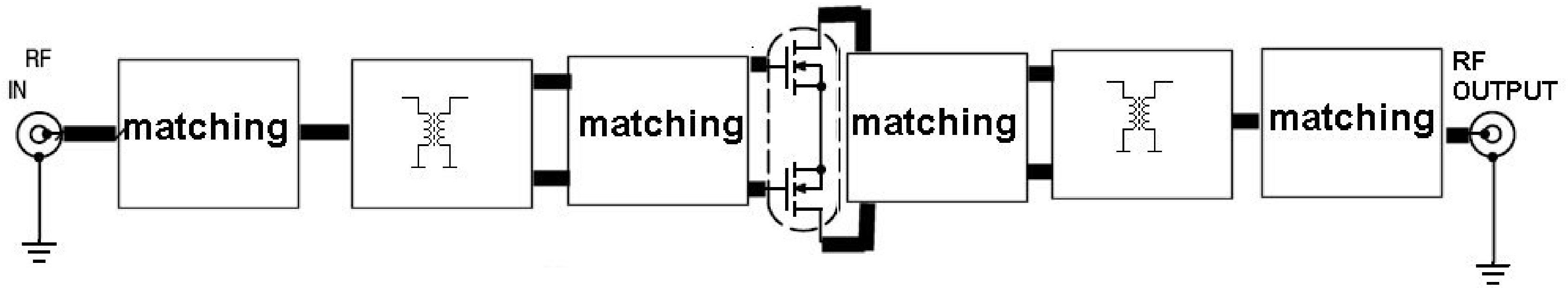
VSWR 1.24:1

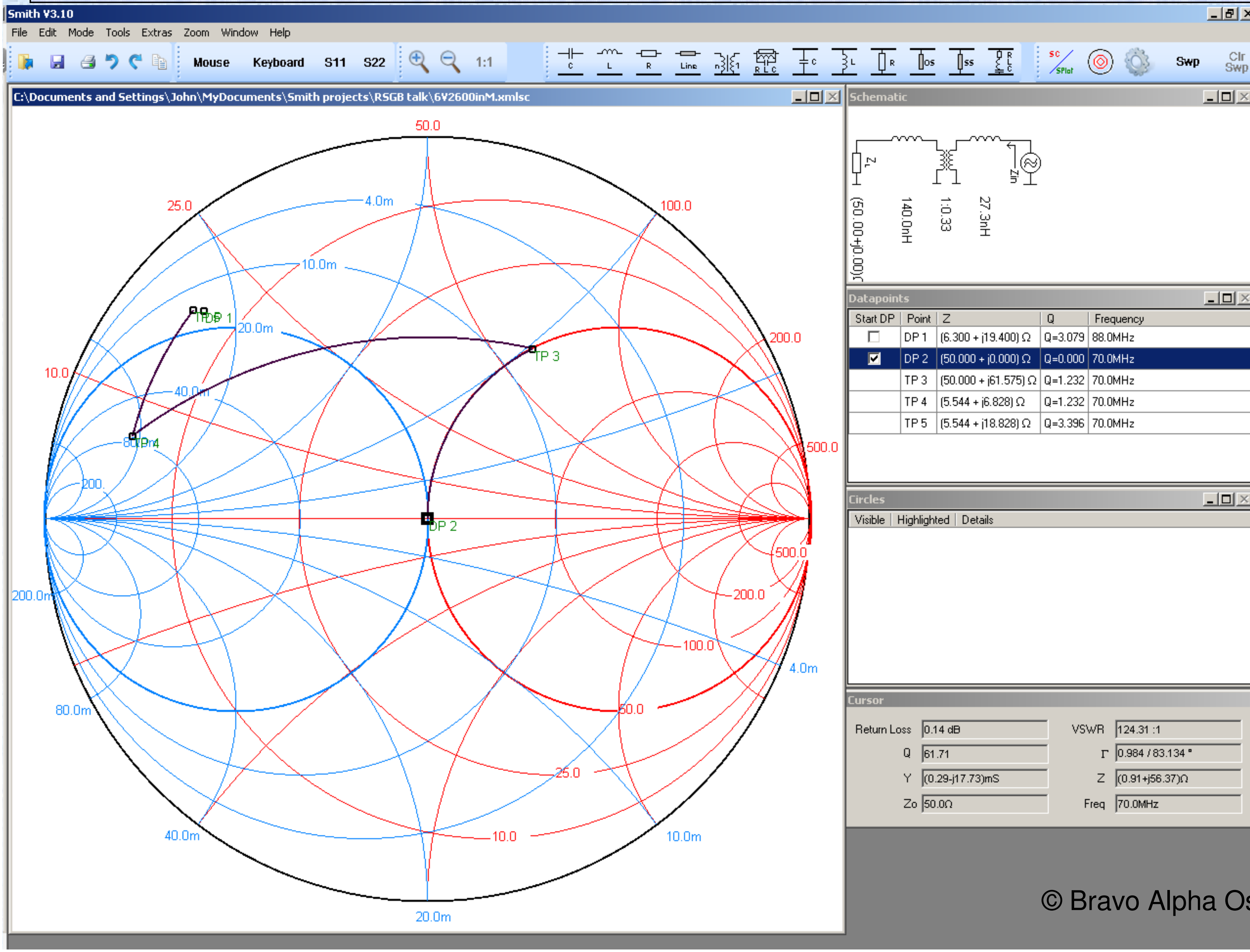
Gemini Devices - Transformer matching

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





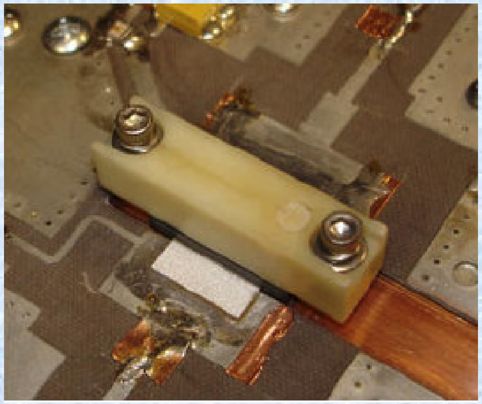



Smith V3.10
File Edit Mode Tools Extras Zoom Window Help
Mouse Keyboard S11 S22 1:1 Swp Clr Swp
C:\Documents and Settings\John\MyDocuments\Smith projects\RSGB talk\6V2600inM.xmlsc
Schematic
(50.00+j0.00)Ω 140.0nH 1:0.33 27.3nH Zin
Datapoints
Start DP Point Z Q Frequency
DP 1 (6.300 + j19.400) Ω Q=3.079 88.0MHz
DP 2 (50.000 + j0.000) Ω Q=0.000 70.0MHz
TP 3 (50.000 + j61.575) Ω Q=1.232 70.0MHz
TP 4 (5.544 + j6.828) Ω Q=1.232 70.0MHz
TP 5 (5.544 + j18.828) Ω Q=3.396 70.0MHz
Circles
Visible Highlighted Details
Cursor
Return Loss 0.14 dB
VSWR 124.31 :1
Q 61.71
Γ 0.984 / 83.134 °
Y (0.29-j17.73)mS
Z (0.91+j56.37)Ω
Zo 50.0Ω
Freq 70.0MHz
DP 1
DP 2
TP 3
TP 4

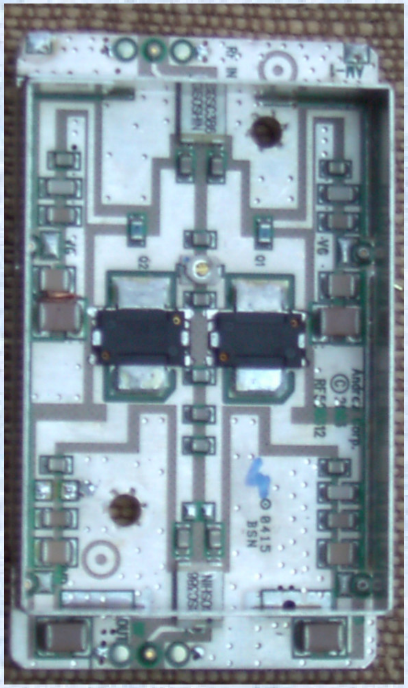
Device mounting -The choices

Bolt

Clamp



Solder



Device mounting - clamping vs bolting

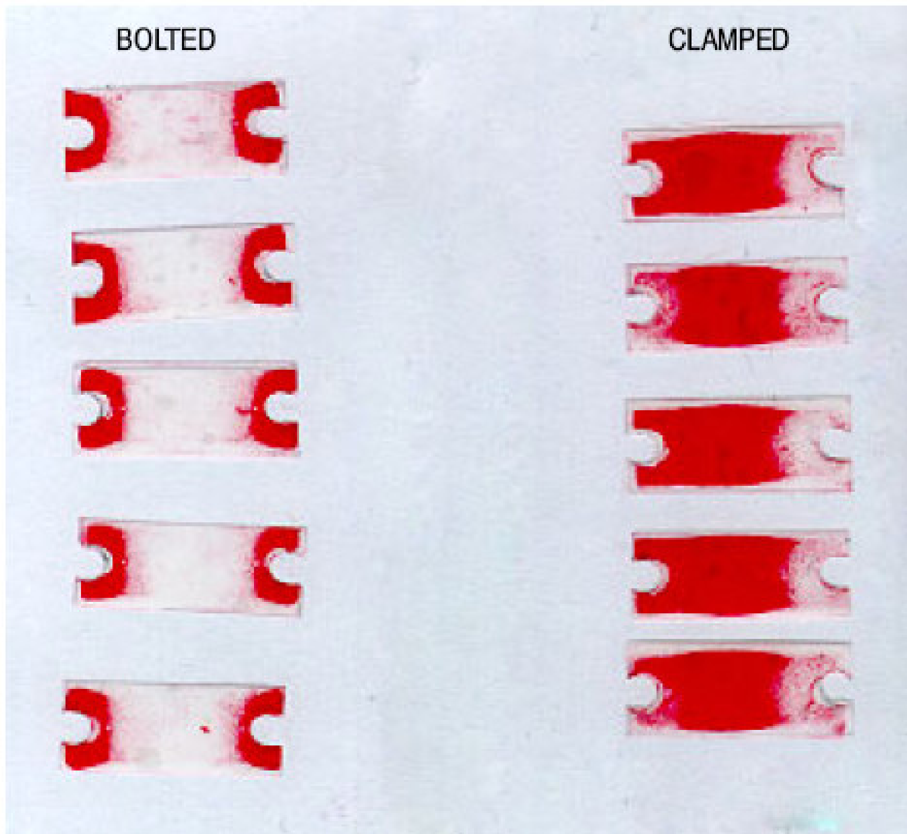
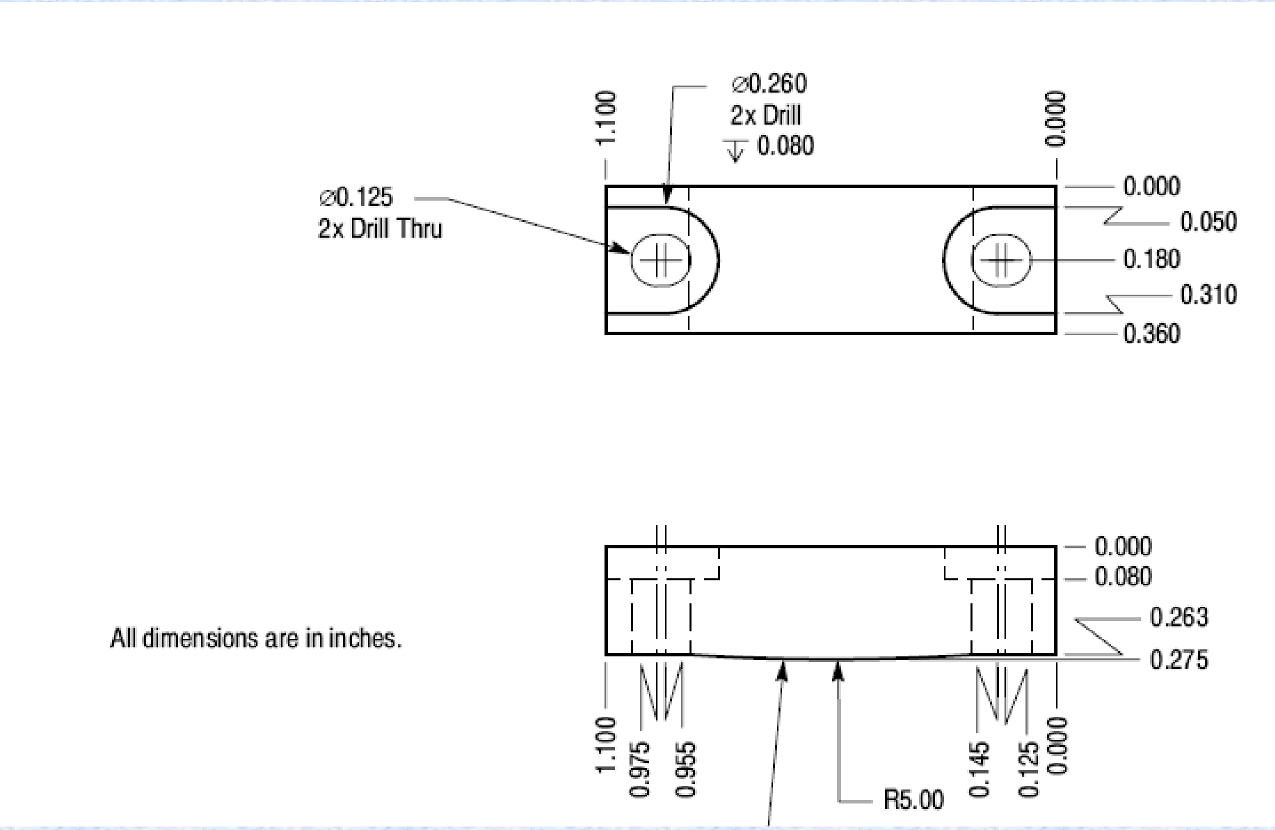


Figure 7. Pressure Paper Test Results for Five TO-272WB Packages with #4-40 Screws at a Mounting Torque of 4.0 in-lb

Source Freescale AN-3789

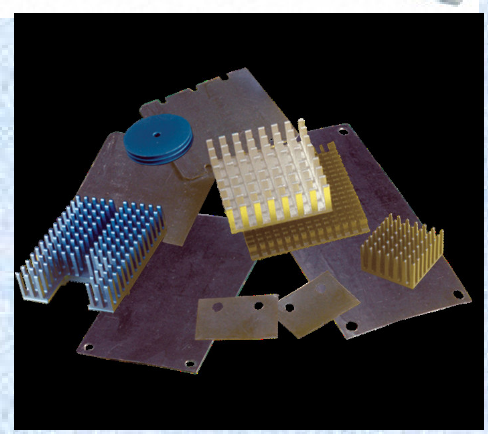
Device mounting – Typical clamp design



Source Freescale AN-3789

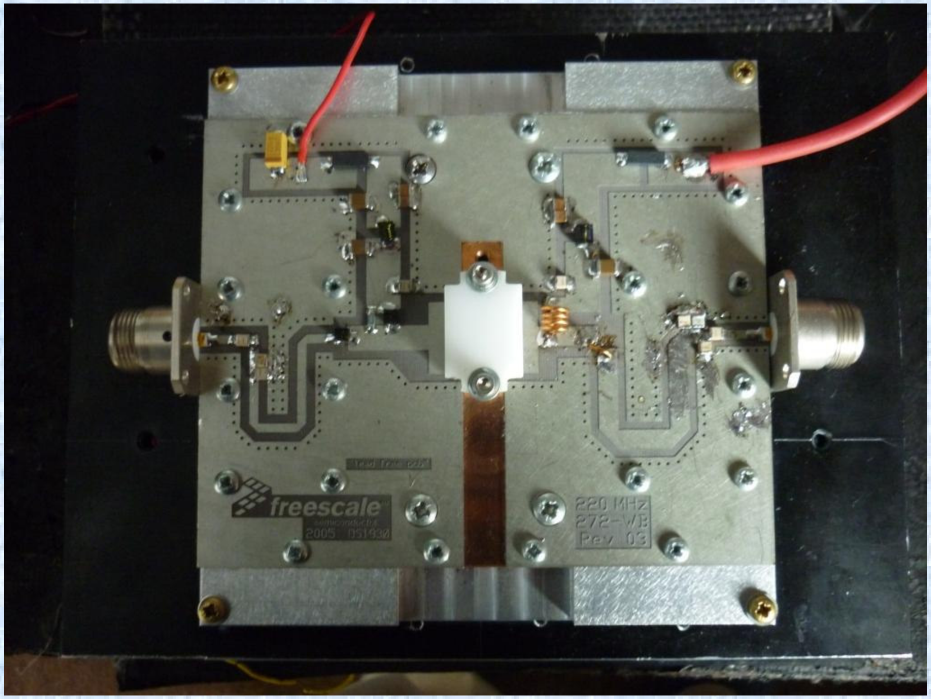
Device mounting – Getting the heat away

- 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.



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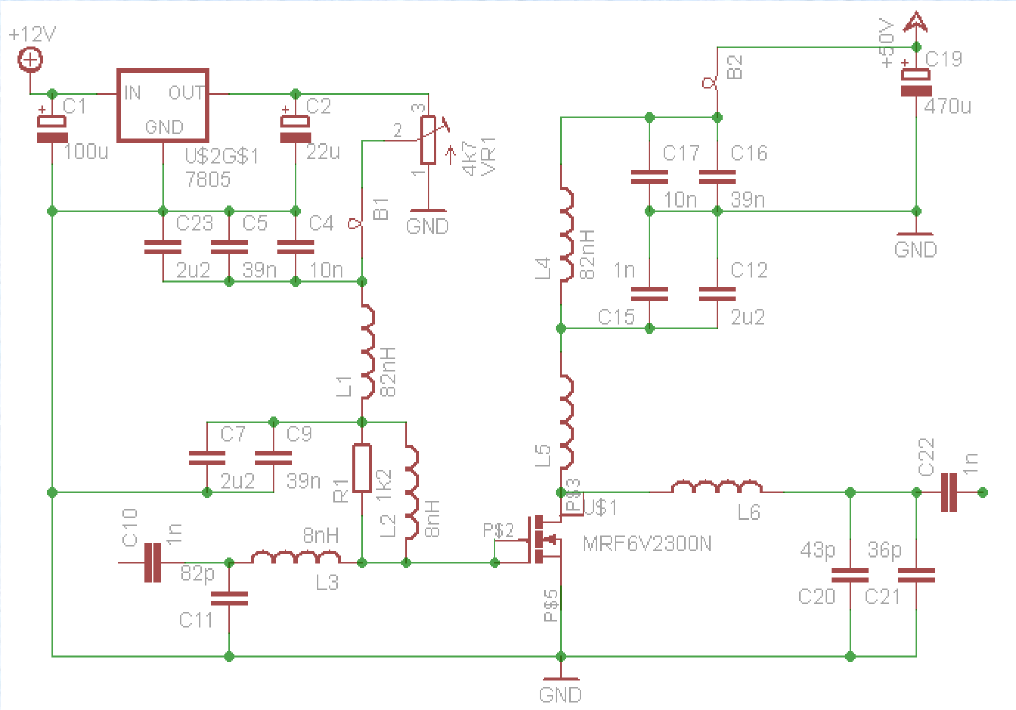
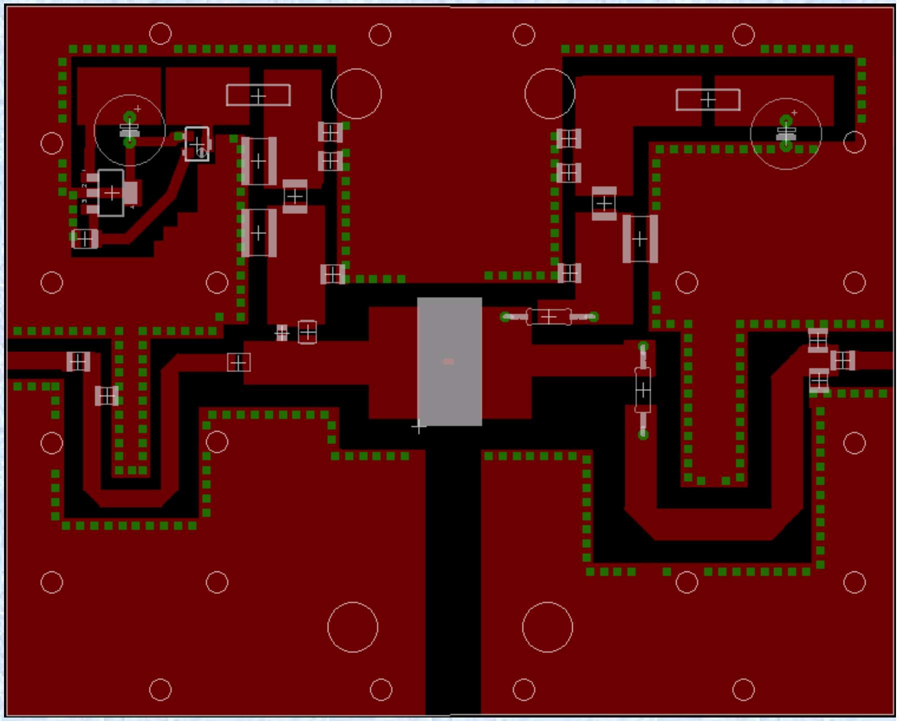
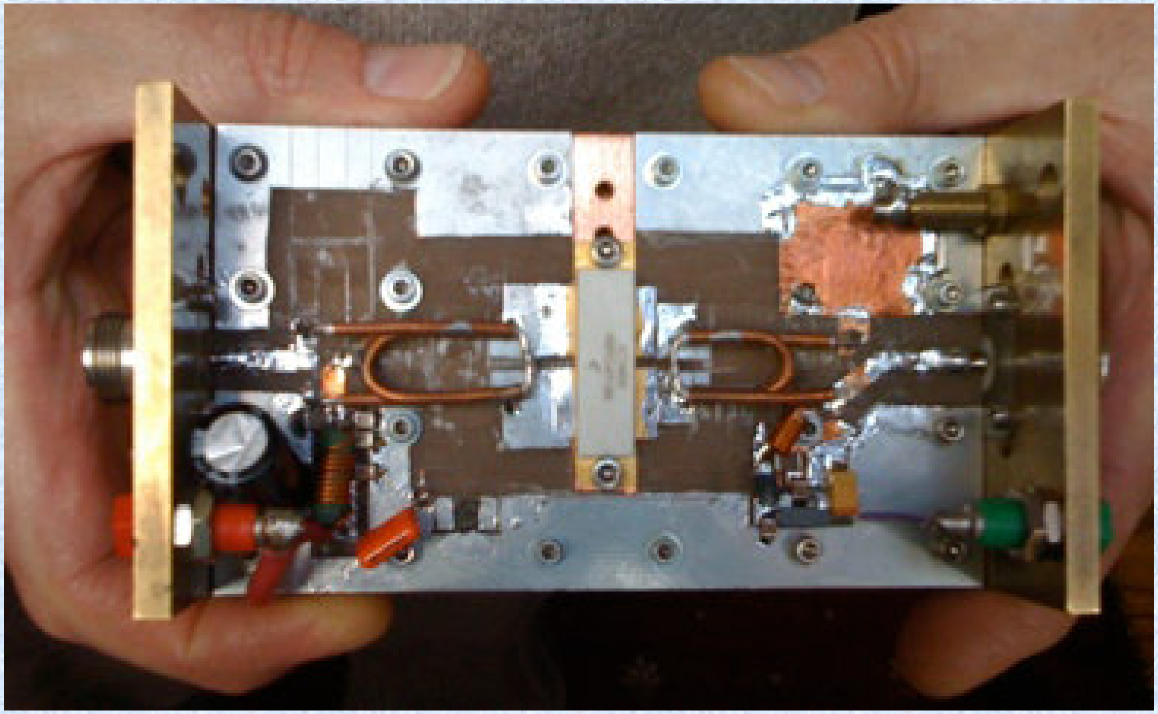




A wideband design with the MRF6V2600H

- Target
  - 400W PEP 4m and 6m
- Flanged device
- Under development
  - Not powered up yet!
- Uses transformer matching



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

- Freescale Applications Engineering (They Rock!)
- Bernie, G4HJW – "Bodger extraordinaire"
  - (And RF design professional :-)
- LDMOS pictures – ST Microelectronics
- "Smith" program Prof. Dellsperger Univ of Berne
- Appcad program