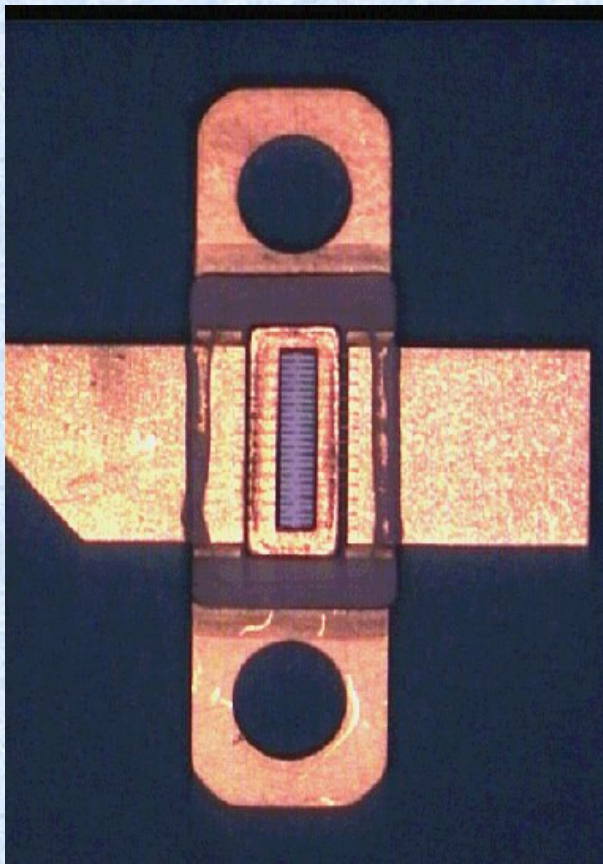


The Bodger's Guide to Solid State QRO

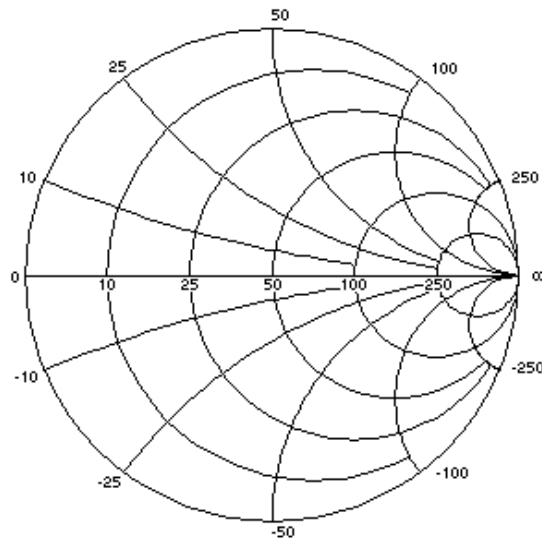
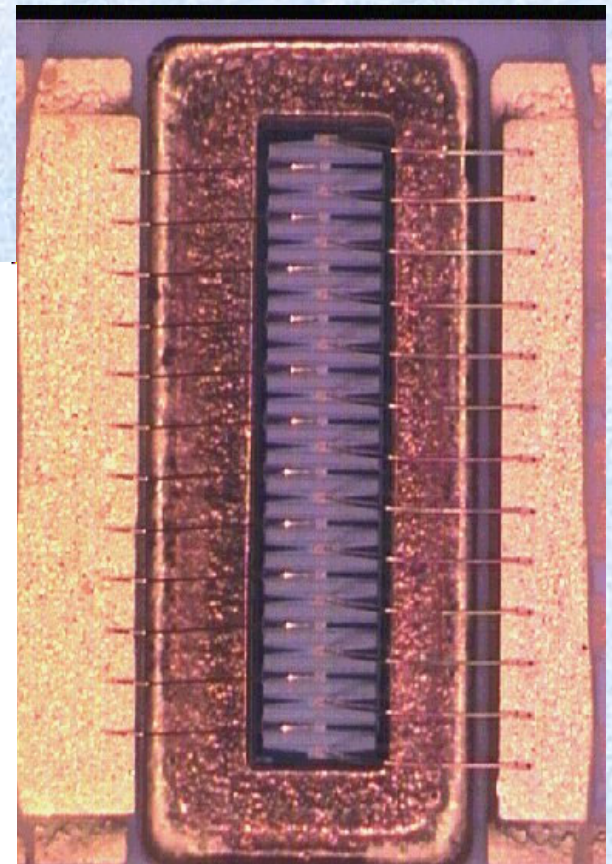
or

How to get serious power without potential electrocution!

John Worsnop G4BAO

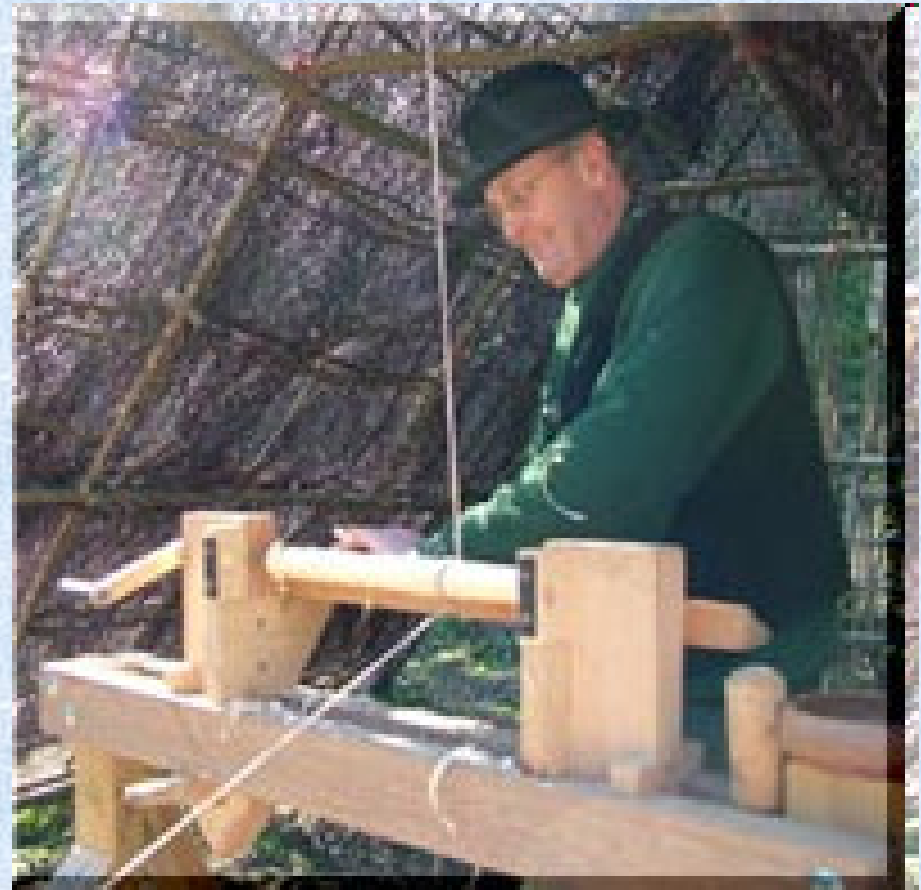


Laterally Diffused Metal
Oxide Semiconductor



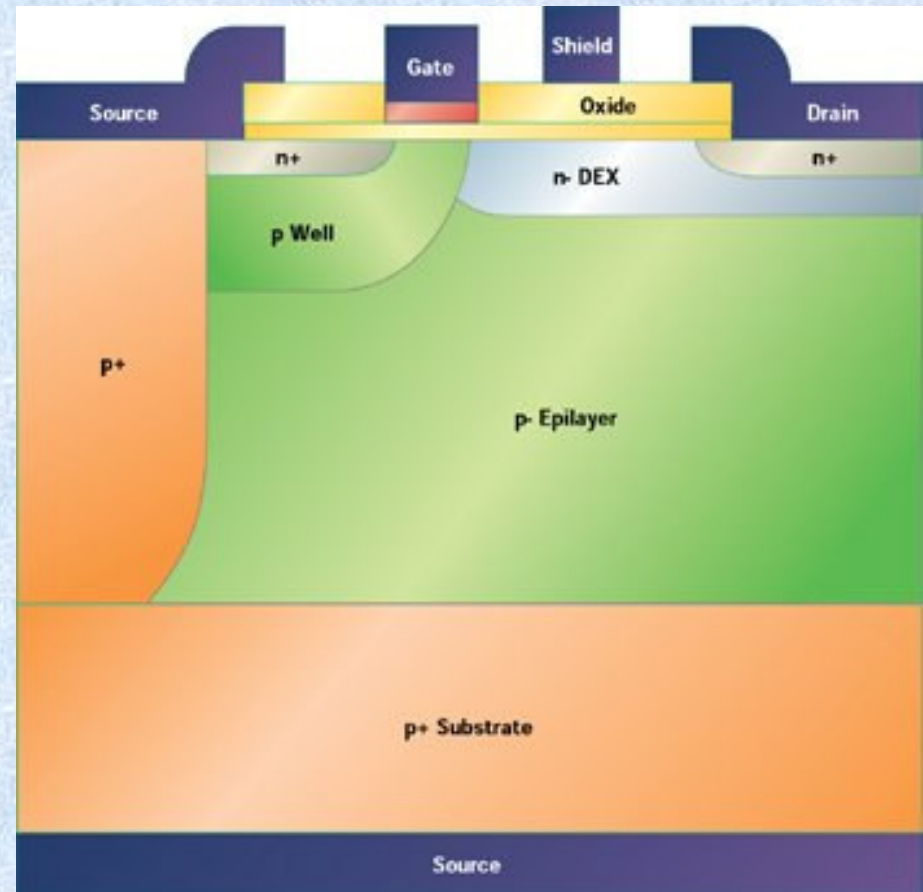
© Bravo Alpha Oscar 2011

- 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.



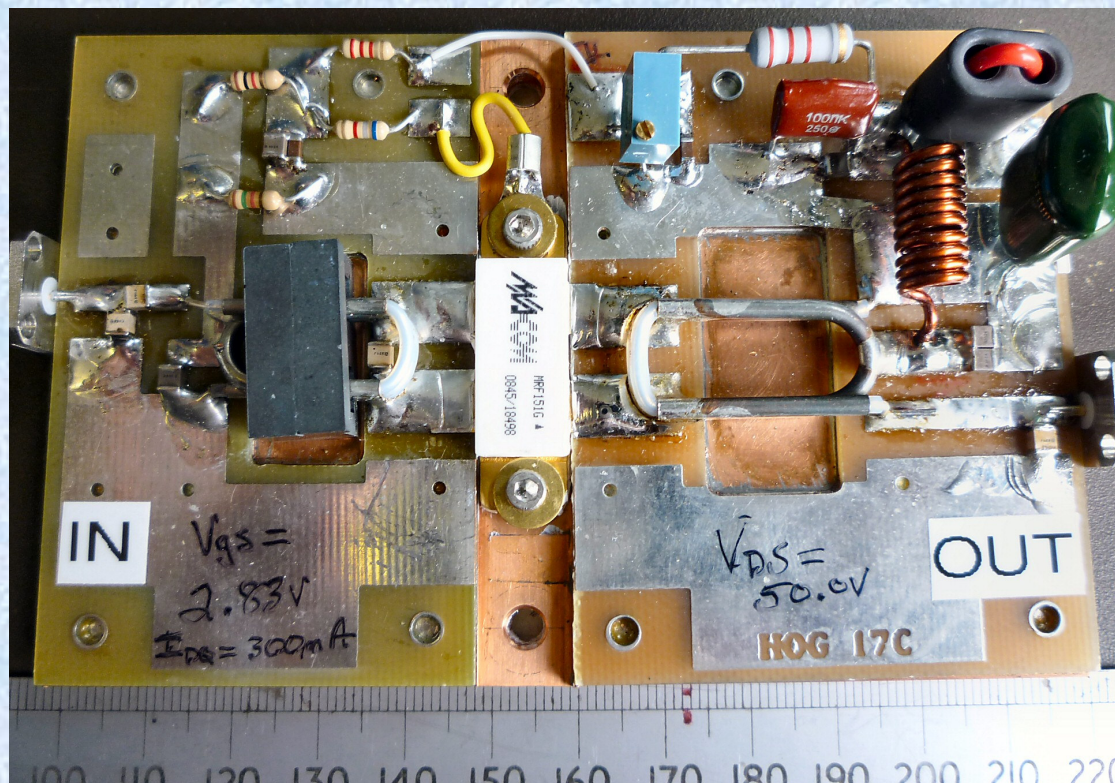
LDMOS for Bodgers

- 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?

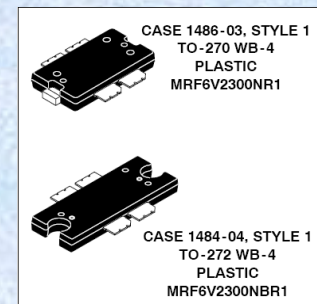
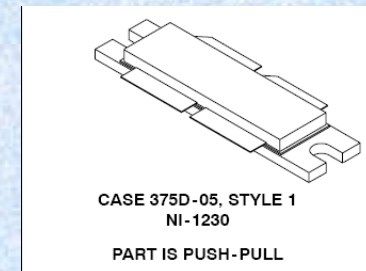
- Freescale

- Single ended

- MRF6V2300 – 300 Watts 24dB gain 10-600MHz - \$83
 - MRF7S35120HSR3 - 3.4GHz 120W Pulsed -\$250

- “Gemini”

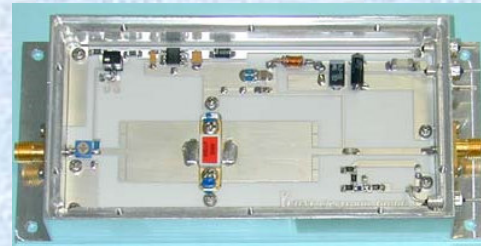
- MRFE6VP6k125 1.8-600MHz; 1250 watt
 - MRF6VP121KH? - 965-1215 MHz, 1kW (23cms?)



Amplifier Choices for Amateurs

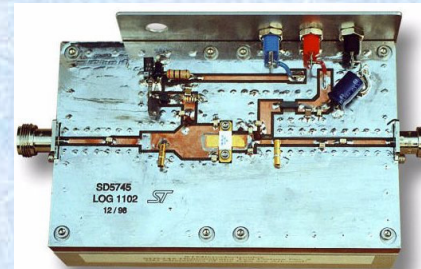
- **Buy one (£££)!**

» image © DB6NT



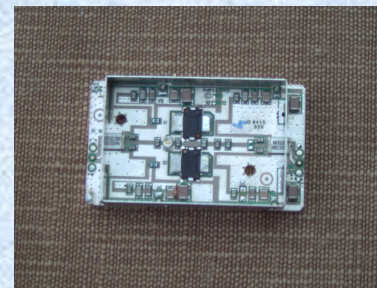
- **“Grow your own”**

» Various kits available



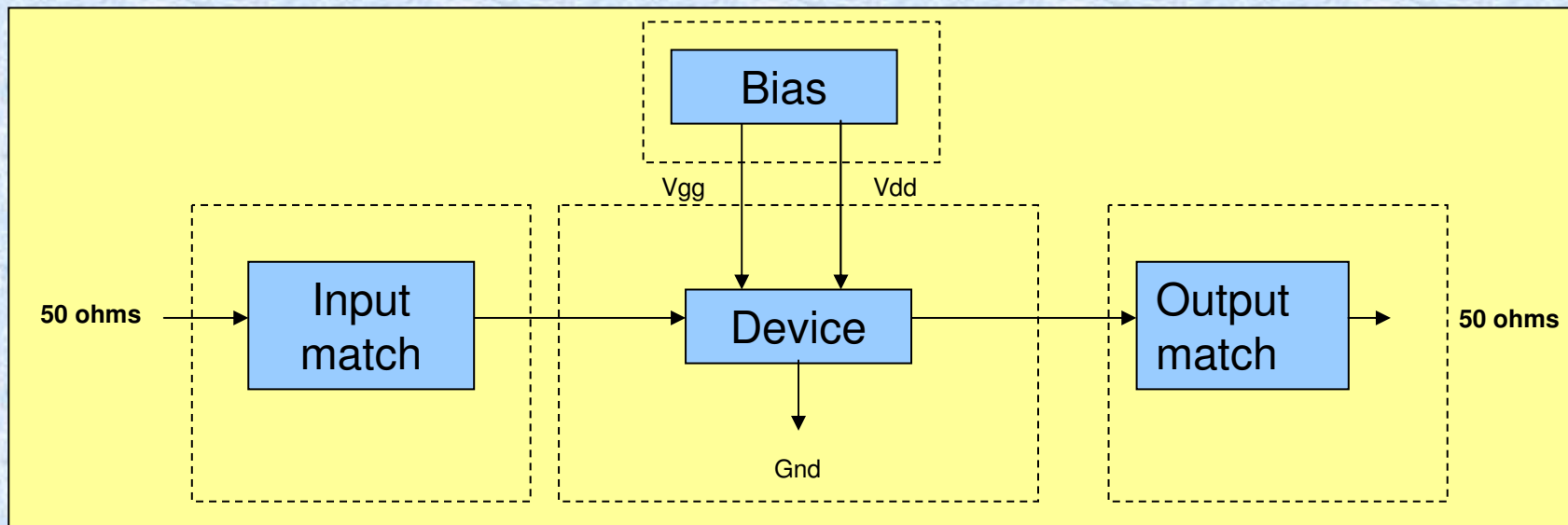
- **Modify surplus**

» The Bodger's choice



It's the impedances, stupid!

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

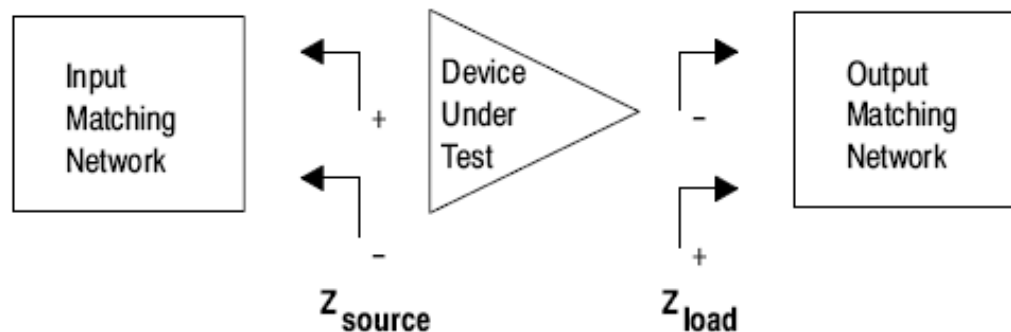


It's the impedances, stupid!

- 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 LDMOS is designed for cellular or broadcast
- 88-108MHz, 225MHz, 890 -1215 MHz

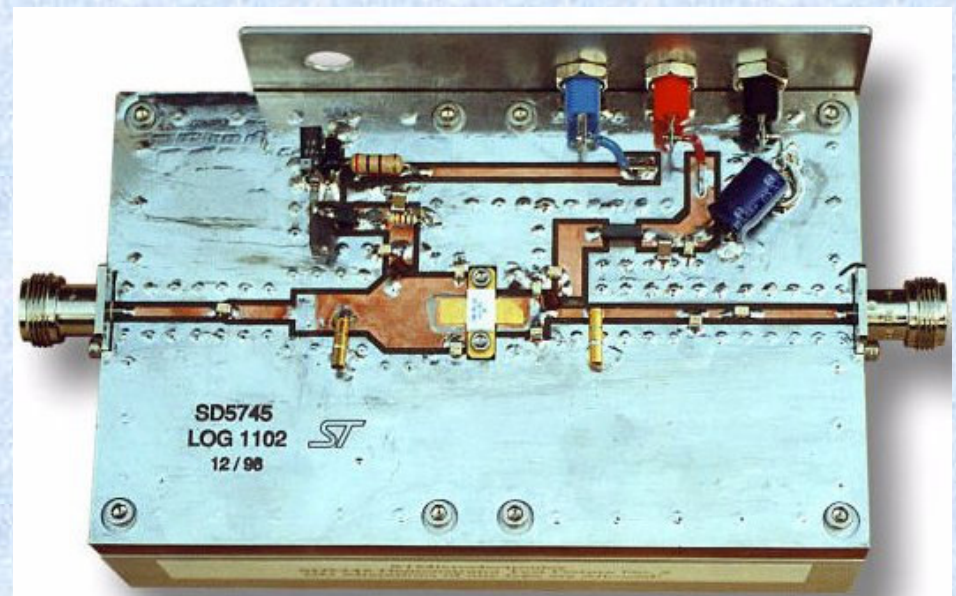
So we're stuck?

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

The Bodger's subroutine!

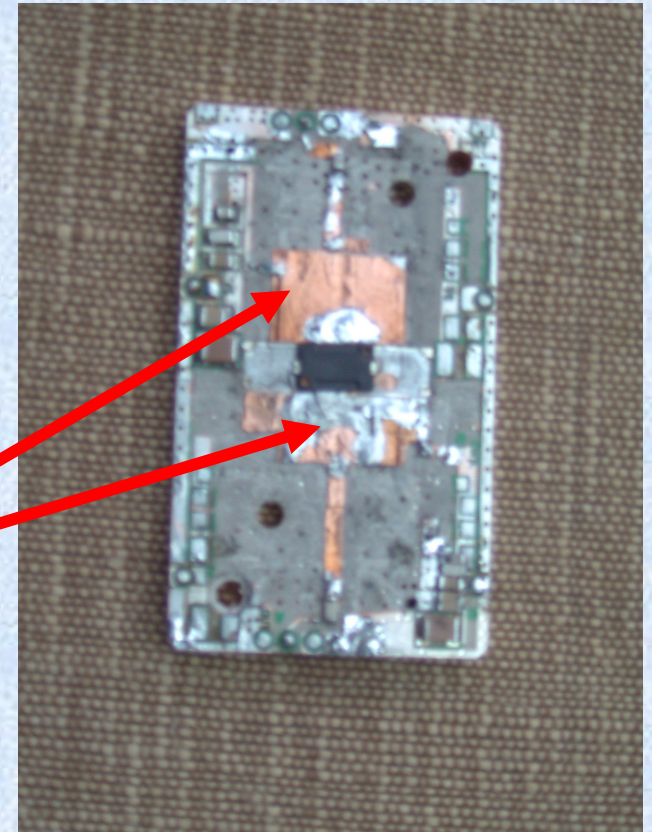
Applicable to a "new" design or retuning surplus

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



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 ϵ_r
- Measure Ls, Cs and microstrip lines
 - Scale line lengths by 1296/900
- Plot on your Smith Chart
 - Assume that Z_{in} 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.

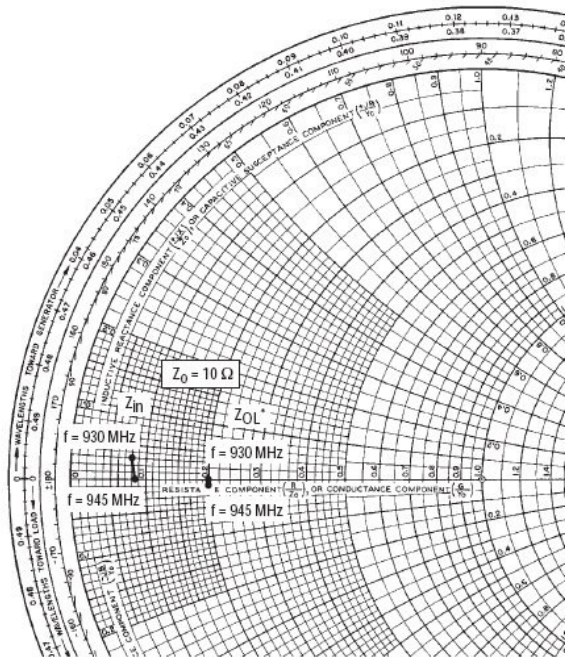
Reverse Engineer the existing input circuit

Example $1.7+j1$ at 900MHz from datasheet

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

- $0.131\lambda = 0.188\lambda$ at 1296
- Assume Z_{in} changes to $3+j3$ and see what C will have to do to rematch

Freescal MRF9045



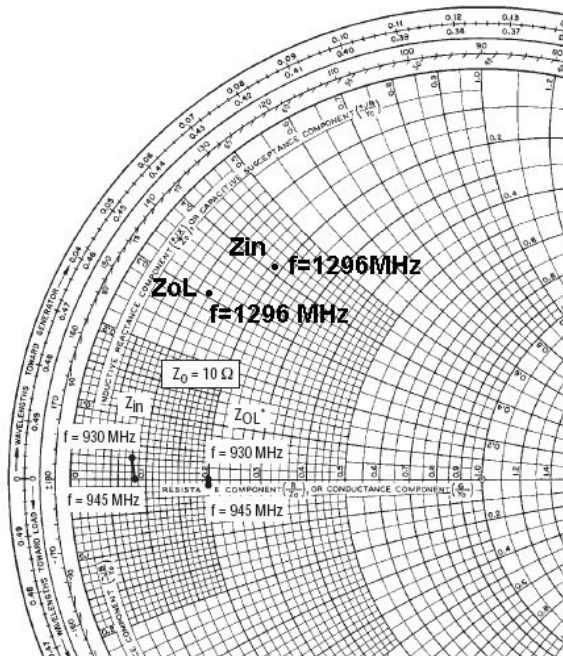
$V_{DD} = 28 \text{ V}$, $I_{DQ} = 350 \text{ mA}$, $P_{out} = 45 \text{ W (PEP)}$

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.

Freescal MRF9045 1296MHz



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

f MHz	Z_{in} Ω	Z_{oL}^* Ω
1296	$1.9+j4.1$	$1.2+j3.1$

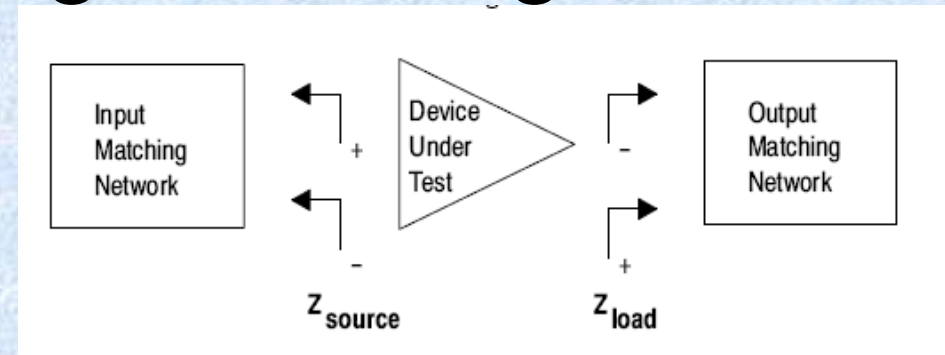
Z_{in} = Complex conjugate of source impedance.

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

“measured” impedances

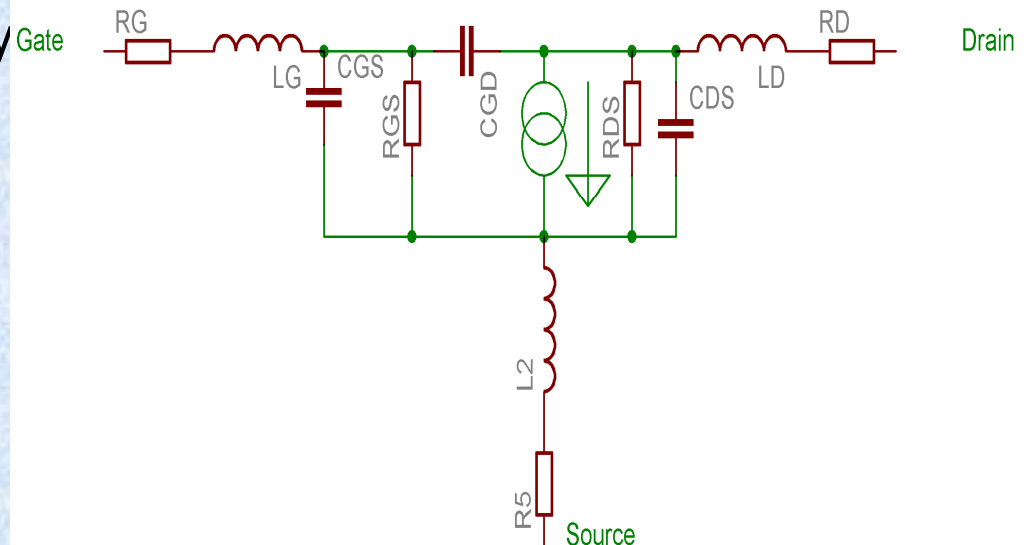
Output matching for Bodgers

- Drain voltage swings from V_{dd} to $V_{dd_{on}}$
- This is approximately 0 to V_{dd}
- If we assume the waveform is sinusoidal



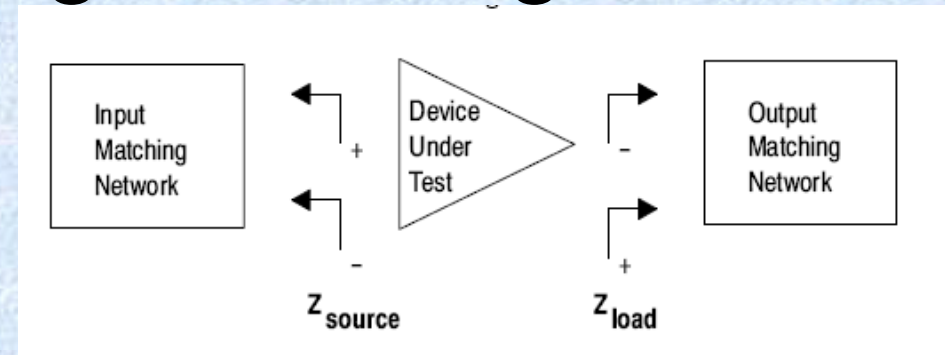
Equivalent circuit for LDMOS

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

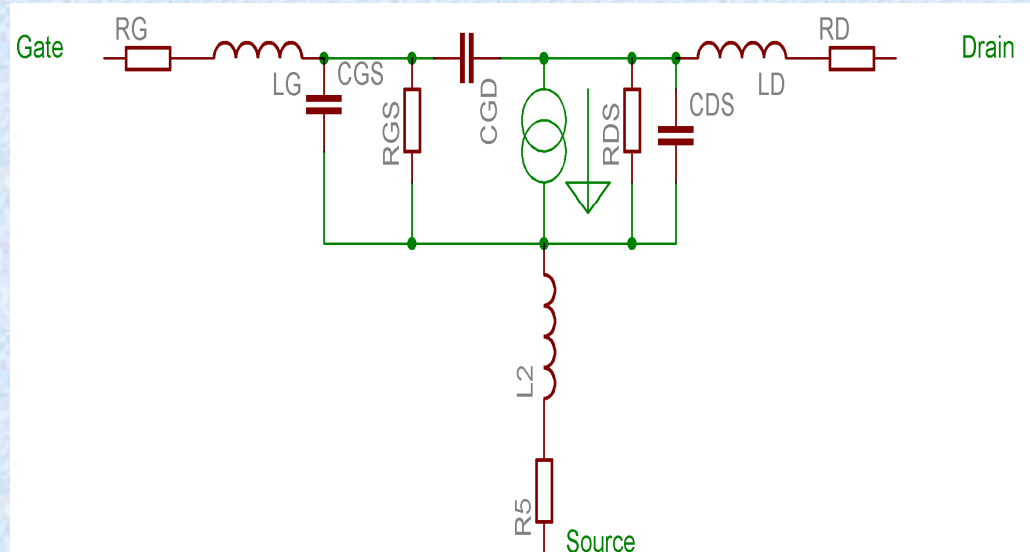


Output matching for Bodgers

- So to deliver the power, the device needs to “see”
- $R_{Load} = V_{dd}^2 / 2P_{out}$
- 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

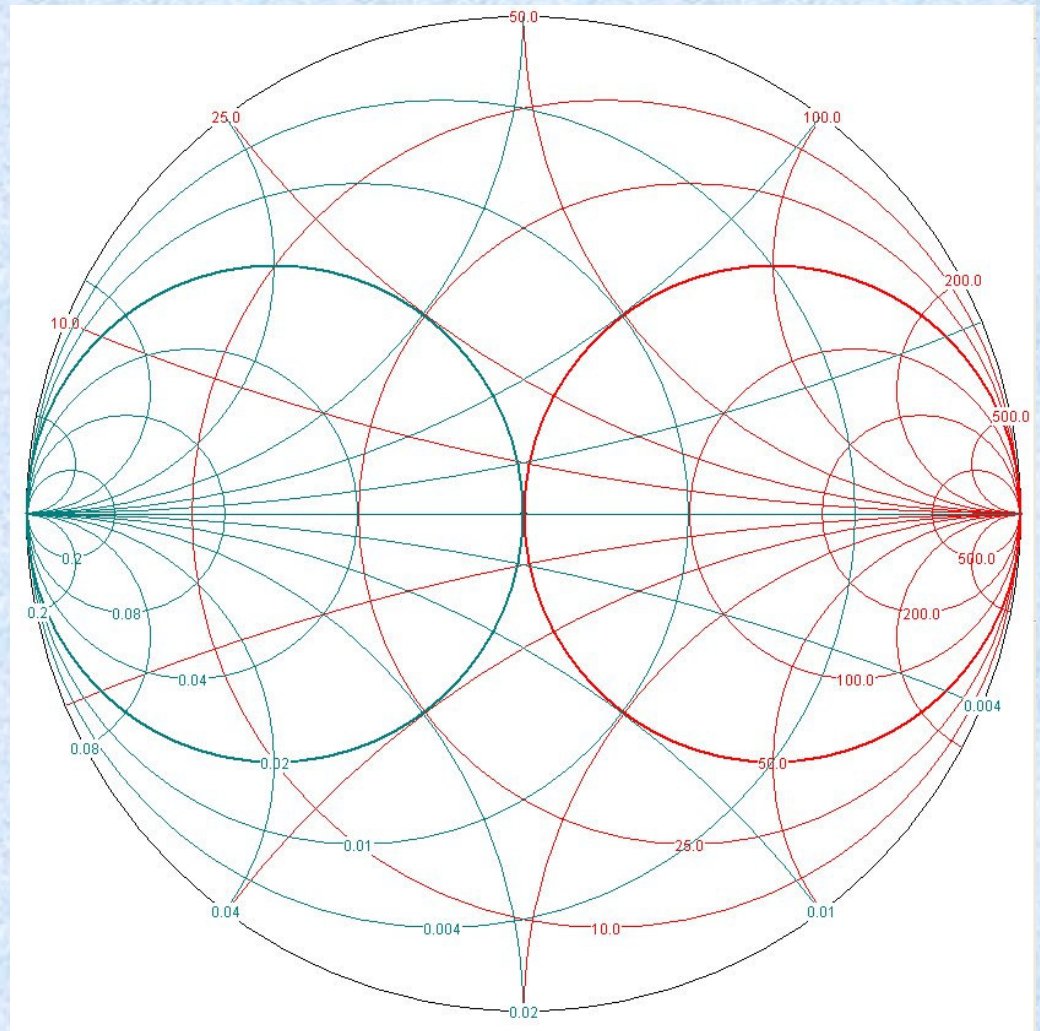
- So we have our output network requirements!
- $R_{\text{Load}} = V_{\text{dd}}^2 / 2P_{\text{out}}$
- in parallel with conjugate of C_{DS}
- But I prefer series circuits because impedances add.
- So
- Convert this to a series $R + jX$ format using Maths or a Smith Chart.

Example 6VP2300H device at $P_{out} = 300\text{Watts}$, 50 Volts

- This gives $R_{Load} = 4.16$ ohms in parallel with $C_{DS} = 120\text{pF}$
- 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

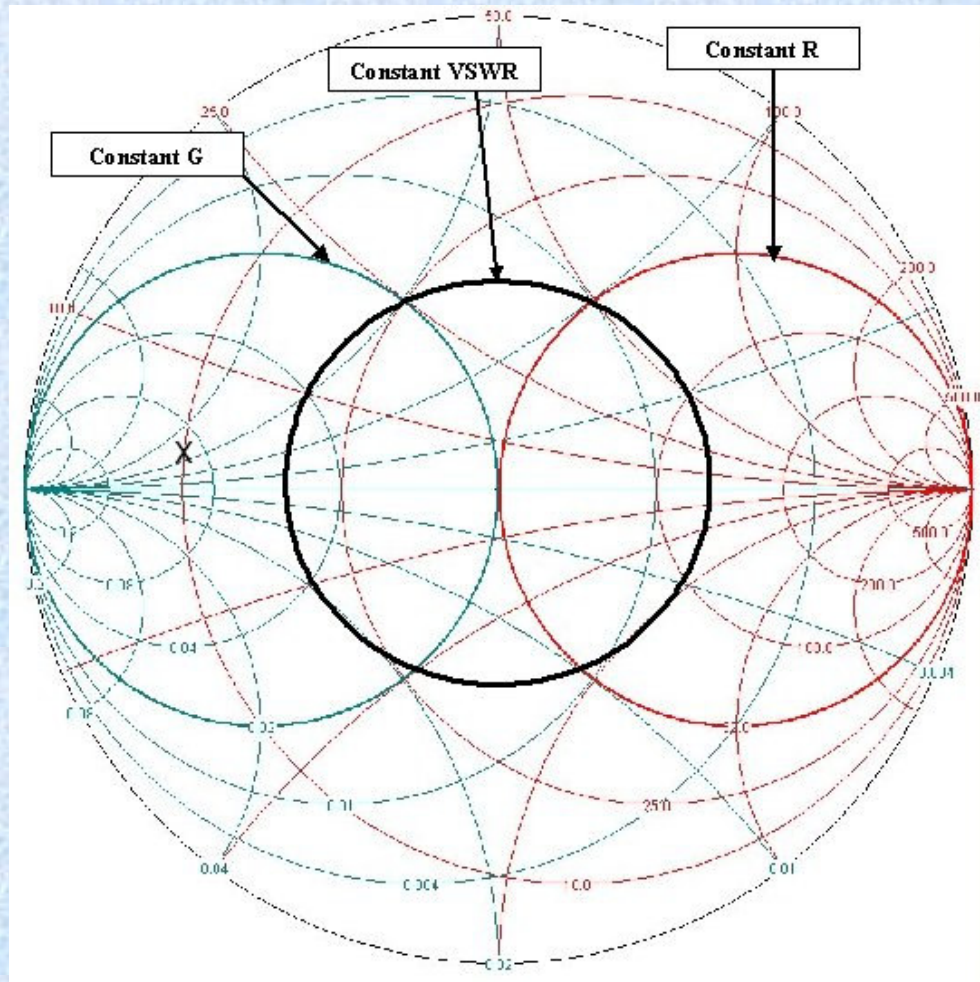
A brief aside on the Smith Chart

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



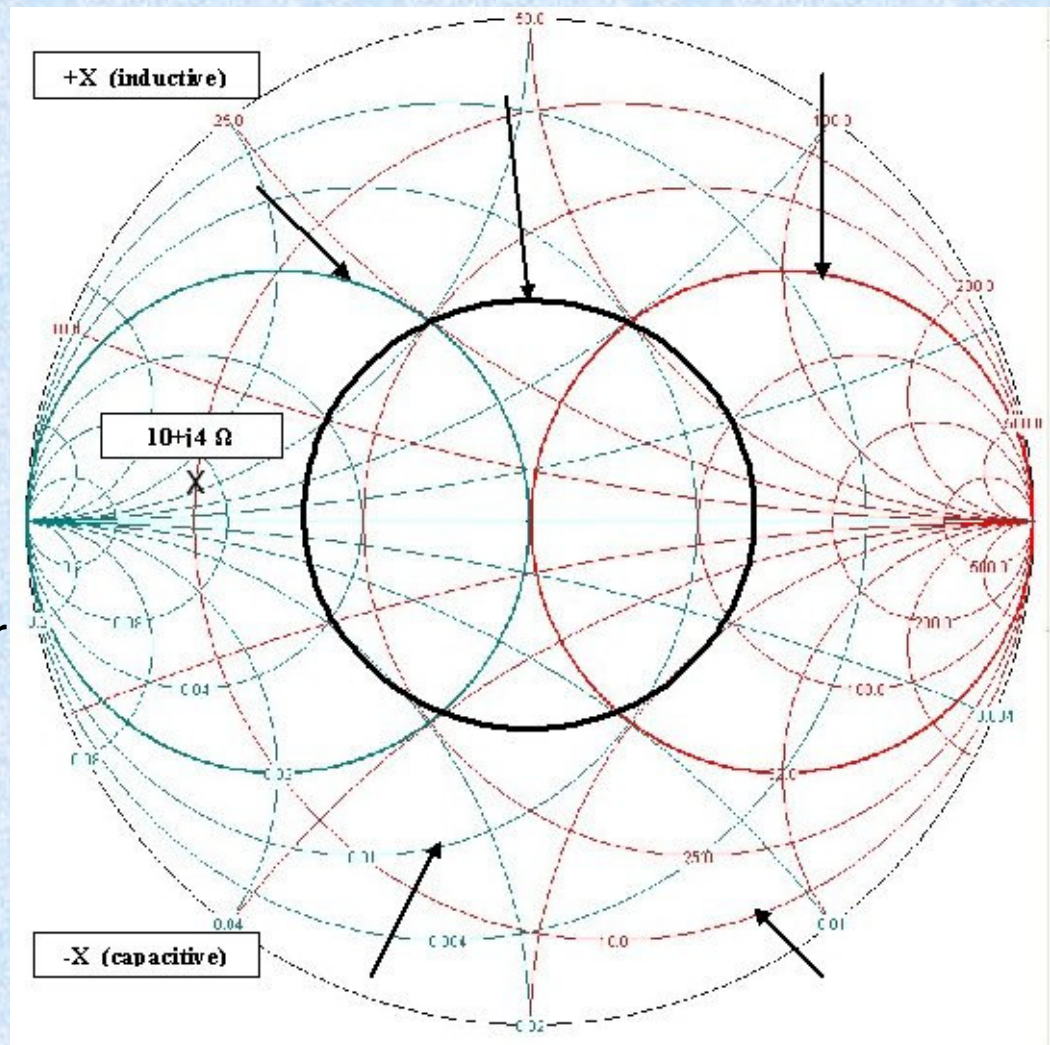
A brief aside on the Smith Chart

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



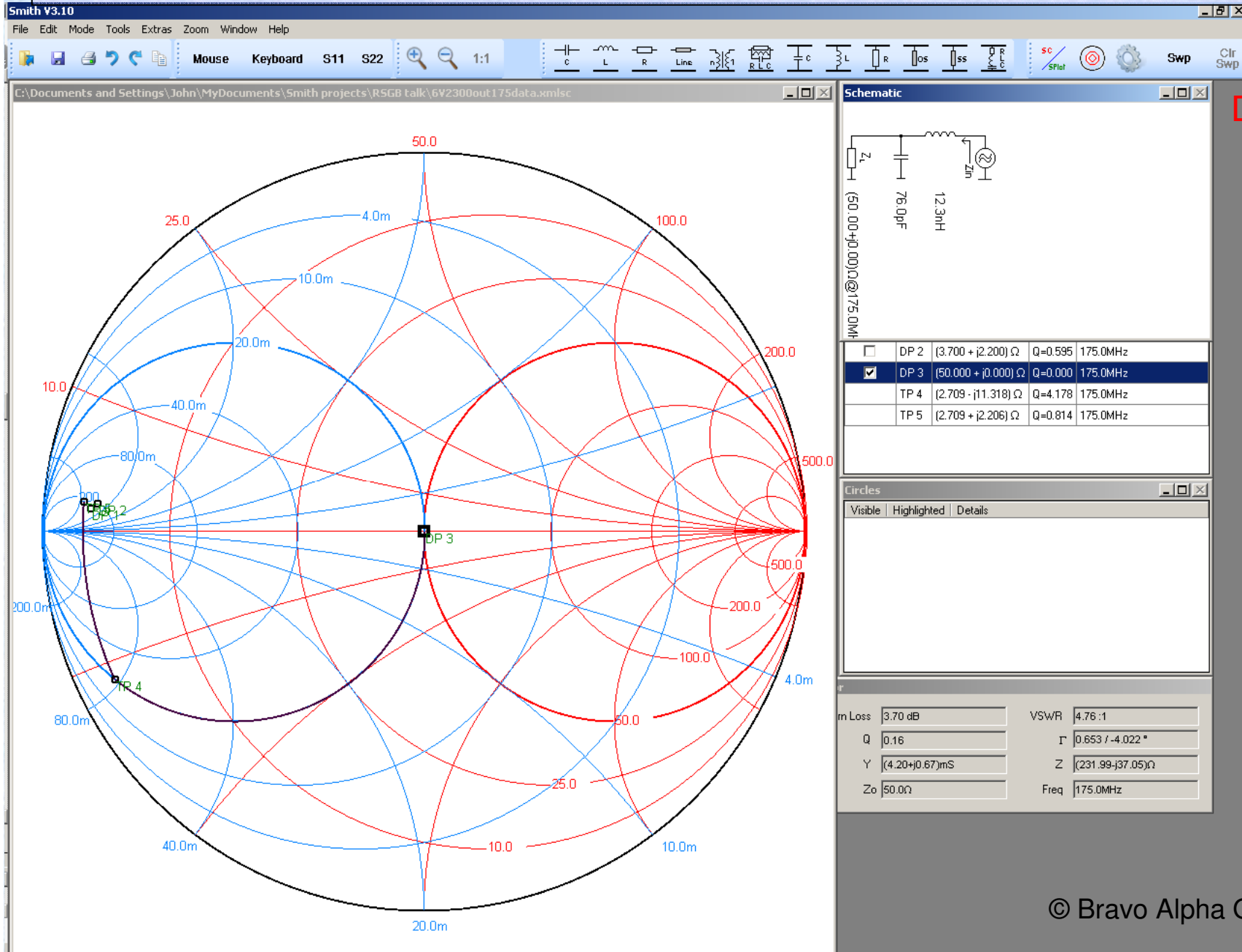
A brief aside on the Smith Chart

- Usually use “normalised” impedances,
 - i.e (actual Z)/ Z_0
- 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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John Worsnop G4BAO



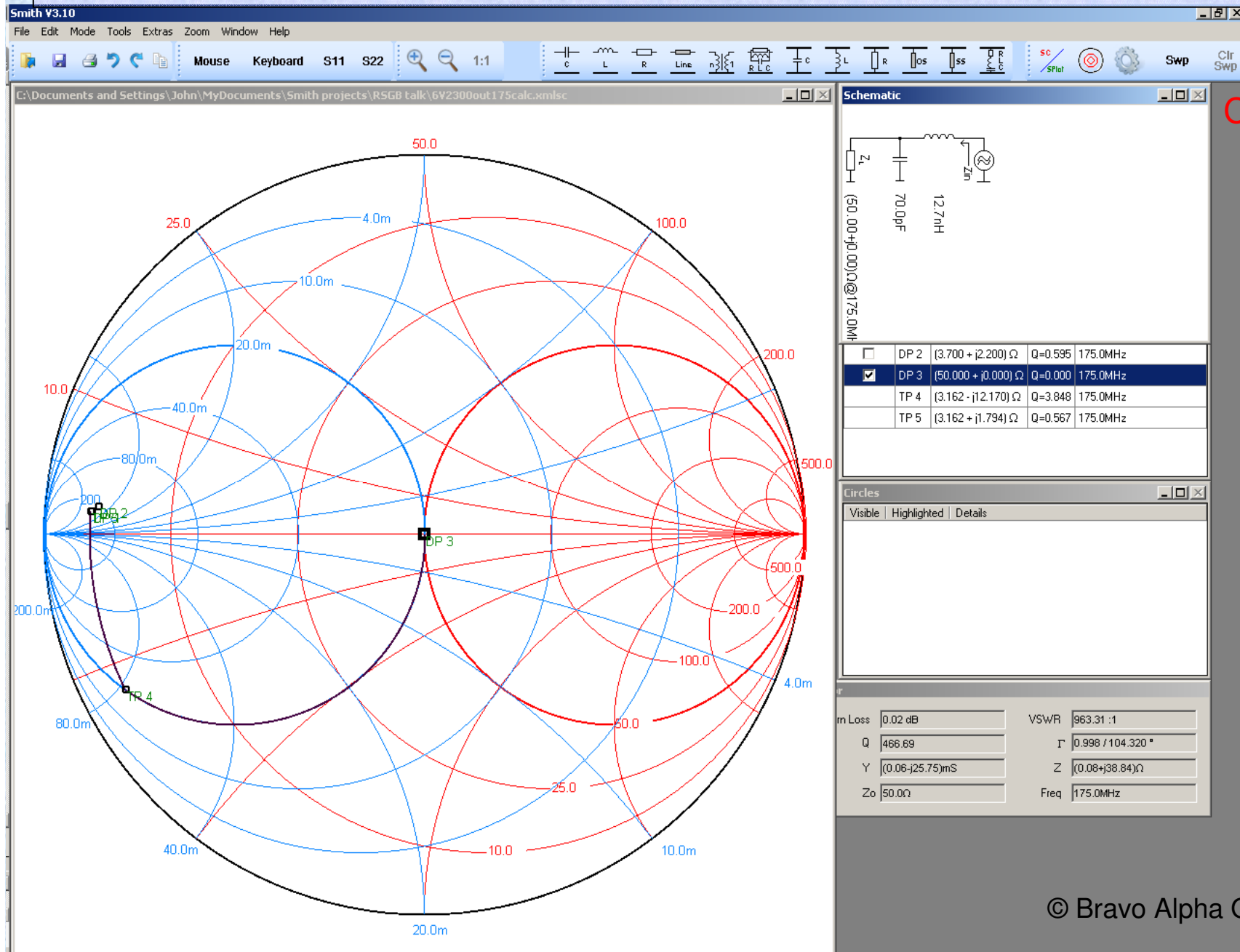
Datasheet

12.3nH
76pF

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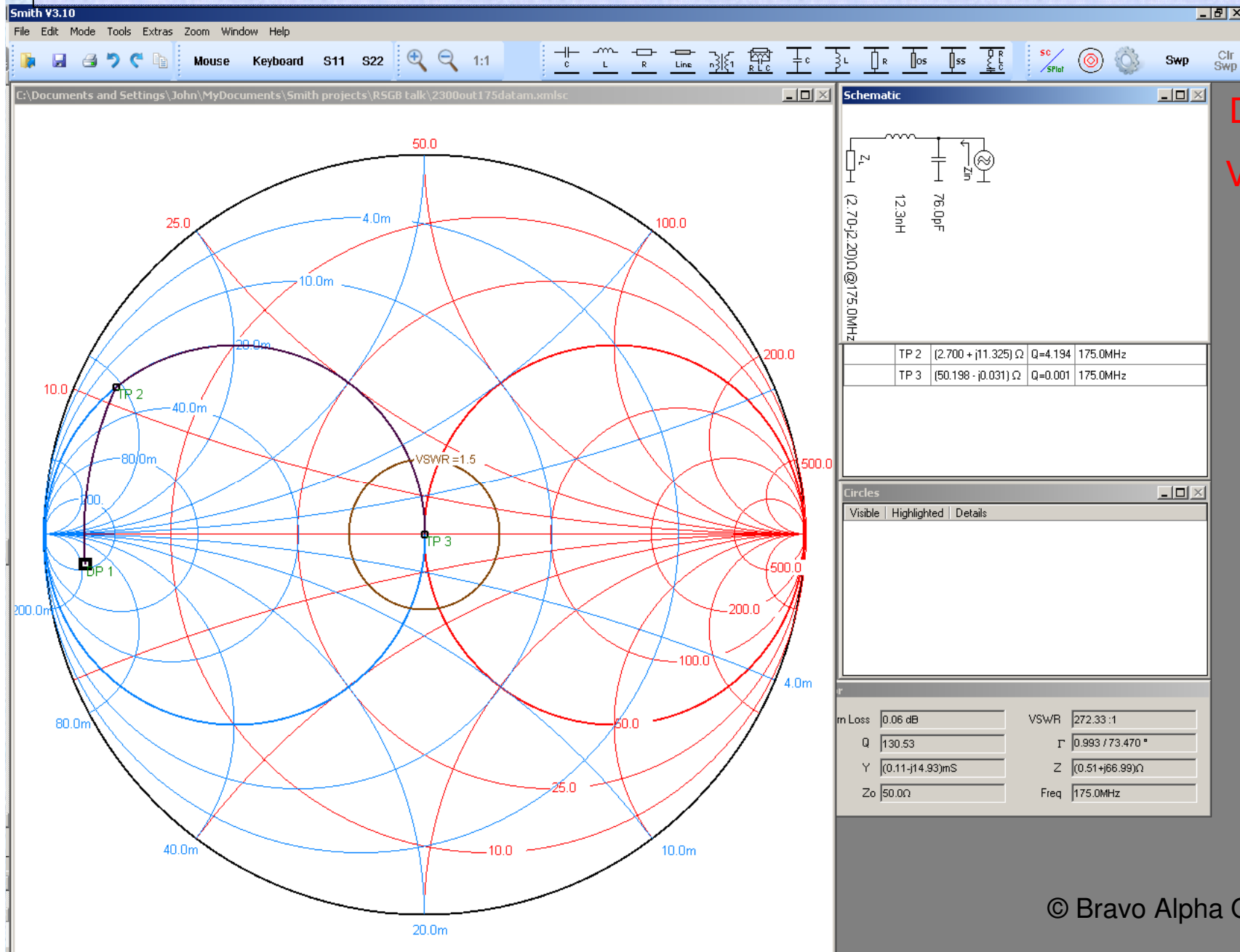


Calculated
12.7nH
70pF

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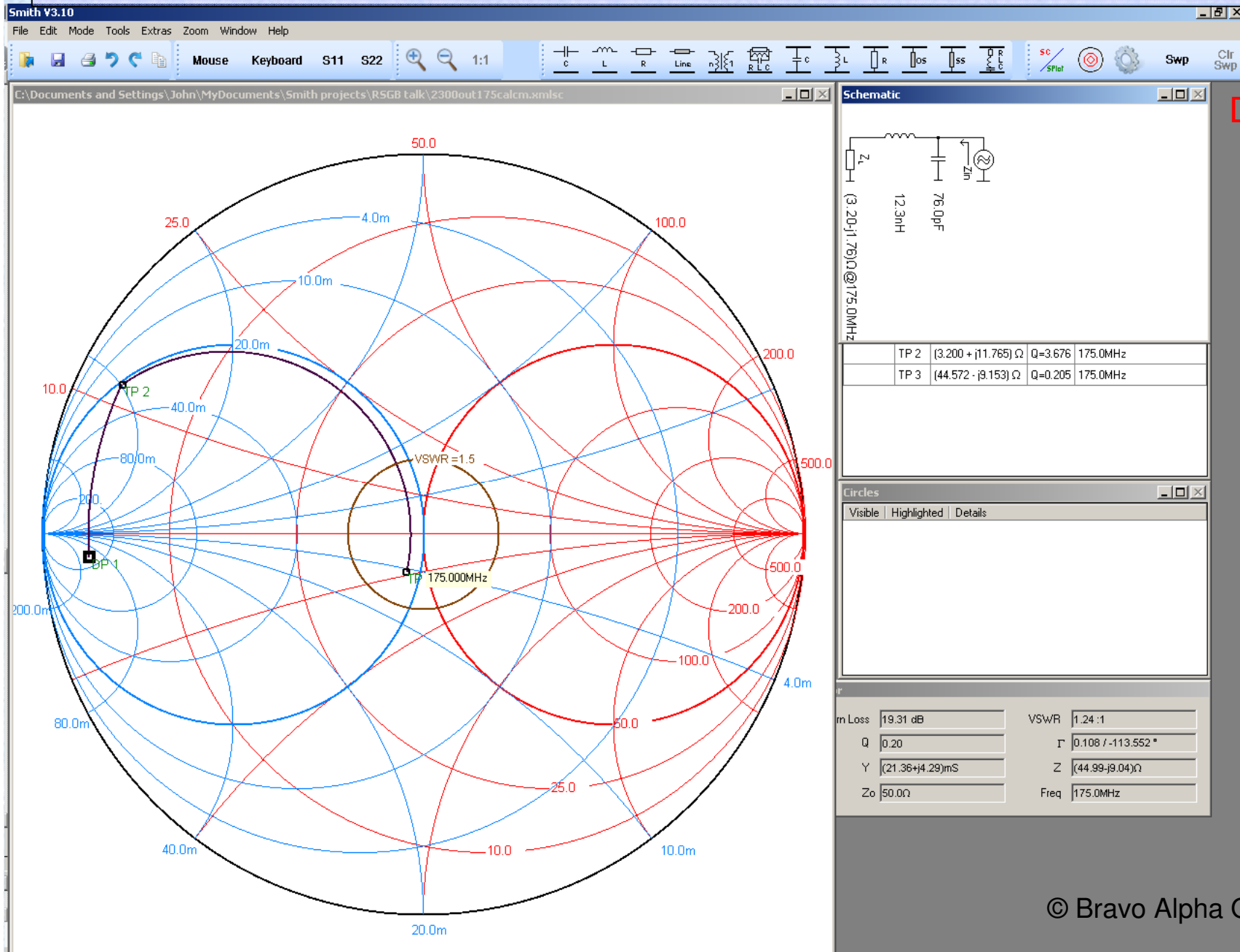


Datasheet
VSWR 1:1

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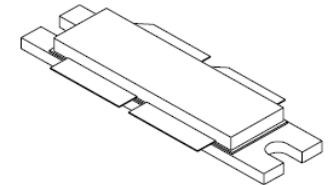
Datasheet

VSWR
1.24:1

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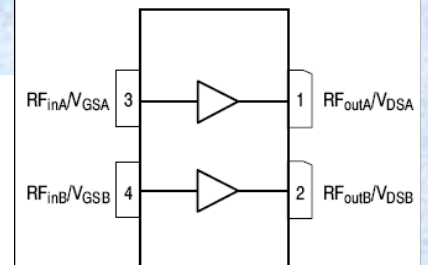
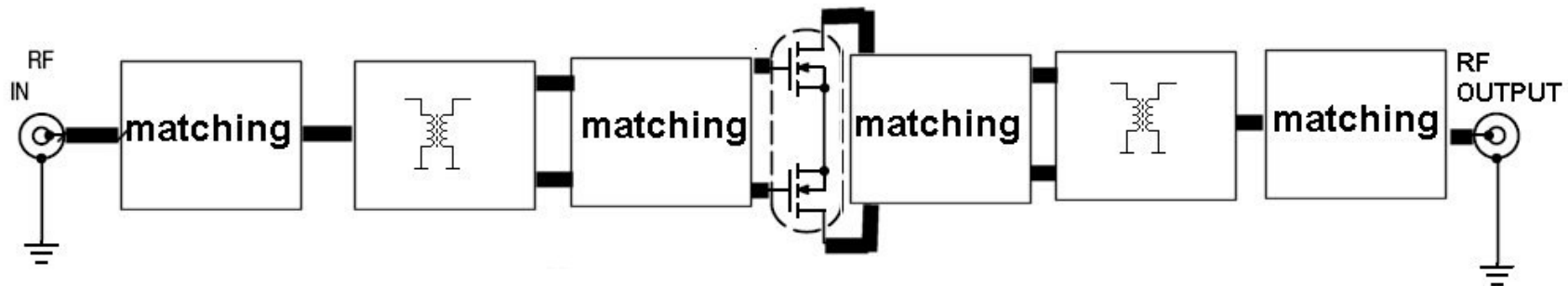
Gemini Devices - Transformer matching

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



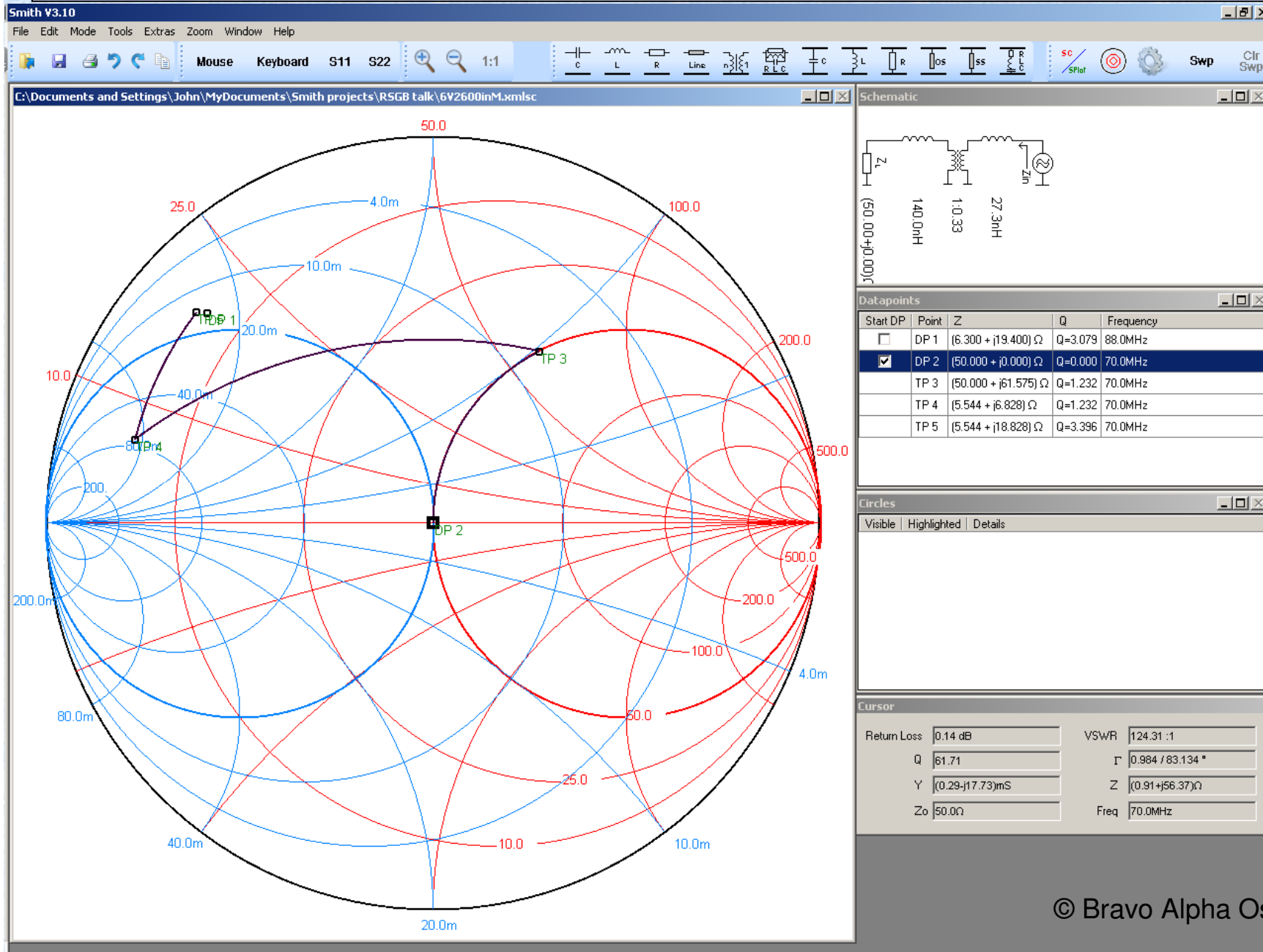
CASE 375D-05, STYLE 1
NI-1230

PART IS PUSH-PULL



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John Worsnop G4BAO



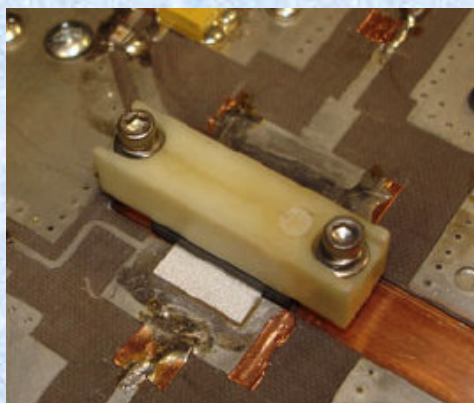
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Device mounting -The choices

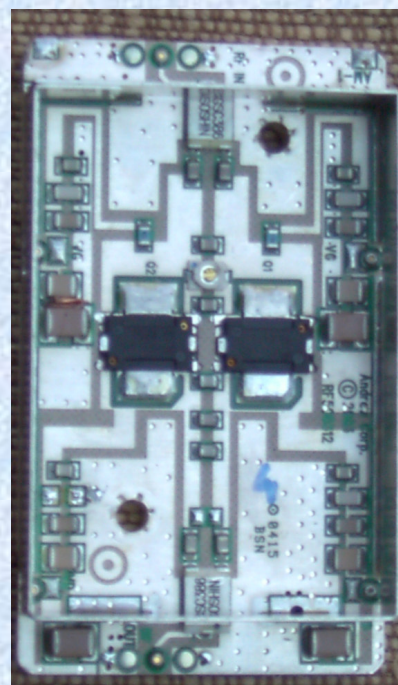
Bolt



Clamp



Solder



Device mounting - clamping vs bolting

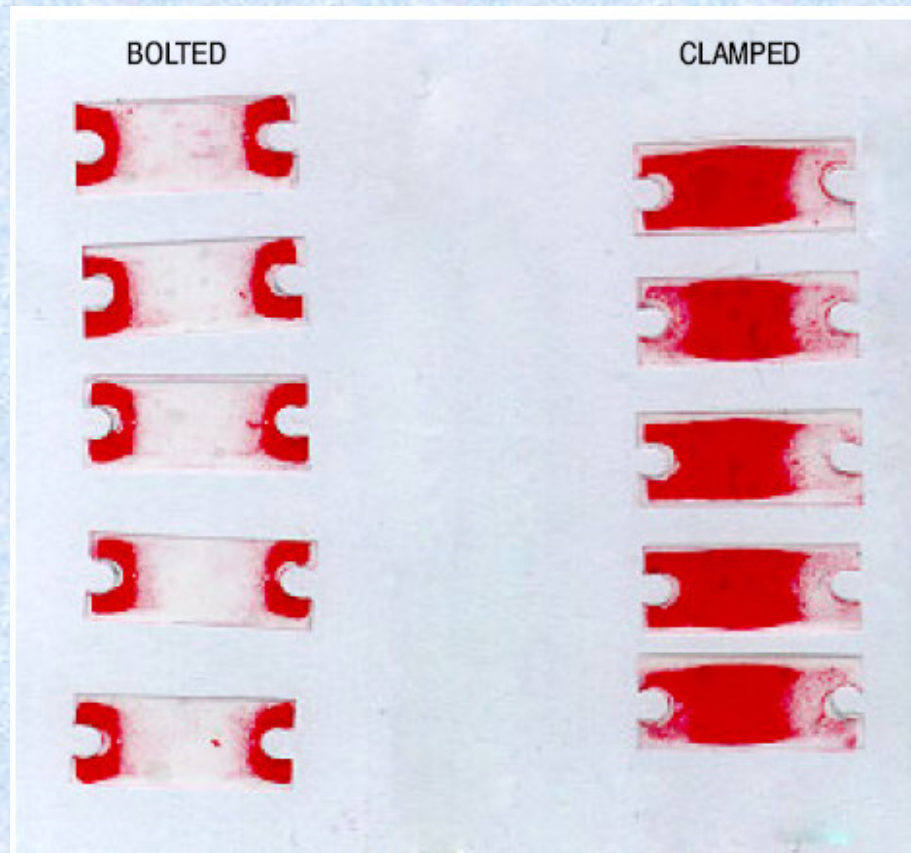
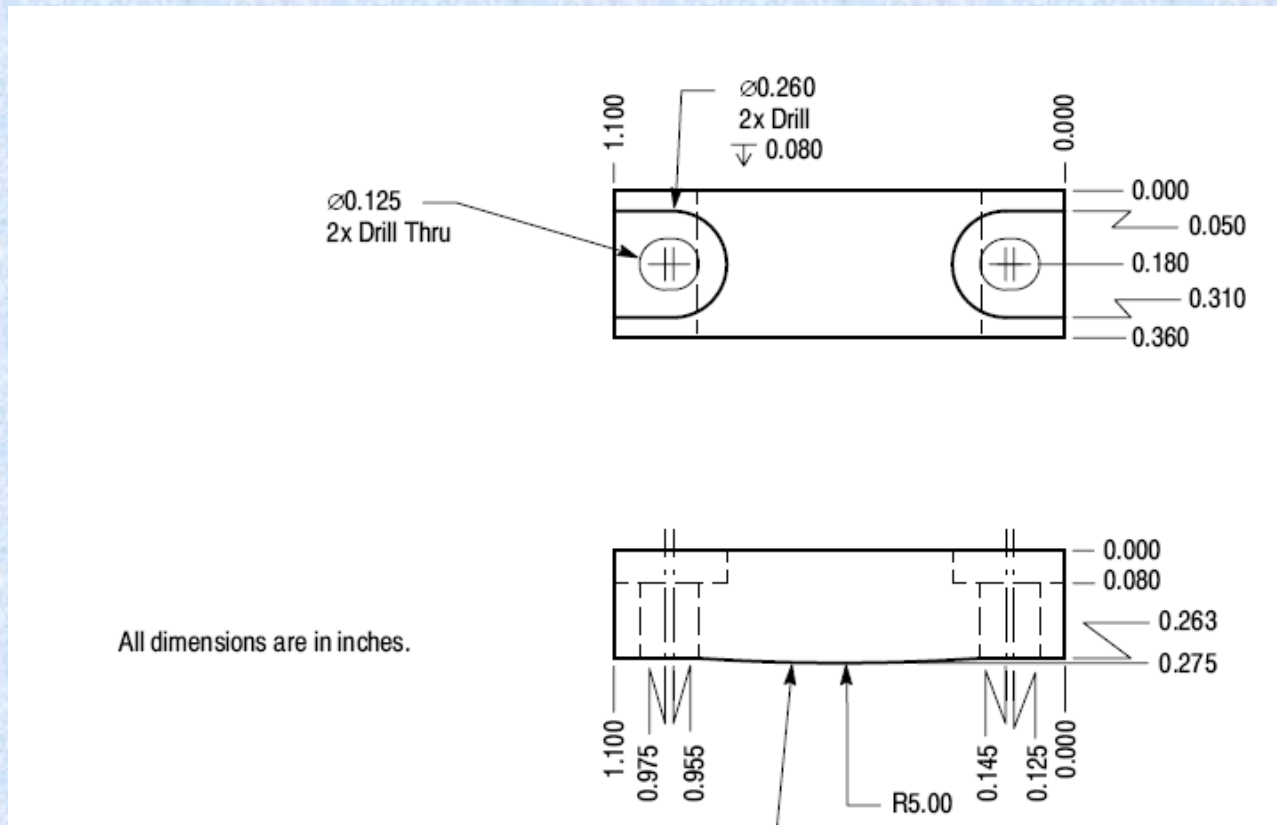


Figure 7. Pressure Paper Test Results for Five TO-272WB Packages with #4-40 Screws at a Mounting Torque of 4.0 in-lb

Source Freescale AN-3789

Device mounting – Typical clamp design

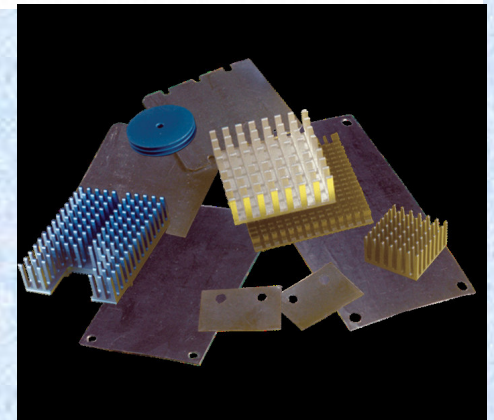


Source Freescale AN-3789

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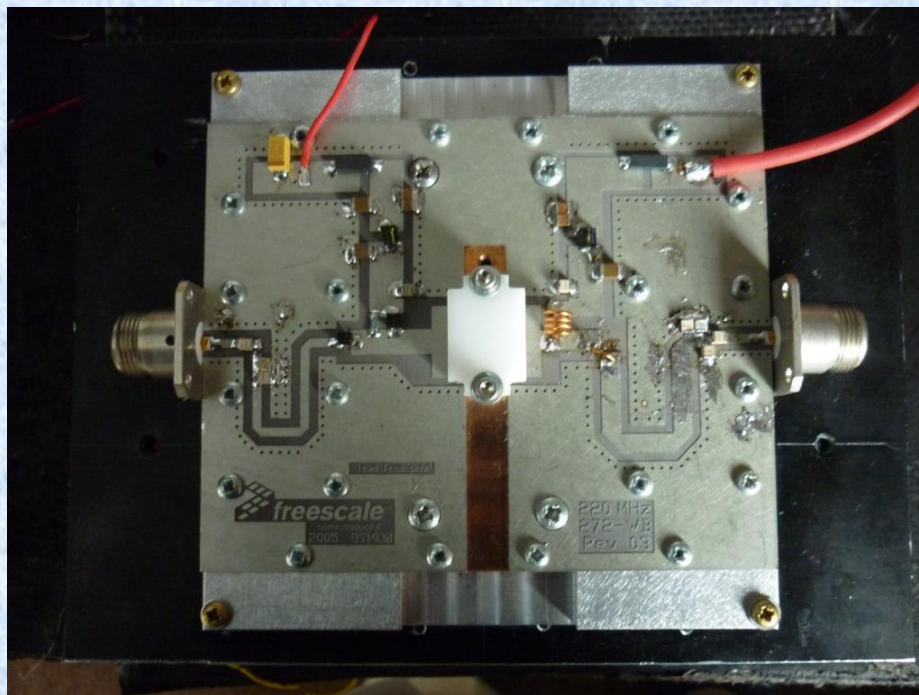
Device mounting – Getting the heat away

- 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)



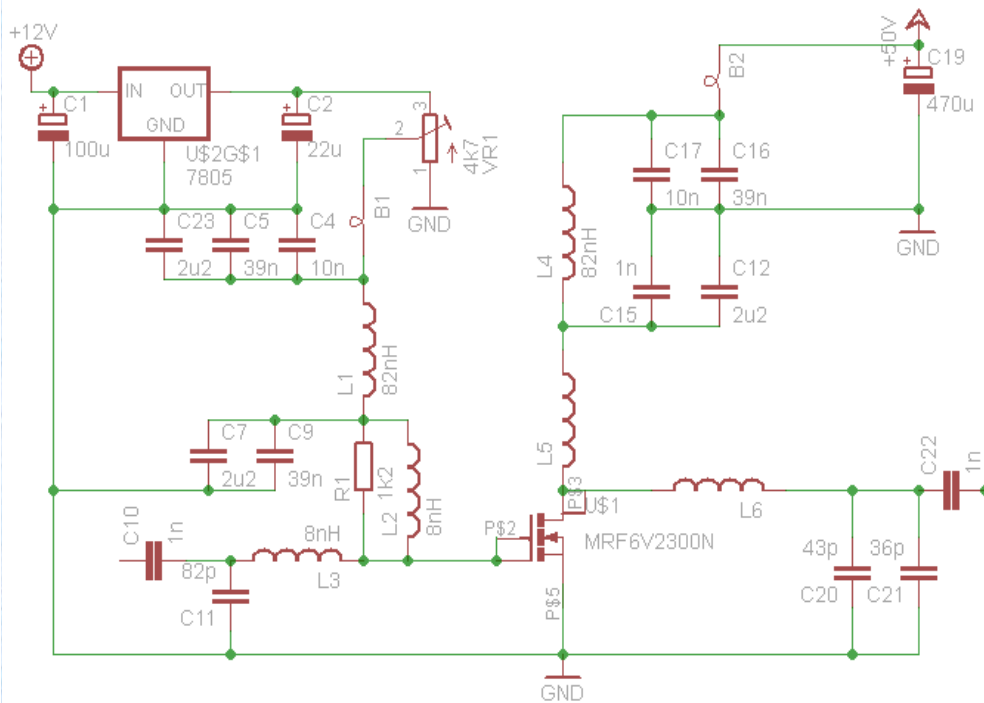
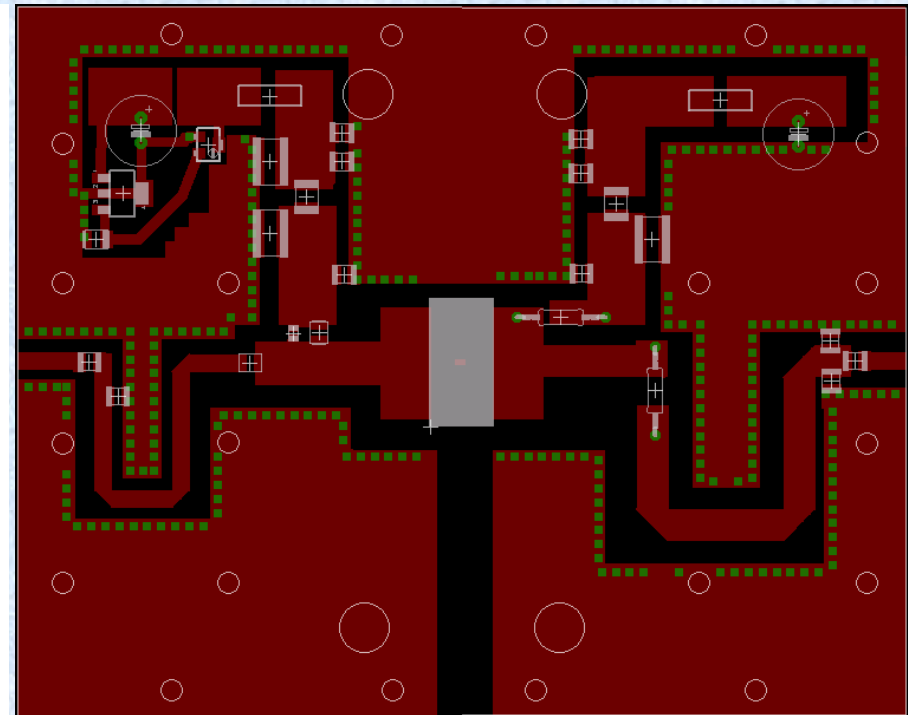
A 144MHz design with the 6V2300

- 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.



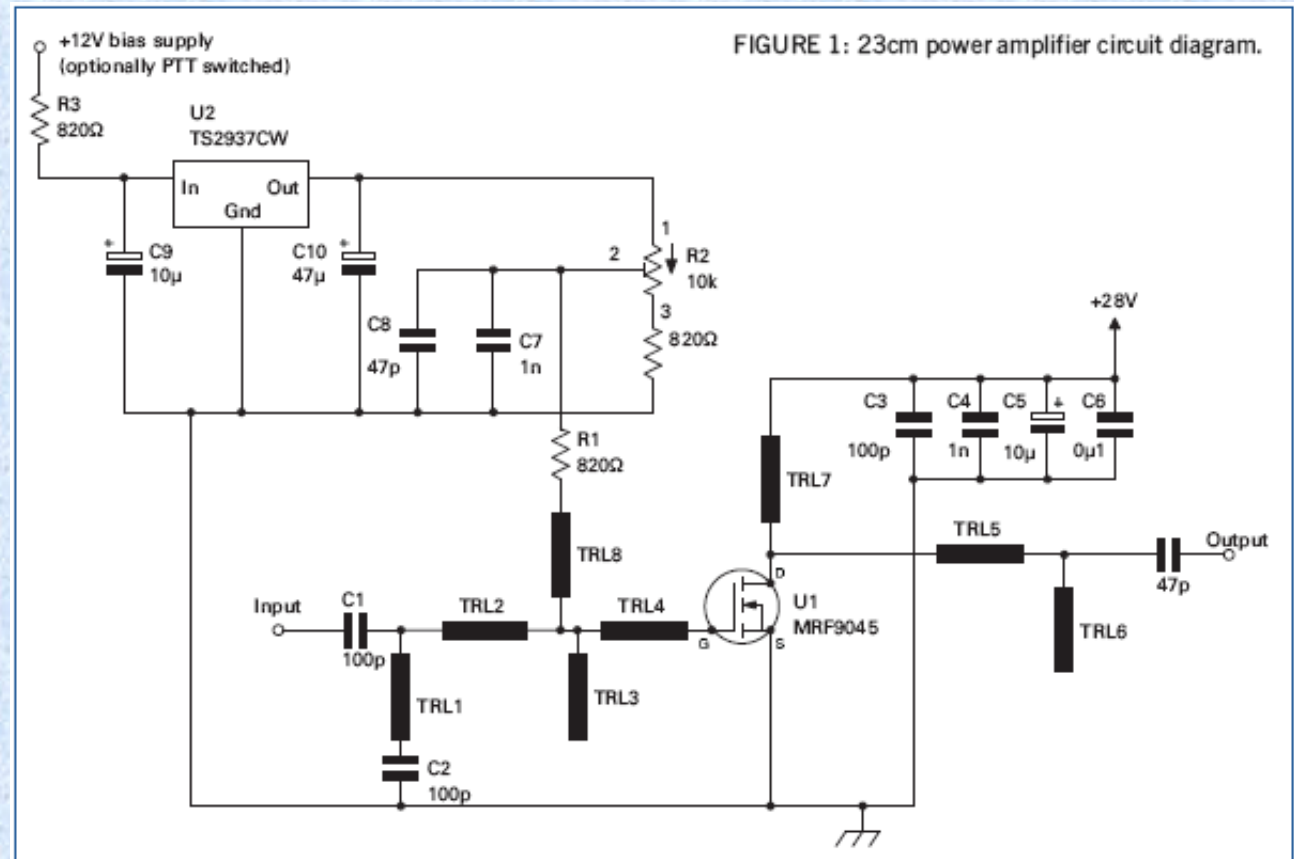
A 144MHz design with the 6V2300

- Eagle PC design done with bias regulator.



The G4BAO 23cm design with the MRF9045

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



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