AMPLIFICATION CIRCUITS AND PATTERNING METHODS OF ORGANIC FIELD-EFFECT TRANSISTORS

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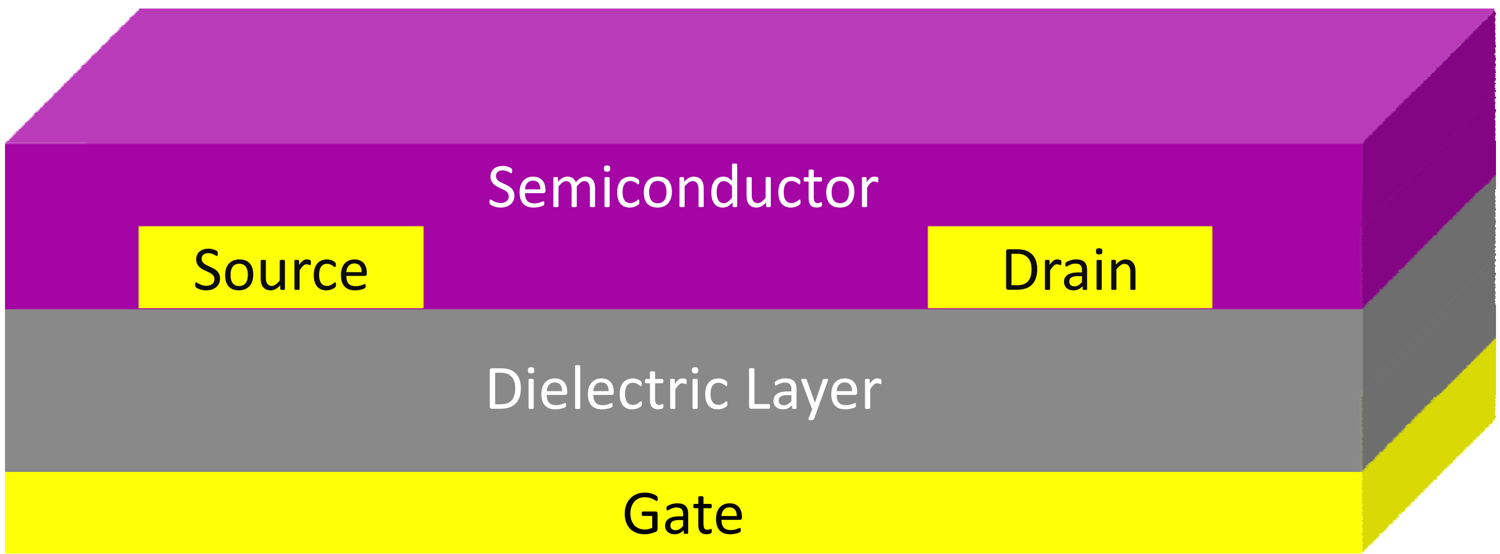
Organic Field-Effect Transistors

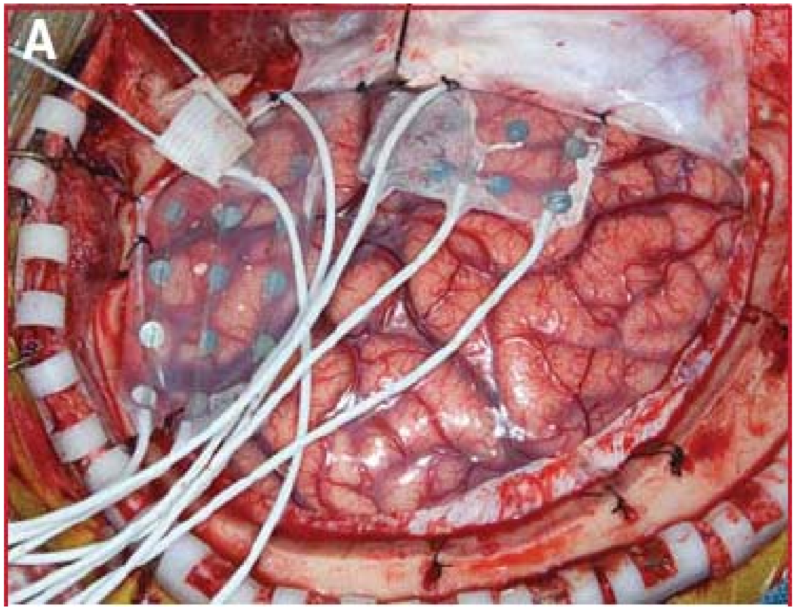
- Doped Si bottom gate and SiO2 dielectric layer
- Pentacene semiconductor
- Self-Assembled Molecules on source and drain for ambipolar characteristics
- Mobility around 0.25cm2/Vs
- Maximum drain currents near 30μA



Background

- OFETs hold great promise for the future of brain-computer interfaces
    - Conformal
    - Small feature size
    - Greater neural selectivity
    - Devices placed directly on surface rather than wired

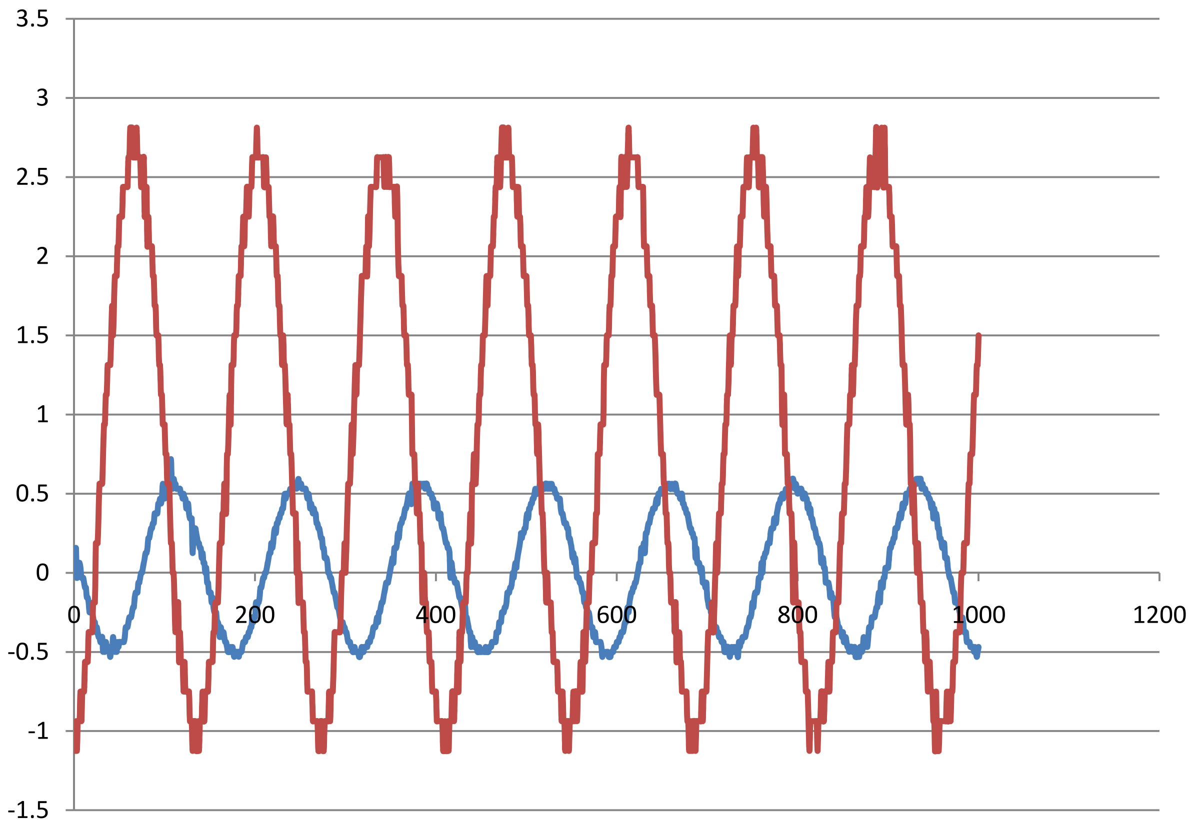
- Current techniques
    - 3mm diameter sensors
    - 1cm spacing between sensors
    - Around 150,000 neurons/mm2
    - Bulky wire arrays attaching to machinery



J.J. Van Gompel, G.A. Worrell, M.L. Bell, T.A. Patrick, G.D. Cascino and C. Raffel et al., Intracranial Electroencephalography with Subdural Grid Electrodes: Techniques, Complications, and Outcomes, *Neurosurgery*, 63 (2008) 498–505.

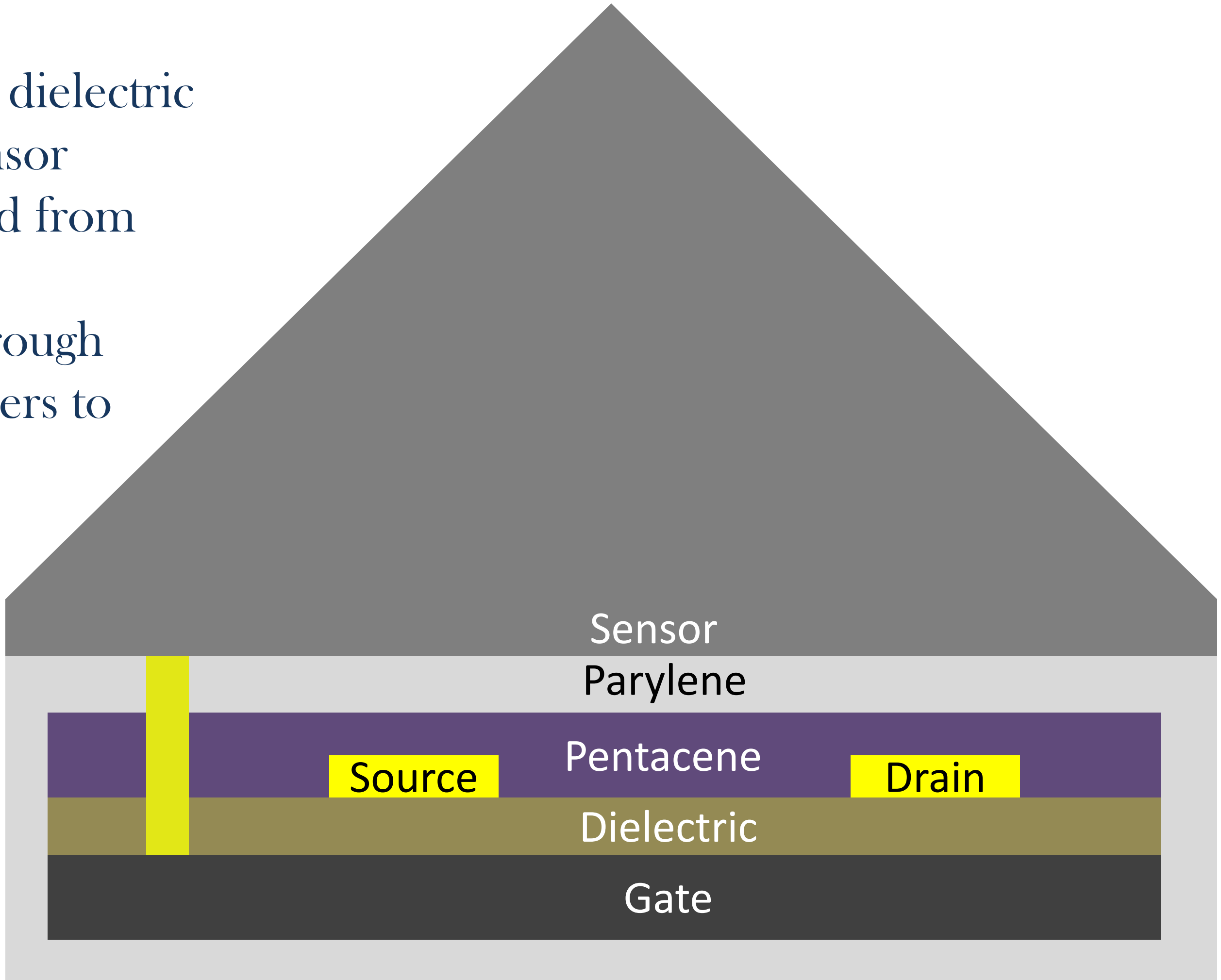
What needs to be done

- Amplification
  - Brain signals are very low voltage, order of microvolts
  - Need to amplify these signals for use in electronics
  - Organic transistors can be made in amplifying configuration

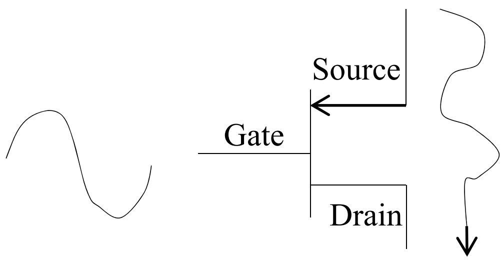


What needs to be done

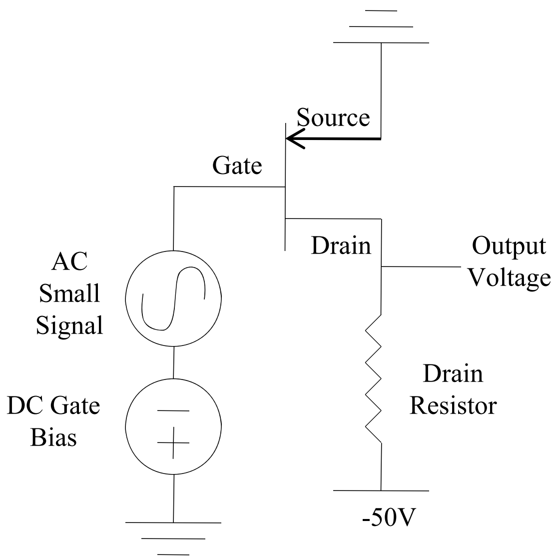
- Patterning via holes
  - Brain is in aqueous environment
  - Parylene can serve as encapsulant for devices
  - Parylene can also act as a dielectric between transistor and sensor
  - Electrodes must be placed from sensor in brain to gate
  - Holes must be etched through parylene and transistor layers to make this connection



FET Amplifiers



- Transistors in amplifying topology can generate “small signal” gain
    - DC voltage applied to gate
    - Transistor, in saturation, draws drain current
    - Small perturbation of gate voltage (AC signal) causes corresponding small change in drain current
    - Take advantage of this drain current oscillation

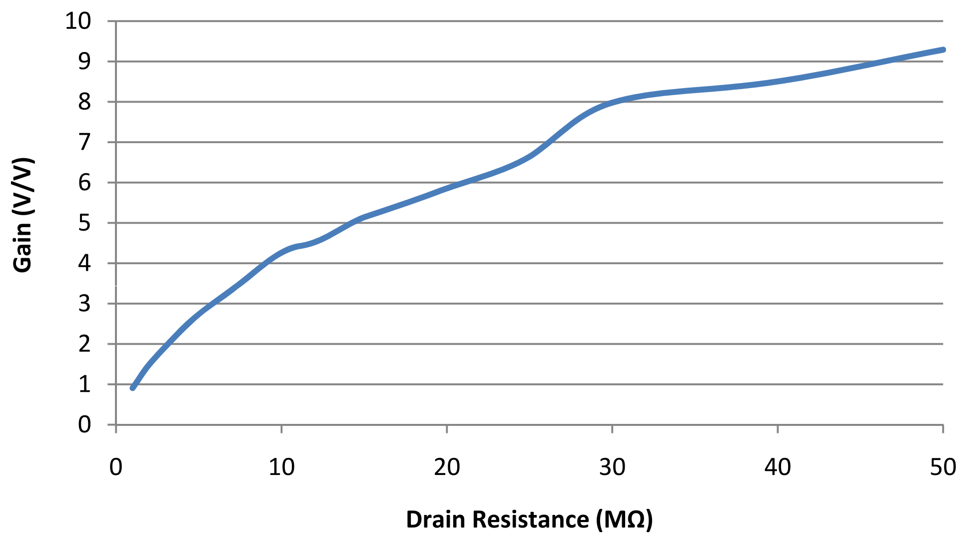


Common Source Amplifier

•Source is grounded
•Drain is connected to power supply by resistor
•Small drain current perturbation now causes a small voltage signal at the drain
•Amount of gain is determined by the device characteristics, resistance, and DC biasing

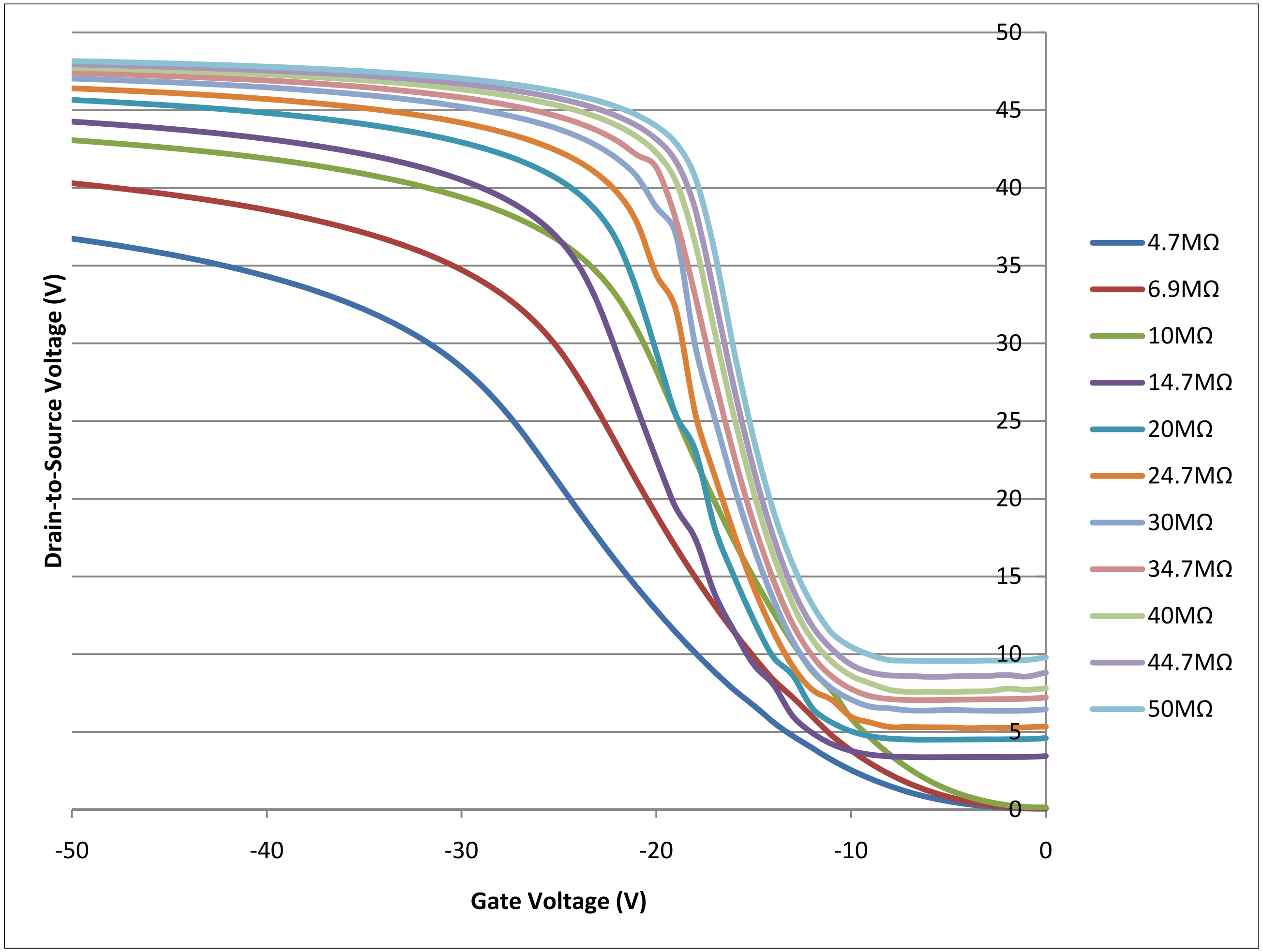
Common Source Amplifier Calculations

$$|Gain| = g_m R_d = \mu C_{ox}(|V_{gs}| - |V_t|)R_d$$



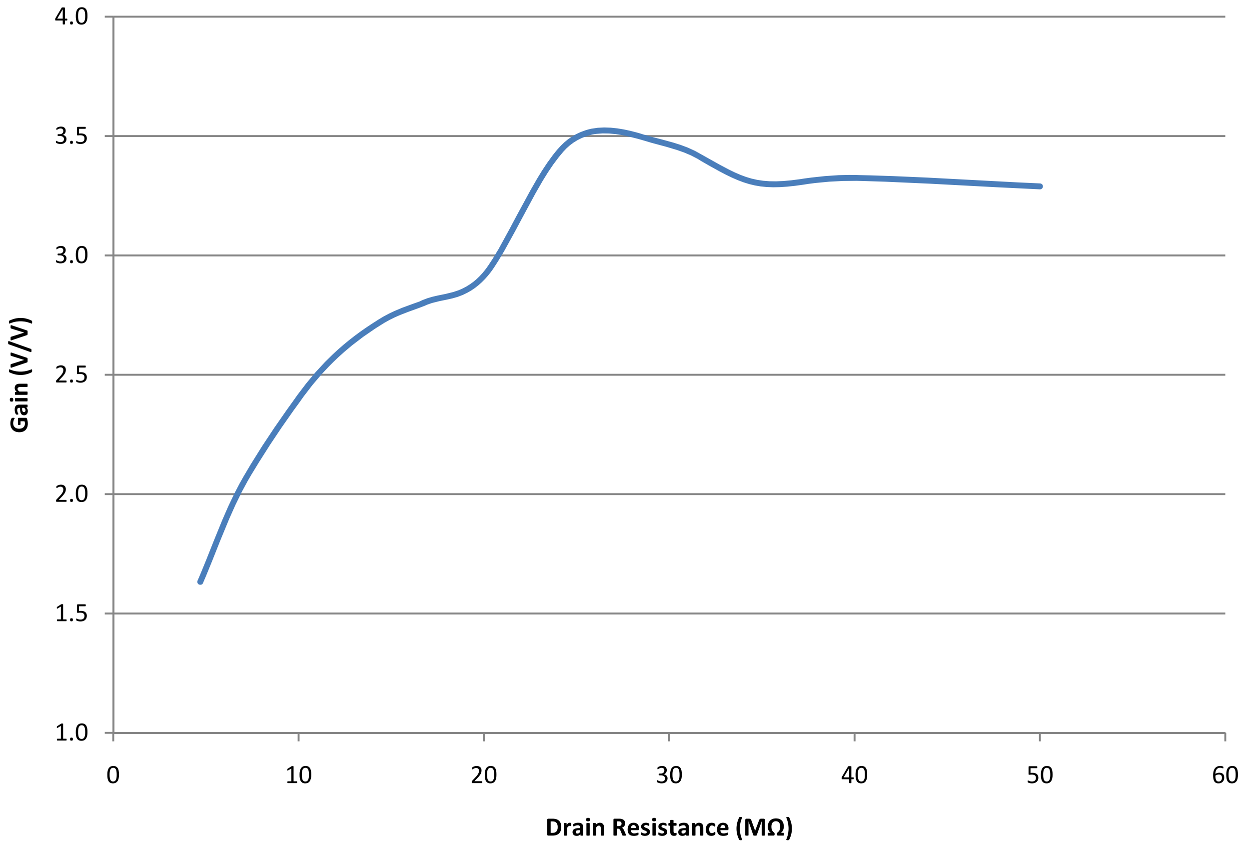
•Used constant mobility and threshold voltage

DC Analysis Gain Predictions



Drain Resistance	Slope
4.7MΩ	-1.599
6.9MΩ	-2.161
10MΩ	-2.695
14.7MΩ	-3.08
20MΩ	-3.368
24.7MΩ	-3.776
30MΩ	-3.929
34.7MΩ	-4.108
40MΩ	-4.287
44.7MΩ	-4.349
50MΩ	-4.319

Small Signal Gain Results



Drain Resistance (Mohm)	Maximum Gain (V/V)
4.7	1.63233
6.9	2.02963
10	2.40055
12.2	2.59399
14.7	2.73468
16.9	2.80596
20	2.91431
24.7	3.48040
30	3.46452
34.7	3.30461
40	3.32467
50	3.28924

- Used 1Vpp small signal input at 15Hz
- About half as much as calculated; only slightly less than DC prediction

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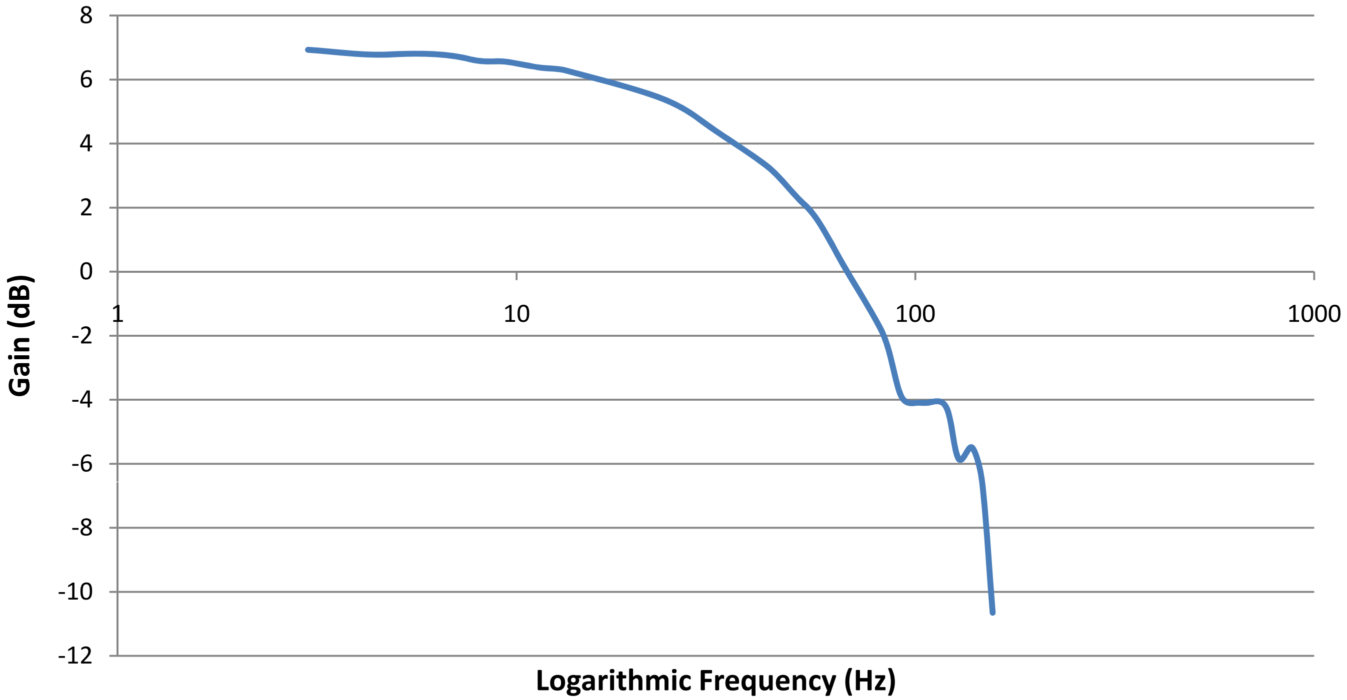
Frequency Response

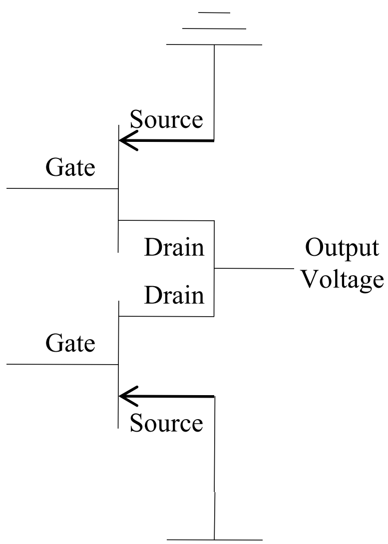


- -3dB point near 35Hz
- Higher frequencies severely limited gain due to high gate capacitance
- Rolls off greater than -20dB/decade

Further Investigation

•Why calculations were off (determining how mobility and threshold voltages change with gate voltage)

•Different amplifying circuits to take advantage of ambipolar characteristics



Ambipolar active load

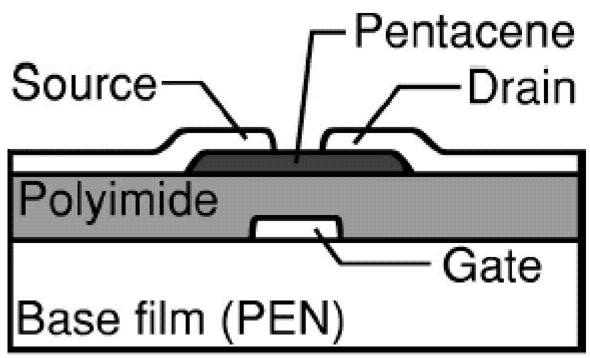
Patterning Methods

- Parylene was etched using oxygen plasma
  - Glass and silicon substrates measured well on profilometer
  - 100W, 500mTorr showed a rate of 0.2µm/minute
  - Kapton samples gave no decent measurements

- BCB and spin-on-glass were etched with SF6
  - Spin-on-glass did not exhibit etching with O2
  - SF6 etching did not give any consistent resuslts
  - BCB results could not yet be measured

Further Investigation

•Using polyimide to avoid SoG and Kapton etching problems



•Attempt etching using photoresist in hole pattern, then test with deposited electrode

H. Kawaguchi , T. Sakurai, High Mobility of Pentacene Field-Effect Transistors with Polyimide Gate Dielectric Layers, *Appl. Phys. Lett.*, 84 (2004) 3789-3791.

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