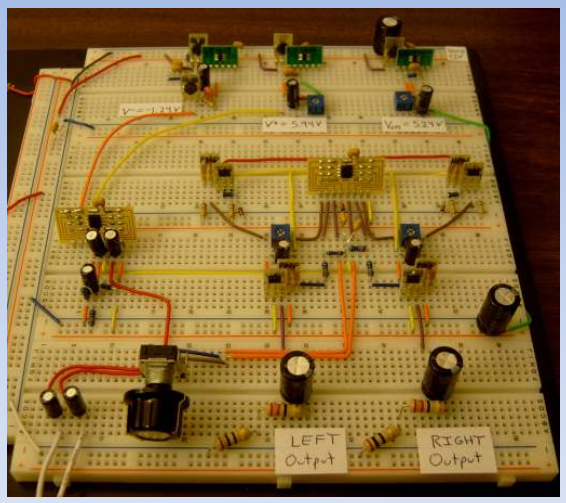
High Efficiency Headphone Amp

EE 410 Design Competition



Devin Ott Kevin Cheng Xiangyu Dong Greg Abrami

Outline

- Design Requirements and Goals
- Design Approach
- Circuit Design
  - Schematic
  - Flowchart
- Experimental Data
- Results Summary
- Conclusion

Purpose and Goals

- Design High Efficiency Headphone Amplifier:

Power Requirements	
Power Consumption	< 400mW
Battery Life	> 90hrs
Noise Requirements	
THD (10mW output)	< 0.1%
THD (100mW output)	< 1.0%
Noise Density (output)	< -128dB/√Hz
Material Cost	
Overall	< $40

Design Approach

Minimize power consumption

1. Minimize supply voltage
   - Load requires ≥ $2.53V_{PEAK}$
2. Minimize currents

$$P = IV$$

Rail-to-Rail Output

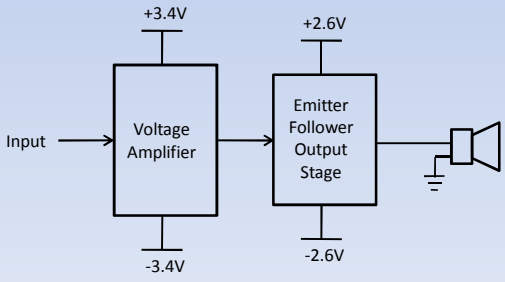
- Advantage: lower power consumption
  - Only requires 2 x 2.53V = 5.06V supply
- Disadvantage: complexity
  - Difficult to design output stage

CHALLENGE:
Is it possible to attain the efficiency of rail-to-rail output using a simple output stage?

SOLUTION:

Emitter Follower Output Stage

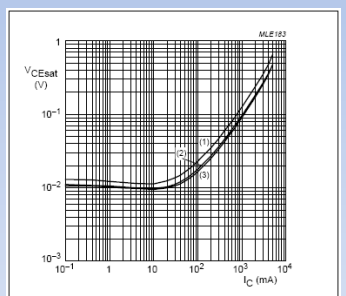
- Keep collector voltages low: $|V_C| = 2.6V$
- Use low $V_{CE(sat)}$ transistors (BISS)
- Use ±3.4V amplifier circuit to drive V_B



Reduces Power Consumption by approximately $V_{BE} \times I_C \times 2$

BISS (**B**reakthrough **I**n **S**mall-**S**ignal) Transistor

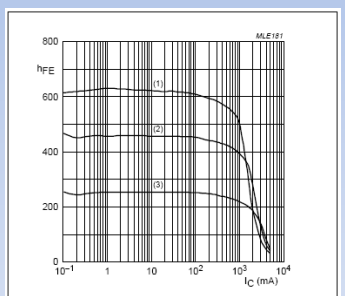
Very low $V_{CE(sat)}$ < 100mV



I_C/I_B = 20.
(1) T_{amb} = 100 °C.
(2) T_{amb} = 25 °C.
(3) T_{amb} = −55 °C.

Fig.8 Collector-emitter saturation voltage as a function of collector current; typical values.

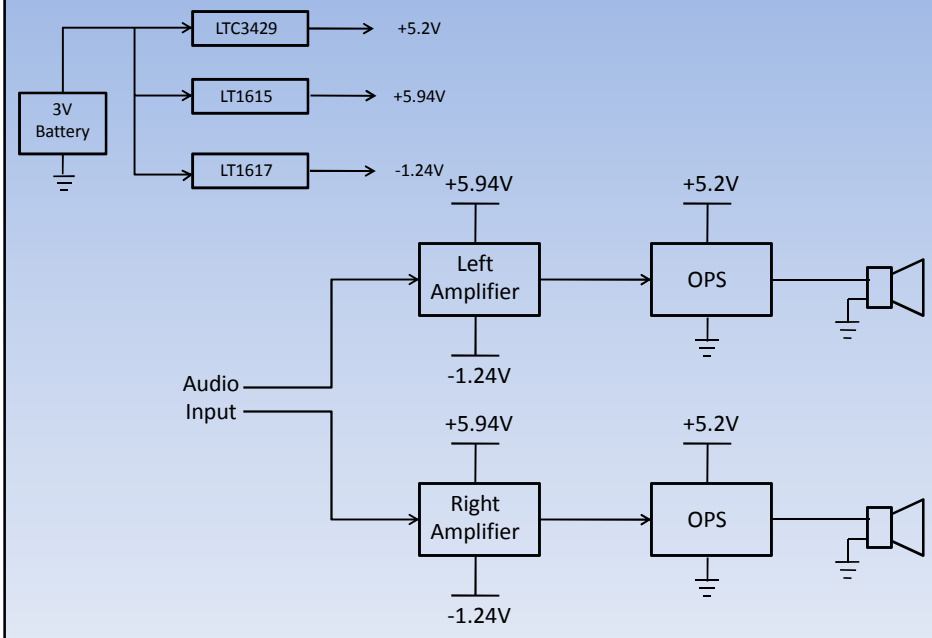
High Gain: $h_{FE} \approx 450$



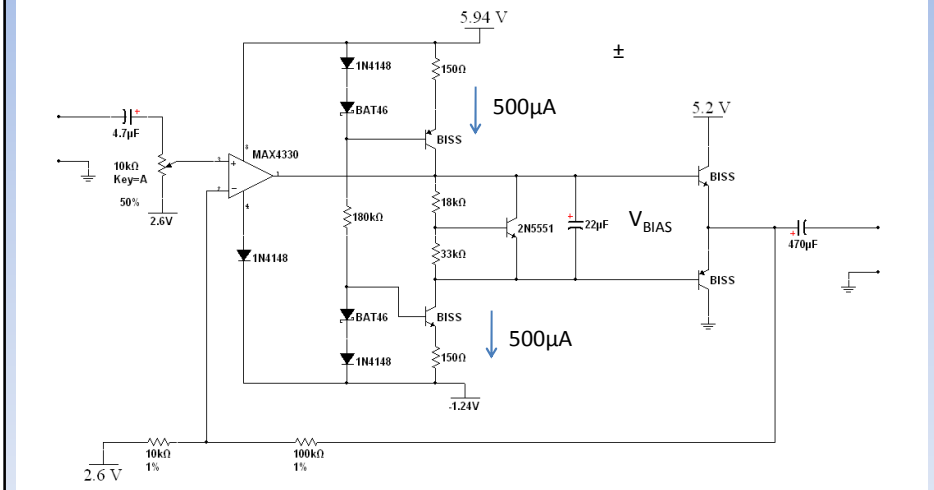
V_{CE} = 2 V.
(1) T_{amb} = 100 °C.
(2) T_{amb} = 25 °C.
(3) T_{amb} = −55 °C.

Fig.6 DC current gain as a function of collector current; typical values.

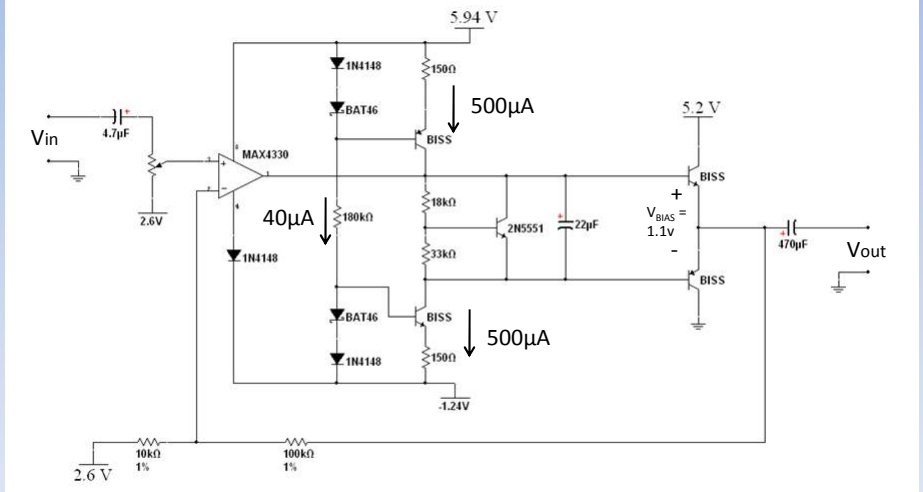
Circuit Diagram



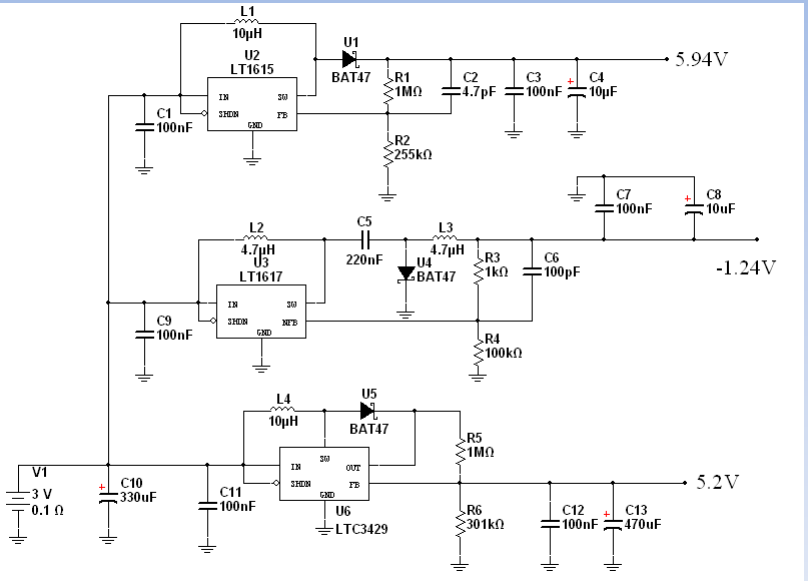
Amplifier Stage



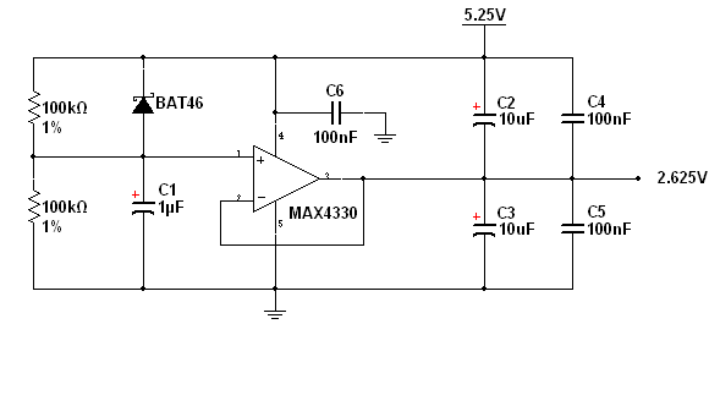
Amplifier Stage



DC/DC Converters

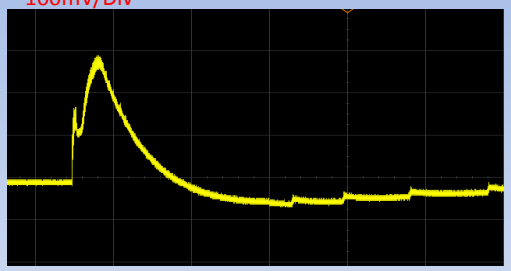


Half Supply Generator

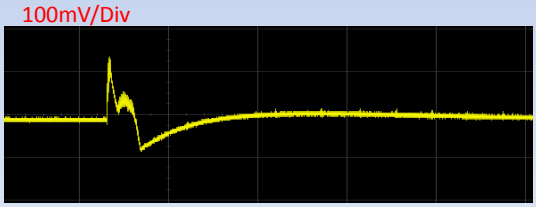


Turn-On Transient

100mV/Div

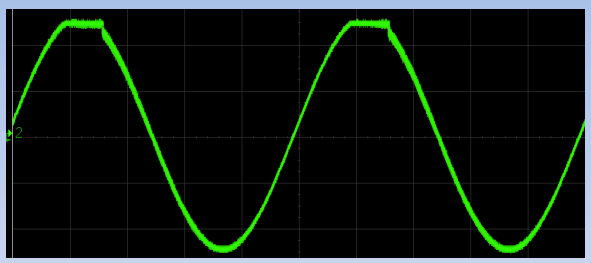


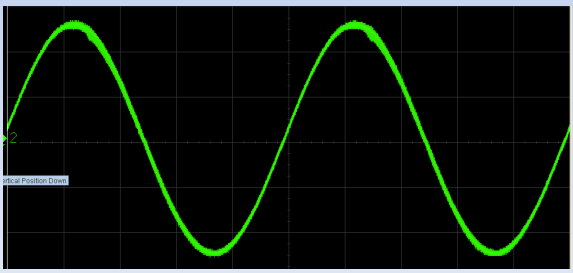
100mV/Div



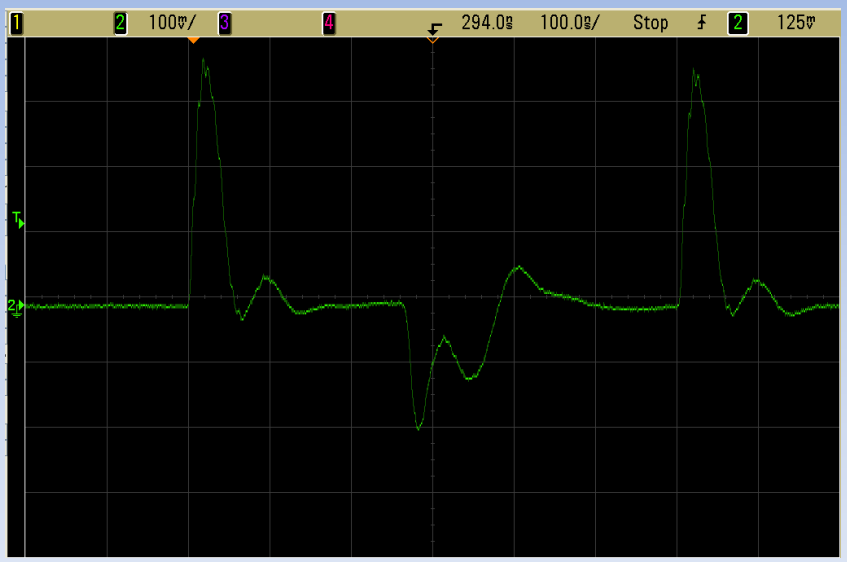
C=4.7uF

Bias Capacitors





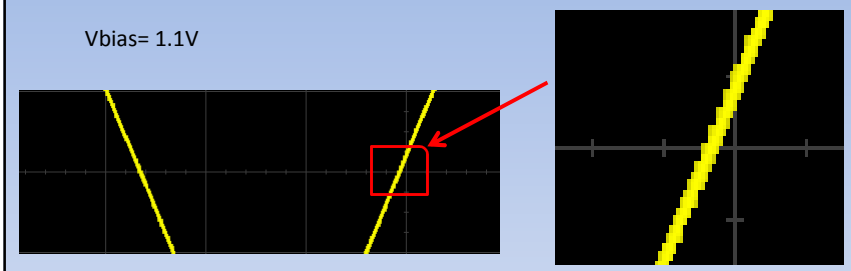
Switching Noise



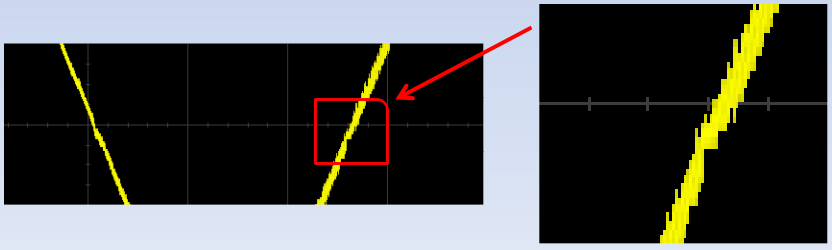
Switching Frequency→ 1.67MHz

Crossover Distortion

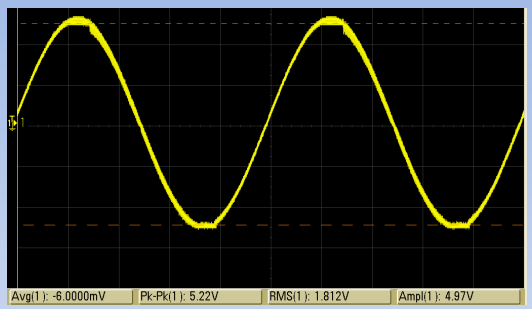
Vbias= 1.1V



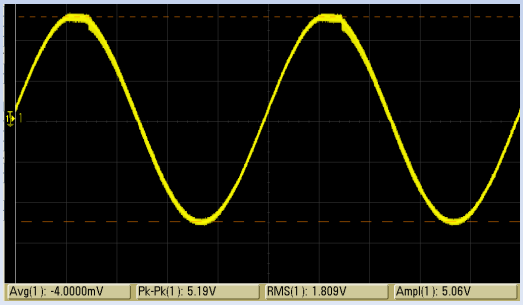
Vbias= 0.6V



Output at Max Power

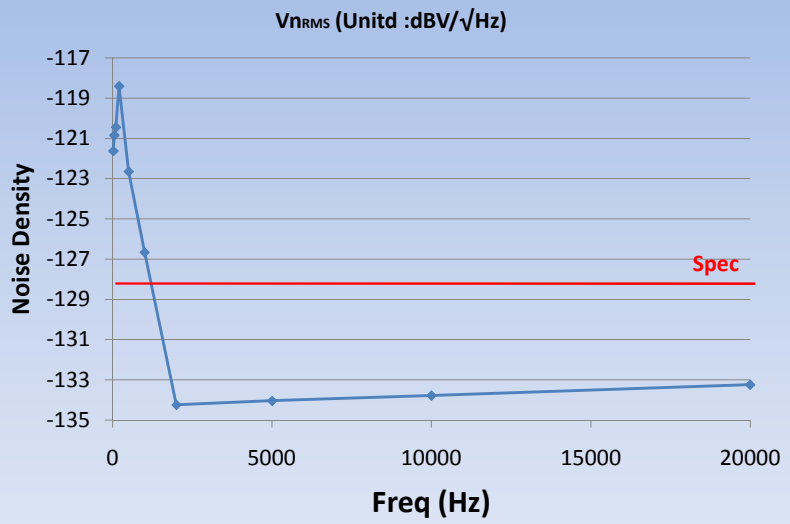


Left Channel



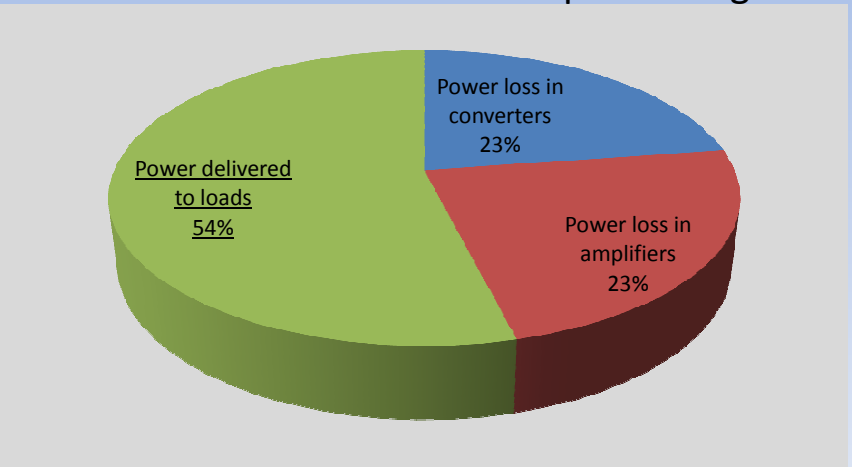
Right Channel

Spot Noise Density Vs. Frequency



Power Breakdown

- Power measured at 100dB output setting



Results Summary

Power Requirements	Measured	Goal
Power Consumption	371mW	< 400mW
Battery Life	101hrs	> 90hrs
Noise Requirements		
THD (10mW output)	.0333% (L) / .0393 % (R)	< 0.1%
THD (100mW output)	.457% (L) / .506% (R)	< 1.0%
Noise Density (output)	See Prev. Slide	< -128dB/√Hz
Material Cost		
Amplifier Stage	$16.01	
Converters	$19.16	
Jack/Plug	$1.81	
Overall	$36.98	< $40

DC-DC Converter Circuitry

Component name	DigiKey Part #	Manufacturer	Qty.	Cost per unit	Total Cost
LT1615 (Step-up DC-DC converter)	LT1615ES5#TRMPBFCT-ND	Linear	1	$ 3.330	$ 3.330
LTC3429 (Step-up DC-DC converter)	LTC3429ES6#TRMPBFCT-ND	Linear	1	$ 3.667	$ 3.667
LT1617 (Inverting DC-DC converter)	LT1617ES5#TRMPBFCT-ND	Linear	1	$ 3.330	$ 3.330
BAT47 (Schottky Diode)	497-3773-1-ND	STMicroelectronics	3	$ 0.460	$ 1.380
1/4 W Carbon Film Resistor	CF1/4(Value)%5RCT-ND	Stackpole Electronics, Inc.	4	$ 0.019	$ 0.076
1/4 W Metal Film Resistor	(Value)XBK-ND	Yageo	2	$ 0.037	$ 0.074
Radial Aluminum Electrolytic Capacitor					
10 uF	P5567-ND	Panasonic	2	$ 0.077	$ 0.154
330 uF	P5573-ND	Panasonic	1	$ 0.260	$ 0.260
470 uF	P5585-ND	Panasonic	1	$ 0.492	$ 0.492
Ceramic Chip Capacitor					
4.7 pF	478-1159-1-ND	AVX	1	$ 0.124	$ 0.124
100 pF	399-1122-1-ND	Kemet	1	$ 0.057	$ 0.057
100 nF	399-1096-1-ND	Kemet	6	$ 0.012	$ 0.070
220 nF	399-1103-1-ND	Kemet	1	$ 0.183	$ 0.183
Inductor 10uH	308-1311-1-ND	SUMIDA	2	$ 1.490	$ 2.980
Inductor 4.7uH	308-1317-1-ND	SUMIDA	2	$ 1.490	$ 2.980

Total Cost of Converter: $19.16

Amplifier Circuitry

Component name	DigiKey Part #	Manufacturer	Qty.	Cost per unit	Total Cost
MAX4332	MAX4332ESA+-ND	Maxim	2	$ 3.450	$ 6.900
BAT46	497-5559-1-ND	STMicroelectronics	5	$ 0.211	$ 1.056
1N4148	568-1360-1-ND	NXP Semiconductors	5	$ 0.010	$ 0.052
PBSS4350X (NPN transistor)	568-4159-1-ND	NXP Semiconductors	4	$ 0.450	$ 1.800
PBSS5350X (PNP transistor)	568-4170-1-ND	NXP Semiconductors	4	$ 0.600	$ 2.400
2N5551RLRAGOSCT-ND (NPN Transistor)	2N5551RLRAGOSCT-ND	ON Semiconductor	2	$ 0.185	$ 0.370
Radial Aluminum Electrolytic Capacitor					
1 uF	P5563-ND	Panasonic	1	$ 0.077	$ 0.077
4.7 uF	P5566-ND	Panasonic	1	$ 0.069	$ 0.069
10 uF	P5567-ND	Panasonic	2	$ 0.077	$ 0.154
22 uF	P5568-ND	Panasonic	2	$ 0.068	$ 0.136
470 uF	P5585-ND	Panasonic	2	$ 0.492	$ 0.984
Ceramic Chip Capacitor					
100 nF	399-1096-1-ND	Kemet	3	$ 0.012	$ 0.035
1/4 W Metal Film Resistor	(Value)XBK-ND	Yageo	12	$ 0.037	$ 0.444
1/4 W Carbon Film Resistor	CF1/4(Value)%5RCT-ND	Stackpole Electronics, Inc.	4	$ 0.019	$ 0.076
10KΩ Pot	P2U4103-ND	Panasonic	1	$ 1.460	$ 1.460

Total Cost of Amplifier: $16.01

Conclusion

- Better dc/dc converters or design to avoid poor power efficiency at low voltages