# ¿Cómo medir consumo?

- Potencia
  - Alimentación en DC (fija)
  - Alcanza con medir corriente
    - Medir promedios
    - Medidas instantáneas

- Energía = Potencia * tiempo

- El DUT tiene que estar funcionando!!!!
  - Alimentado
  - Con entradas reales
  - Si tiene software tiene que estar corriendo

Co-funded by the Erasmus+ Programme of the European Union

# Alternativas

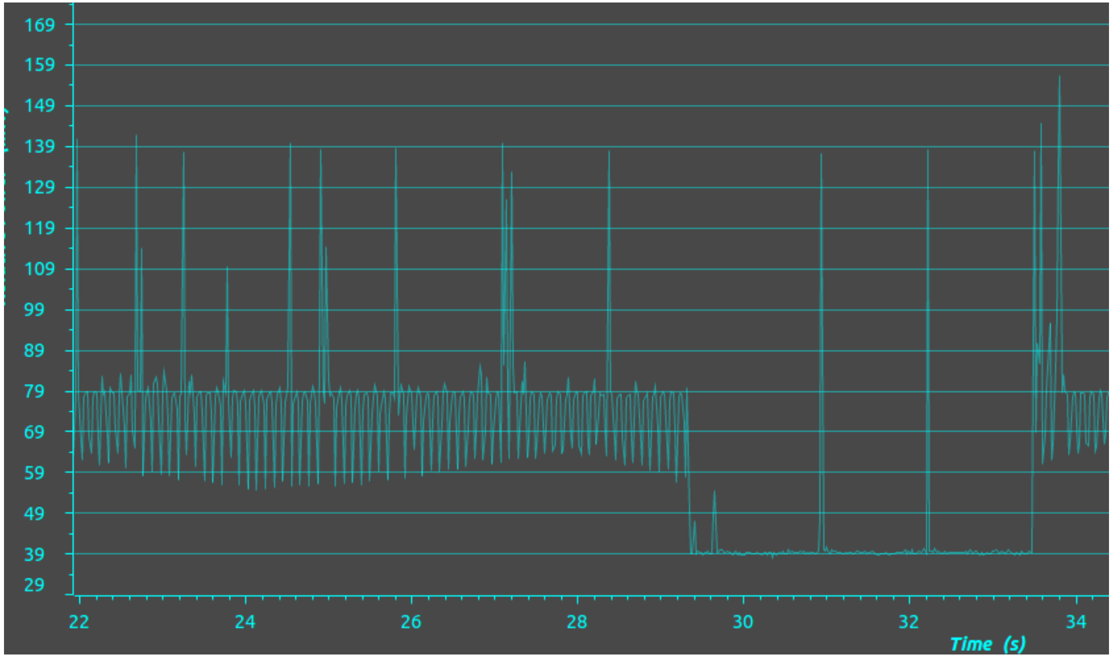
- Amperímetro en serie con la fuente
- Shunt + voltímetro
- VFC: Voltage-to-Frequency Converter
- Espejo de corriente
- Carga/descarga de condensadores
- Celdas de efecto Hall

# Amperímetro

- Conectar un amperímetro en serie con la fuente de alimentación
- Problemas:
  - Resistencia interna del amperímetro
  - Mide promedios de Icc
    - Entradas al circuito (input patterns)
      - ¿Periódicas?
    - Ventana de tiempo en la que promedia el amperímetro >> cambios en las entradas

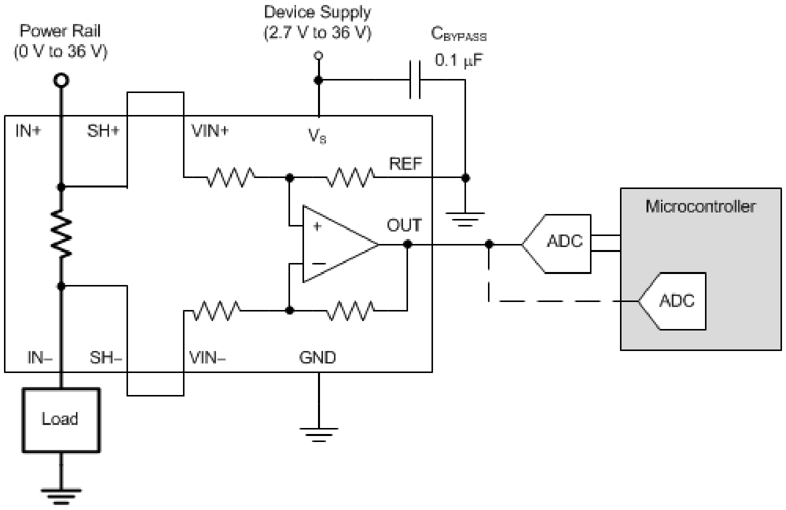
# Shunt + Medida de voltaje

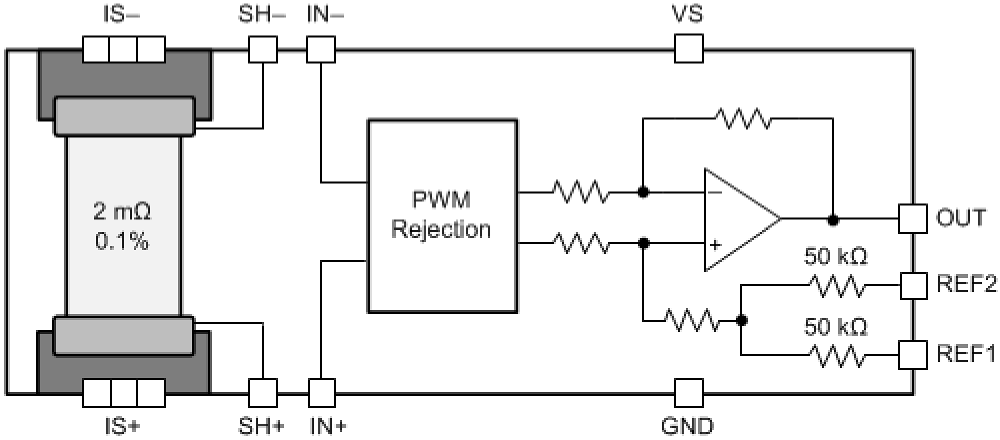
- Shunt
  - En VCC o en GND
- Shunt + voltímetro
  - Medida flotante
  - Atención: modo común
- Voltímetro
  - Directo: tester, osciloscopio, A/D
  - Amplificador + voltímetro
- Rango a medir
  - Cambiar shunt?
  - Caídas de voltaje
- Picos de corriente
  - Filtar con capacitor
  - Integrar numéricamente



# Shunt + amp diferencial

- Current sense amplifier with integrated shunt
  - Texas Instrument INA250, INA253



# Current Sense Circuit Collection

*Current Sense Circuit Collection, Making Sense of Current*, Tim Regan, Jon Munson, Greg Zimmer, Michael Stokowski, Application Note 105, December 2005. Linear Technology

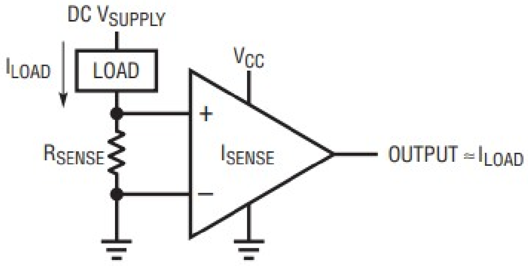



Figure 1. Low Side Current Sensing

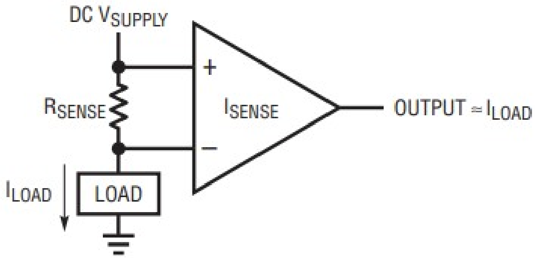



Figure 2. High Side Current Sensing

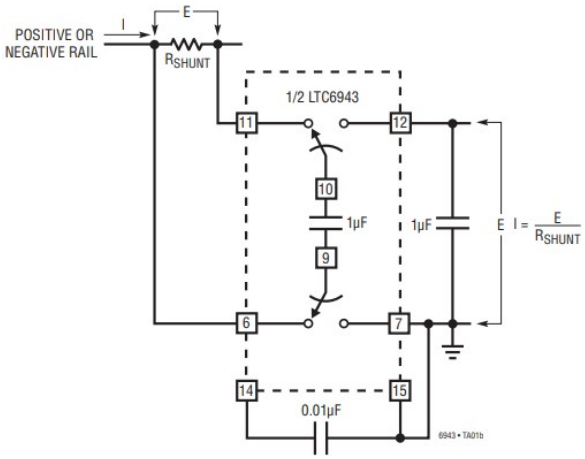



Figure 11. Precision Current Sensing in Supply Rails

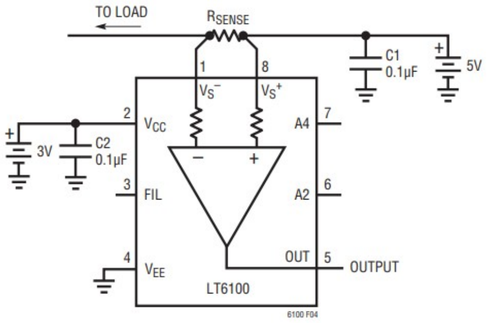



Figure 4. LT6100 Load Current Monitor

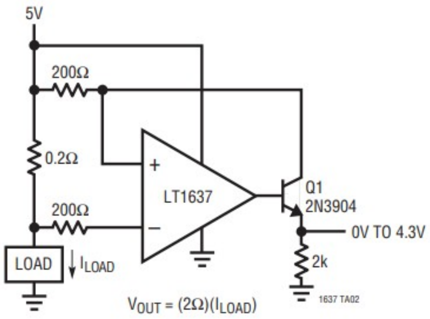
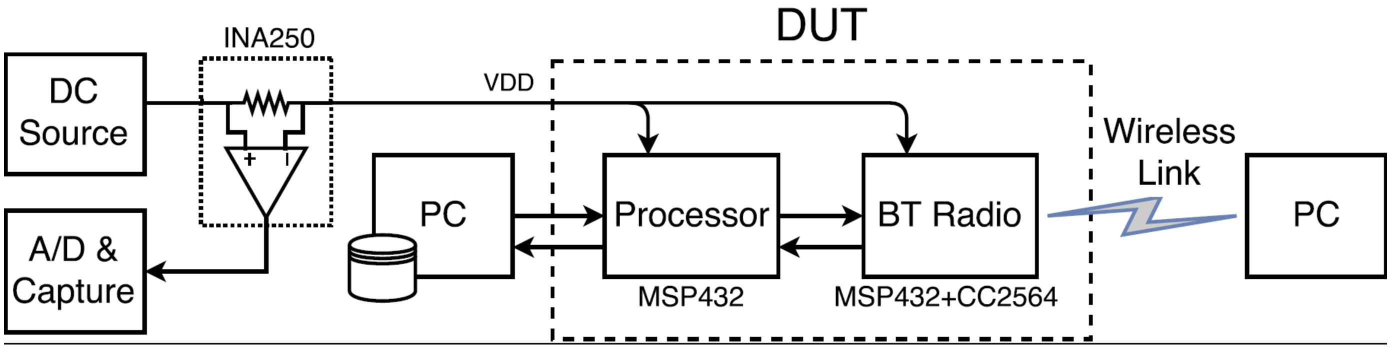



Figure 5. "Classic" Positive Supply Rail Current Sense

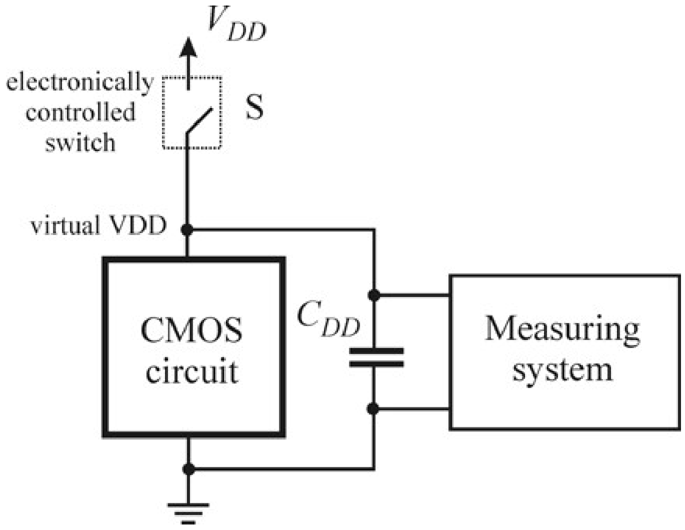
# EEG compression

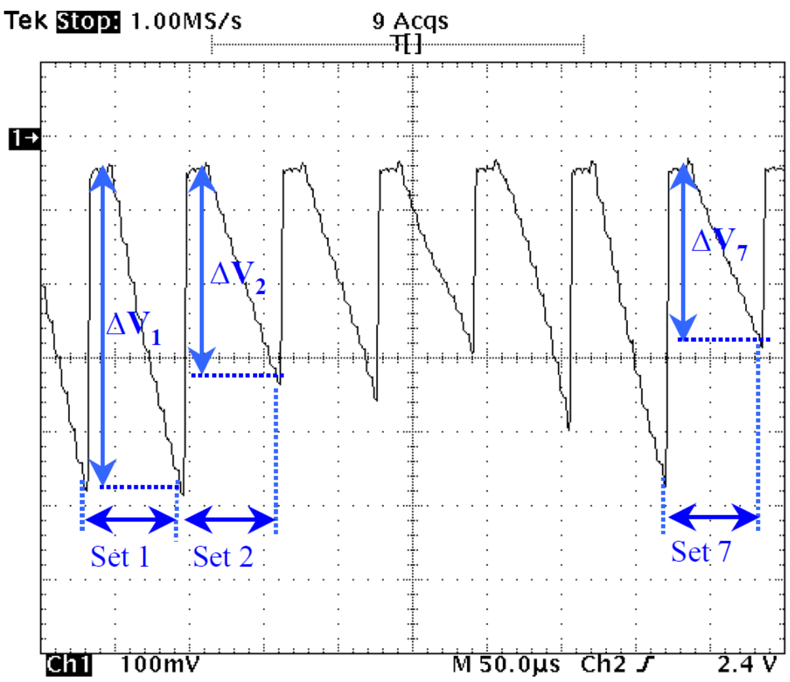



Guillermo Dufort Y Alvarez, Federico Favaro, Federico Lecumberry, Alvaro Martin, Juan P Oliver, Julian Oreggioni, Ignacio Ramirez, Gadiel Seroussi, Leonardo Steinfeld, "Wireless EEG System Achieving High Throughput and Reduced Energy Consumption Through Lossless and Near-Lossless Compression," in IEEE Transactions on Biomedical Circuits and Systems, vol. 12, no. 1, pp. 231-241, Feb. 2018, doi: 10.1109/TBCAS.2017.2779324.

# Cycle energy measurements

## Capacitor-based measurement (switched capacitor)



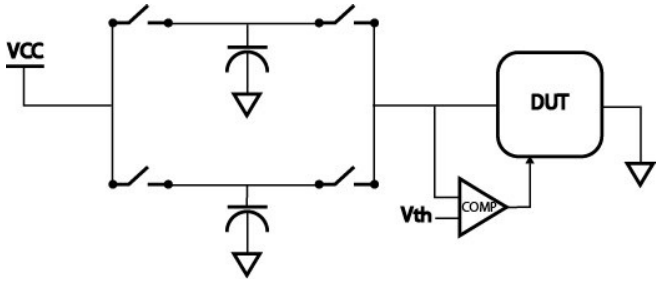




$$E = \frac{1}{2} C_{DD} V_{DD}^2 - \frac{1}{2} C_{DD} \left( V_{DD} - \Delta V \right)^2 = E_0 \left[ 2 \frac{\Delta V}{V_{DD}} - \left( \frac{\Delta V}{V_{DD}} \right)^2 \right]$$

$$E_0 = C_{DD} V_{DD}^2 / 2$$

J. Rius-Vazquez, E. Boemo, A. Peidro-Palanca, S. Manich-Bou and R. Rodriguez-Montañes, "Measuring Power and Energy of CMOS CIrcuits: A Comparative Analysis", Proceedings DCIS 2003 (XVIII Conference on Design of Circuits and Integrated Systems), pp. 89-94, Ciudad Real, November 2003. ISBN: 84-87087-40-X

# Método con 2 capacitores



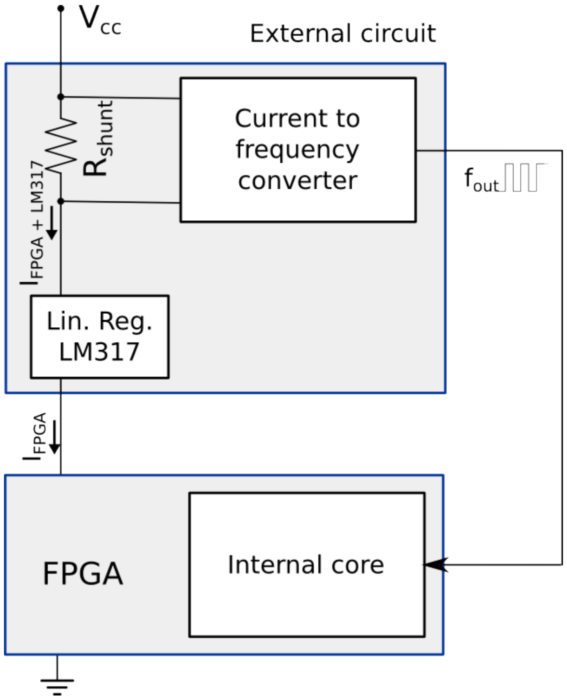

- La diferencia de tensión en los capacitores se utiliza para calcular el consumo del circuito durante un ciclo de trabajo.
- Tensión en C
  - $V_0$ en el instante $t_0$
  - $V_1$ en el instante $t_1$
- La carga consumida durante el intervalo $t_1$ - $t_0$ es: $Q_1 - Q_0 = C(V_1 – V_0)$
- Cuando se llega a $V_{th}$ se intercambian los capacitores

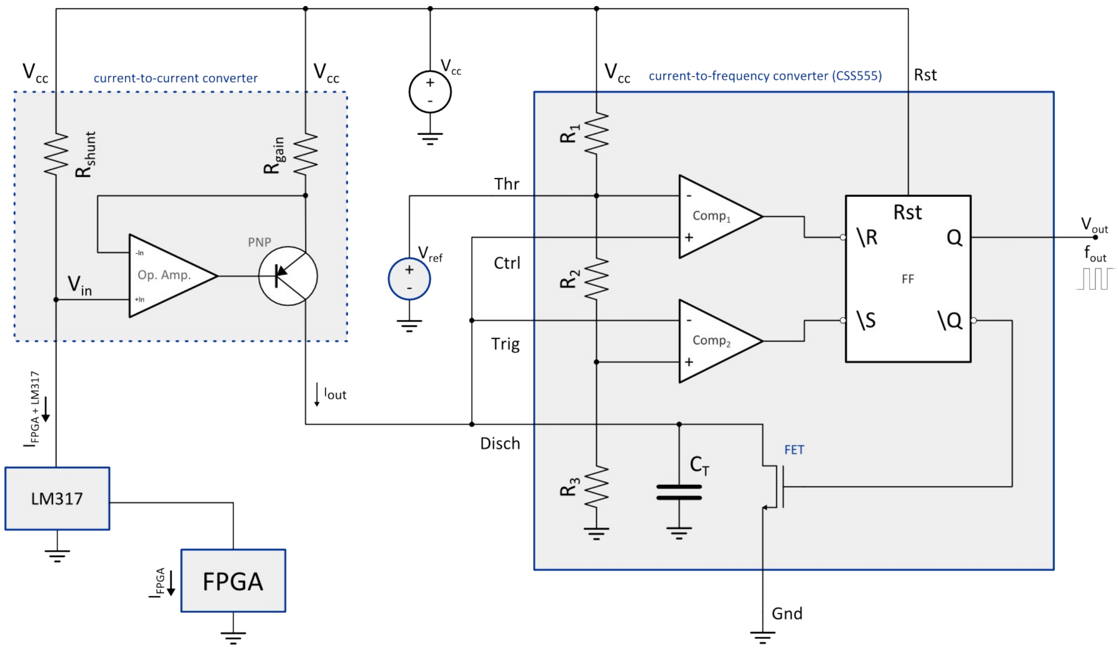
J. Oreggioni and L. Steinfeld, “Automedida de consumo en dispositivos portables,” in Proceedings of the XIX Iberchip Workshop, Cusco, Peru, 2013. [Online]. Available: http://iie.fing.edu.uy/publicaciones/2013/OS13

# Más bibliografía


- J. Oreggioni and L. Steinfeld, “Automedida de consumo en dispositivos portables,” in Proceedings of the XIX Iberchip Workshop, Cusco, Peru, 2013. [Online]. Available: http://iie.fing.edu.uy/publicaciones/2013/OS13
- Villaverde, J., Bouvier, D. A., Fernández, C., Steinfeld, L., & Oreggioni, J. (2013). Low-Power Self-Energy meter for wireless sensors network. IEEE DCoSS, 315-317
- CHANG, Naehyuck; KIM, Kwanho. Real-time per-cycle energy consumption measurement of digital systems. Electronics Letters, 2000, 36.13: 1169-1171.
- Chang, N., Kim, K. and Lee, H.G., 2000, August. Cycle-accurate energy consumption measurement and analysis: Case study of ARM7TDMI. In Proceedings of the 2000 international symposium on Low power electronics and design (pp. 185-190).
- J. Rius-Vazquez, E. Boemo, A. Peidro-Palanca, S. Manich-Bou and R. Rodriguez-Montañes, "Measuring Power and Energy of CMOS CIrcuits: A Comparative Analysis", Proceedings DCIS 2003 (XVIII Conference on Design of Circuits and Integrated Systems), pp. 89-94, Ciudad Real, November 2003. ISBN: 84-87087-40-X
- Lee, H.G., Lee, K., Choi, Y. and Chang, N., 2005. Cycle-accurate energy measurement and characterization of FPGAs. Analog Integrated Circuits and Signal Processing, 42(3), pp.239-251.
- J. Oliver, F. Veirano, D. Bouvier, and E. Boemo, “A low cost system for self measurements of power consumption in field programmable gate arrays,” Journal of Low Power Electronics, vol. 13, no. 1, 2017.

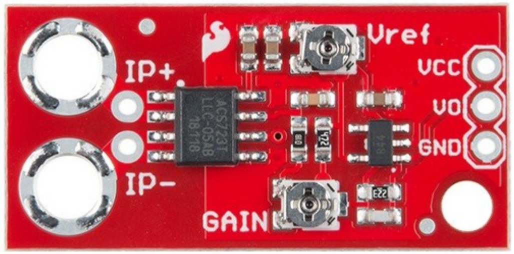
# VFC: Voltage-to-Frequency Converter FPGA automedidor



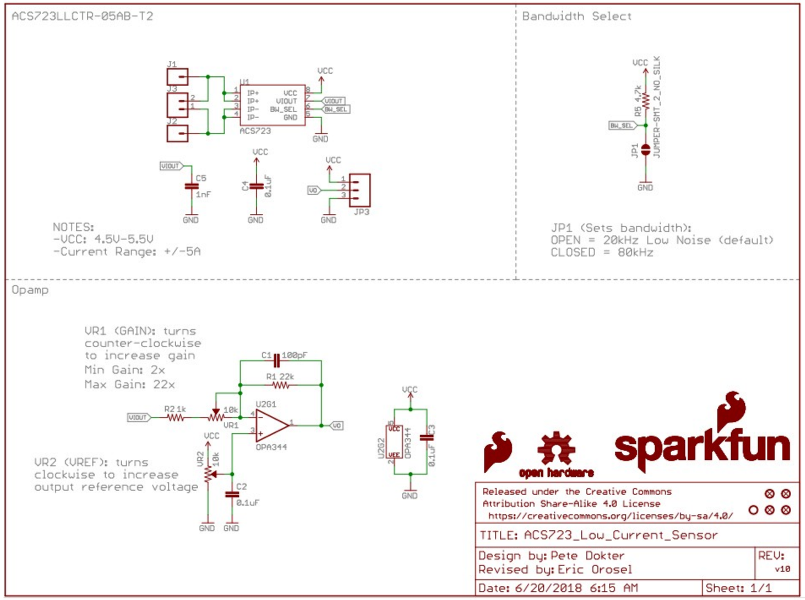




J. Oliver, F. Veirano, D. Bouvier, and E. Boemo, *“A low cost system for self measurements of power consumption in field programmable gate arrays,”* Journal of Low Power Electronics, vol. 13, no. 1, 2017.

# Hall effect sensor



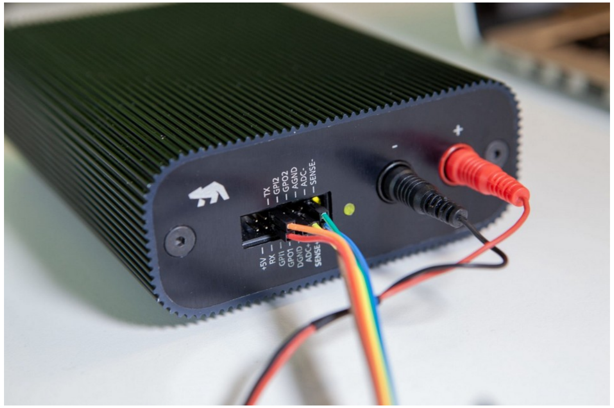

- ACS723 Allegro
- High Accuracy, Galvanically Isolated Current Sensor IC
  - +/- 5A, 10A, 20A, 40A
- Sparkfun module: Measures DC and AC currents from around 10mA up to 5A



# Ejemplos de equipamiento específico

- N6705B DC Power Analyzer (Keysight ex Agilent)

- Otii Arc power analyzer and power supply (Qoitech )



# N6705B DC Power Analyzer

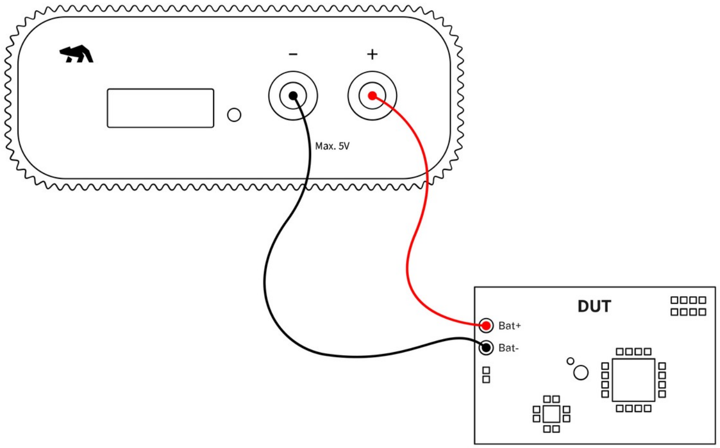
- 4 power supply, modular
- Voltmeter accuracy: Up to 0.025% + 50 µV, up to 18 bits
- Ammeter accuracy: Up to 0.025% + 8 nA, up to 18 bits
- Arbitrary waveform generator function: Bandwidth up to 10( kHz, output power up to 300 W
- Scope function: Digitizes voltage and current at up to 200 kHz, up to 18 bits
- Data logger function: Measurement interval from 20 µs to 60 s
- USD 8500 + DC power modules (600-1000)

https://www.newark.com/keysight-technologies/n6705c/dc-power-analyzer-current-pow/dp/02AC5191

H:\dl\low_power\power_measurements\N6705C - Keysight Technologies - Power Analyzer, Current, Power.mhtml

# Otii Arc

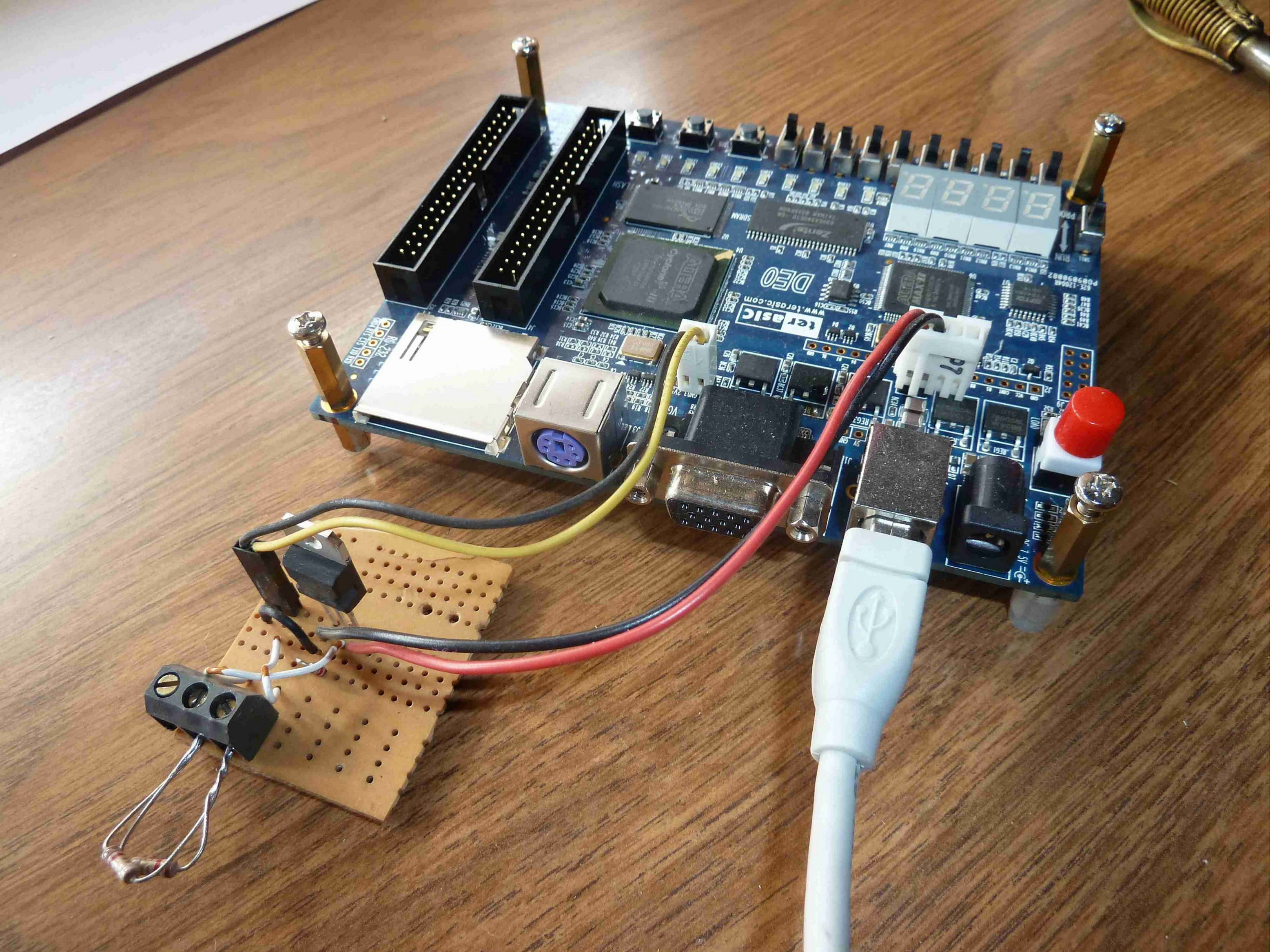
- 1 power supply (0.5 V - 3.75 V, 0.5 V - 5.0 V)
- Voltmeter accuracy ±(0.1% + 1.5 mV)
  - Sample Rate 1 ksps
- Ammeter accuracy ±(0.1% + 50 nA)
  - Sample Rate in ±19 mA range 4 ksps
  - Sample Rate in ±2.7 A range 1 ksps
  - Sample Rate in ±5.0 A range 1 ksps
  - Analog bandwidth (3 dB) 400 Hz
- Extras: UART, A/D, GPIO
- USD 700 + SW




https://www.qoitech.com/docs/quick-start/connect-otii-arc

# Medidas en placas con FPGAs

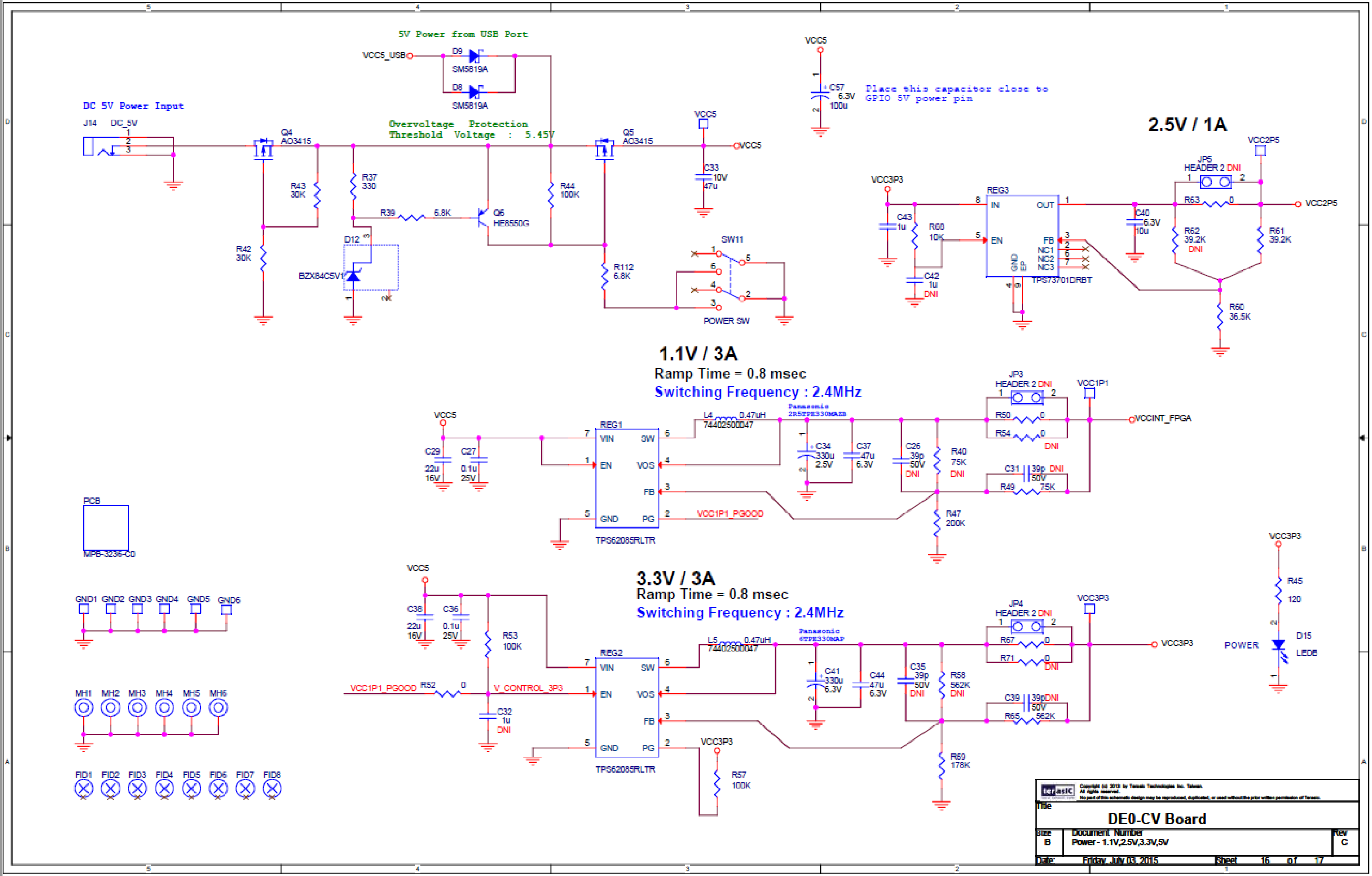
- Placa DE0 (Terasic, usada en Dislog y Micro)
  - Sacar regulador, poner uno externo + shunt
- Cómo medir en una DE0-CV
  - Sacar jumper, poner shunt externo
- Cómo medir en una Arty
  - Tiene un shunt + INA199 y un ADC interno en la FPGA
- Cómo medir en la Spartan-6
  - Tiene un shunt + chip PsoC de Cypress (amplificador y ADC)




# Placa DE0

Adaptación para medir corriente:

- Desoldar regulador original
- Soldar pines de fuentes antes y después del regulador
- Armar placa con regulador externo y shunt


5V Power from USB Port
VCC5_USB
D9 SM5819A
D8 SM5819A
DC 5V Power Input
J14 DC_5V
Q4 AO3415
Overvoltage Protection
Threshold Voltage : 5.45V
Q5 AO3415
VCC5
C33 10V 47u
R43 30K
R37 330
R39 6.8K
Q6 HE8550G
R44 100K
R42 30K
D12 BZX84C5V1
R112 6.8K
SW11
POWER SW
C57 6.3V 100u
Place this capacitor close to
GPIO 5V power pin
2.5V / 1A
VCC2P5
JP5 HEADER 2 DNI
VCC3P3
REG3
IN OUT
EN FB
NC1 NC2 NC3
GND EP
TPS73701DRBT
C43 1u
R68 10K
C42 1u DNI
C40 6.3V 10u
R63 0
R62 39.2K DNI
R61 39.2K
R60 36.5K
1.1V / 3A
Ramp Time = 0.8 msec
Switching Frequency : 2.4MHz
JP3 HEADER 2 DNI
VCC1P1
L4 0.47uH 74402500047
Panasonic 2R5TPE330MAZB
REG1
VIN SW
EN VOS
FB
GND PG
TPS62085RLTR
C29 22u 16V
C27 0.1u 25V
C34 330u 2.5V
C37 47u 6.3V
C26 39p 50V DNI
R40 75K DNI
R50 0
R54 0 DNI
VCCINT_FPGA
C31 39p 50V DNI
R49 75K
R47 200K
VCC1P1_PGOOD
PCB
MPB-3236-C0
3.3V / 3A
Ramp Time = 0.8 msec
Switching Frequency : 2.4MHz
JP4 HEADER 2 DNI
L5 0.47uH 74402500047
Panasonic 6TPE330MAP
REG2
TPS62085RLTR
C38 22u 16V
C36 0.1u 25V
R53 100K
R52 0
V_CONTROL_3P3
C32 1u DNI
C41 330u 6.3V
C44 47u 6.3V
C35 39p 50V DNI
R58 562K DNI
R67 0
R71 0 DNI
C39 39p 50V DNI
R65 562K
R59 178K
R57 100K
R45 120
POWER
D15 LED6
GND1 GND2 GND3 GND4 GND5 GND6
MH1 MH2 MH3 MH4 MH5 MH6
FID1 FID2 FID3 FID4 FID5 FID6 FID7 FID8
terasic
Title
DE0-CV Board
Size B
Document Number
Power - 1.1V,2.5V,3.3V,5V
Rev C
Date: Friday, July 03, 2015
Sheet 16 of 17

# Arty - Digilent

- Ver esquemático Arty
  - INA199A1DCKR Texas
- Artix-7
  - XADC Dual 12-Bit 1 MSPS Analog-to-Digital Converter
- Lectura por USB

# Medidas en placas

- Placas que vienen con capacidad de medida
- Analizar esquemático
  - Diferentes fuentes
  - Shunts
  - Reguladores

# Sistema funcionando

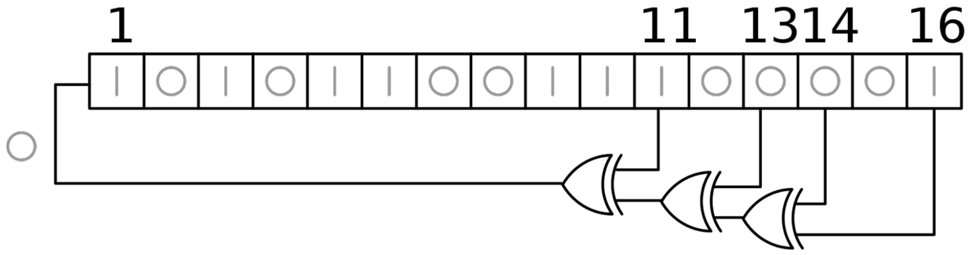
- Generación de entradas
  - ¿Cuáles?
- Modos de funcionamiento
  - Diferentes módulos encendidos
  - Estados:
    - Bajo consumo
    - Alto consumo

# Sistemas Embebidos

- Microcontrolador
  - Varios modos de consumo
- Radio
  - Apagada
  - Encendida, high power, low power
- Medir cada estado y después analizar por software

# FPGAs

- Generador de entradas
  - Reales
  - Pseudoaleatorias
    - Linear Feedback Shift Register LFSR
  - Hay casos que no se pueden usar señales aleatorias



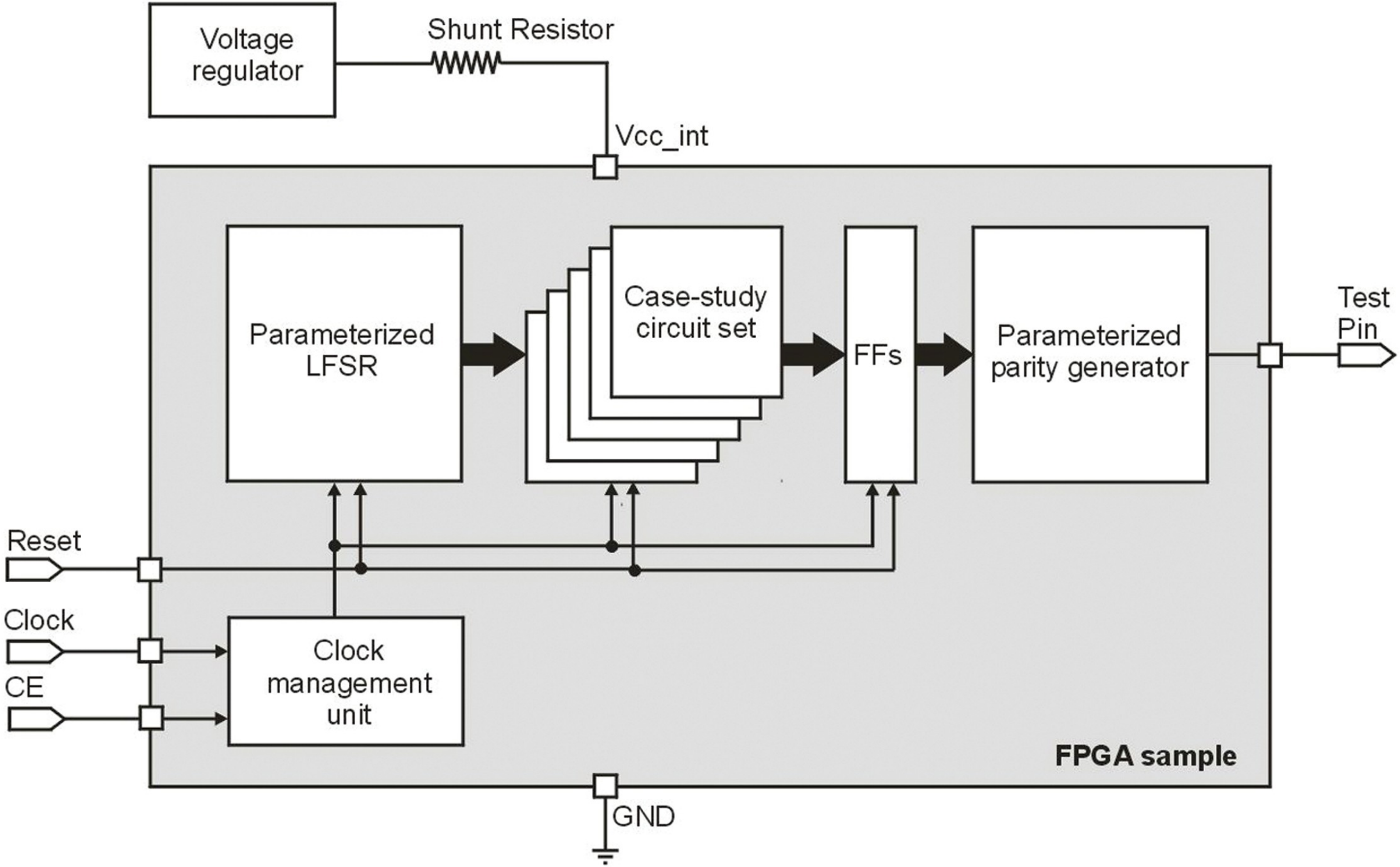
# LFSR Pseudo-Random sequence generator

- Any long LFSR counter generates a long pseudo-random sequence of zeros and ones. The sequence is not exactly random since it repeats eventually, and it also follows a mathematically predictable sequence. But for most practical purposes it can be considered random.
- A 63-bit LFSR counter has a repetition time of (263-1) clock periods. Running at 50 MHz, such a counter repeats after more than five thousand years (5,849 years to be more precise), which is long enough to be irrelevant for most practical purposes.
- Conceptually, a 63-bit LFSR counter consists of a 63-bit shift register, with an XNOR feedback from the last stage and the next-to-last stage.

**Table 3: Taps for Maximum-Length LFSR Counters**

| n | XNOR from | n | XNOR from |
|---|---|---|---|
| 3 | 3,2 | 45 | 45,44,42,41 |
| 4 | 4,3 | 46 | 46,45,26,25 |
| 5 | 5,3 | 47 | 47,42 |
| 6 | 6,5 | 48 | 48,47,21,20 |
| 7 | 7,6 | 49 | 49,40 |
| 8 | 8,6,5,4 | 50 | 50,49,24,23 |
| 9 | 9,5 | 51 | 51,50,36,35 |
| 10 | 10,7 | 52 | 52,49 |

Alfke, P.. “Efficient Shift Registers, LFSR Counters, and Long Pseudo Random Sequence Generators.” (1995). Online: https://www.xilinx.com/support/documentation/application_notes/xapp052.pdf


Voltage regulator
Shunt Resistor
Vcc_int
Parameterized LFSR
Case-study circuit set
FFs
Parameterized parity generator
Test Pin
Reset
Clock
CE
Clock management unit
FPGA sample
GND