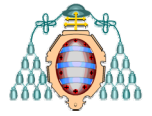


Universidad  
de Oviedo



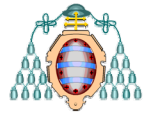
# Implementación digital de reguladores: introducción

Sistemas Automáticos– Tema 12



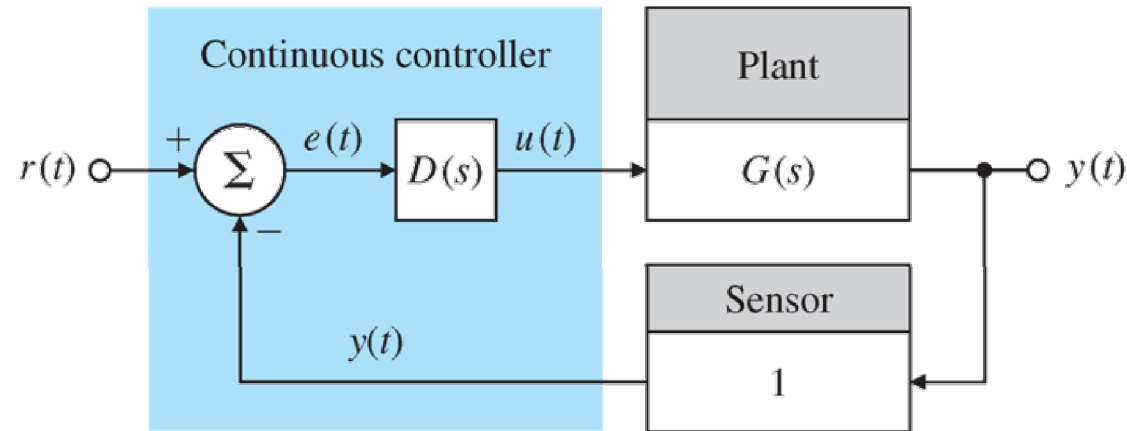
# Contenidos del tema

- ▶ Introducción al control digital
- ▶ Problemas del muestreo
- ▶ Hardware para el control digital

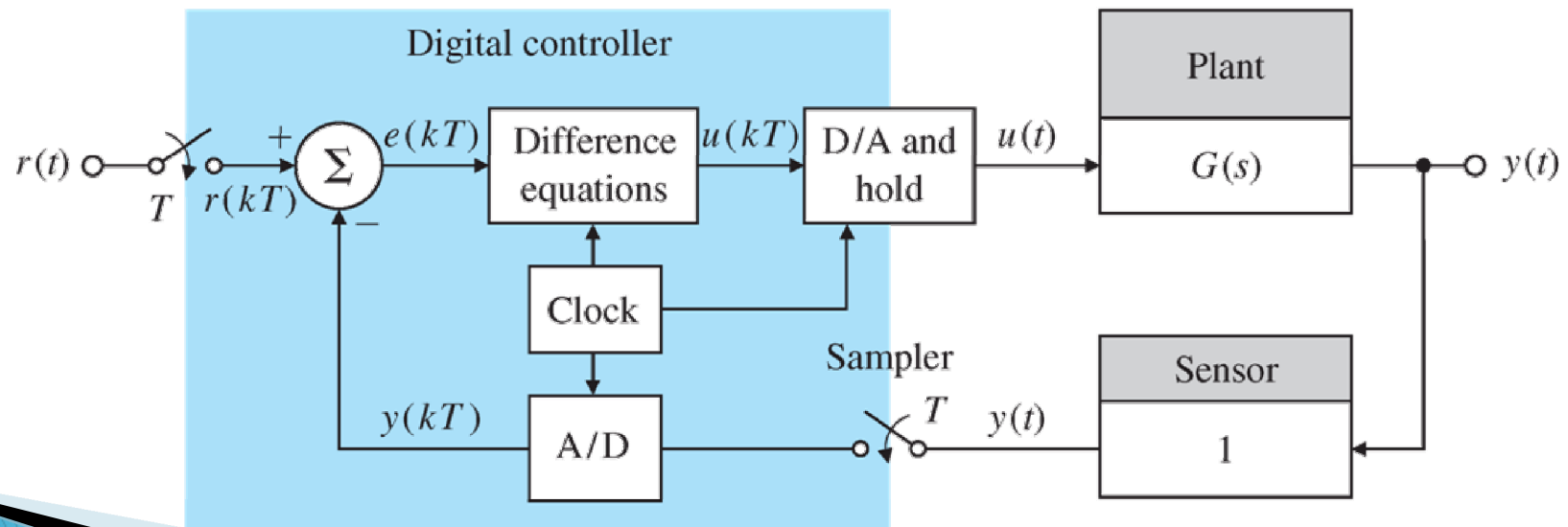


# Introducción a control digital

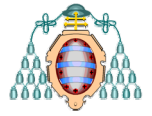
Fig. 8.1  
Franklin, et al., 2006



(a)



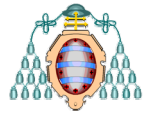
(b)



# Introducción a control digital

## ▶ Ventajas

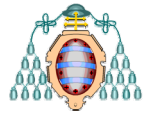
- El control es programado: Las modificaciones, adaptaciones o actualizaciones se hacen por software
- Permite implementar algoritmos avanzados de control
- Permite auto-ajustes, control adaptativo y control no lineal
- Posibilidad de funcionalidades añadidas como monitorización, diagnóstico, protecciones, etc
- Posibilidad de integrarlo en una red de comunicaciones. Redes de control
- Capacidad de almacenamiento



# Introducción a control digital

## ▶ Desventajas

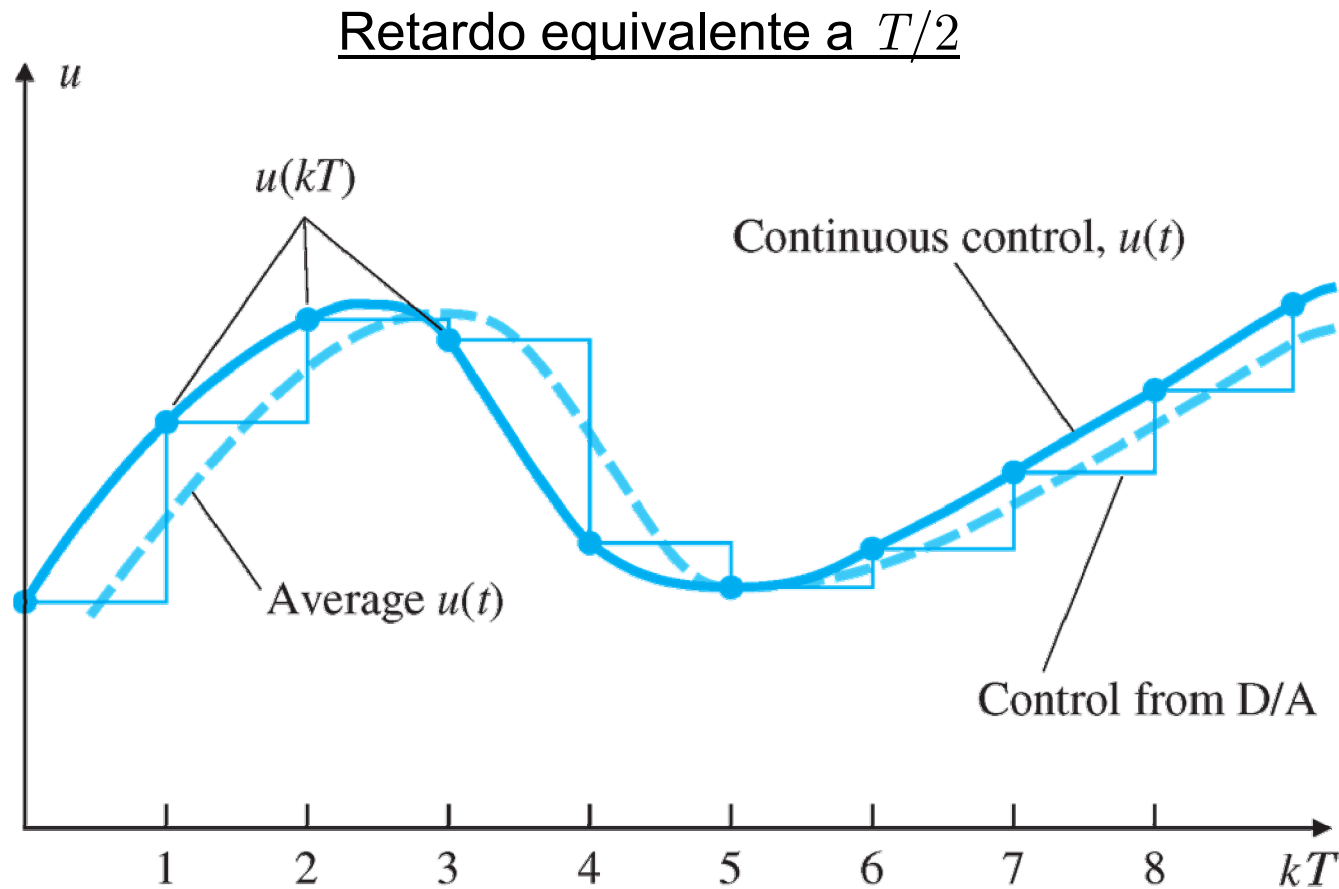
- Requiere hardware de conversión de señales.
- Los métodos de análisis y diseño son más complejos.
- El muestreo y la resolución puede afectar al rechazo de perturbaciones.
- El ancho de banda se ve limitado por el tiempo necesario para cálculos. La estabilidad se puede ver comprometida.
- El error de cuantificación puede reducir la precisión del control.



# Problemas del muestreo

## ► Retardo

Fig. 8.2  
Franklin, et al., 2006



Relevante si  $1/T < 20 \omega_{bw}$

# Problemas del muestreo

## ► Cuantificación

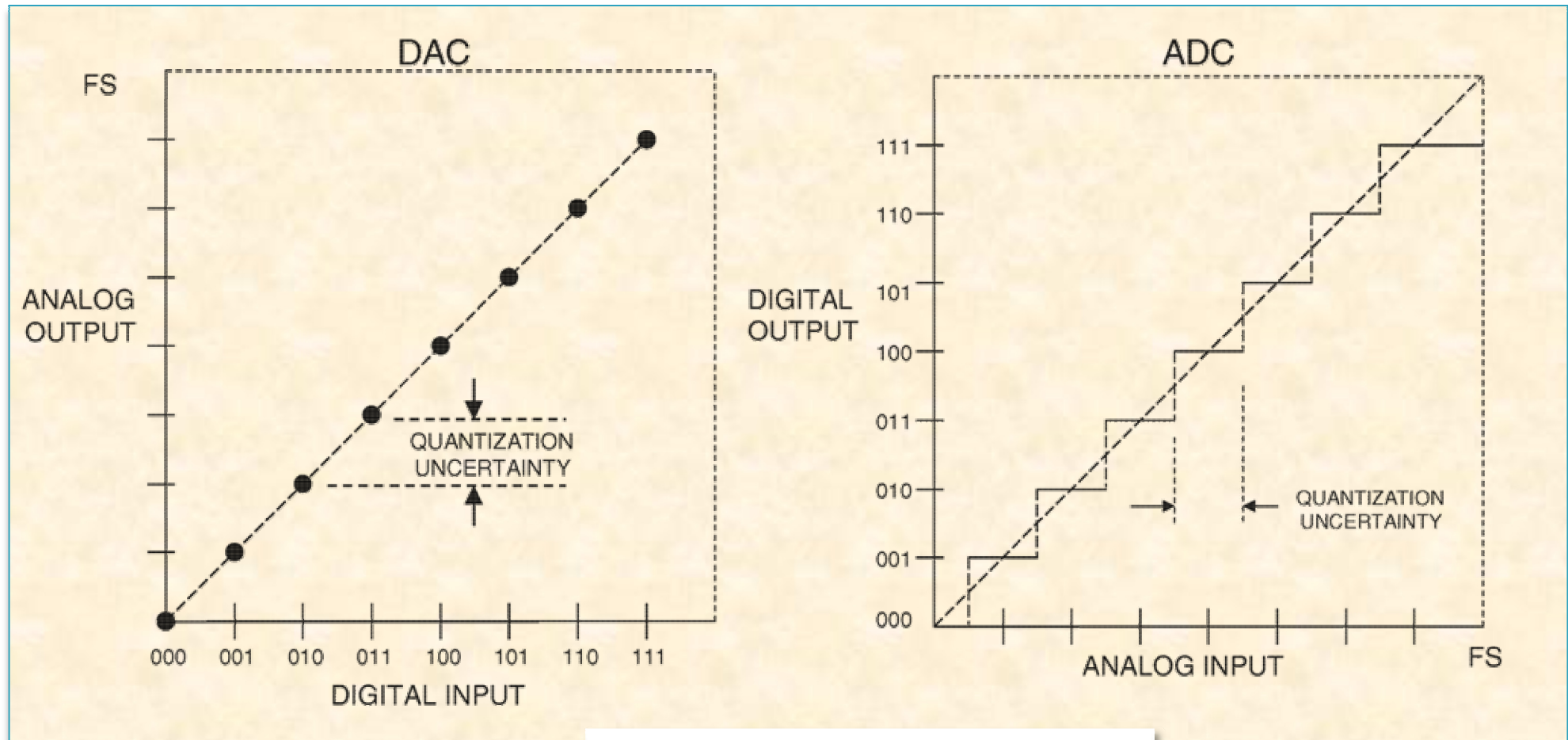
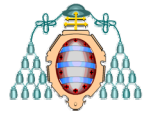


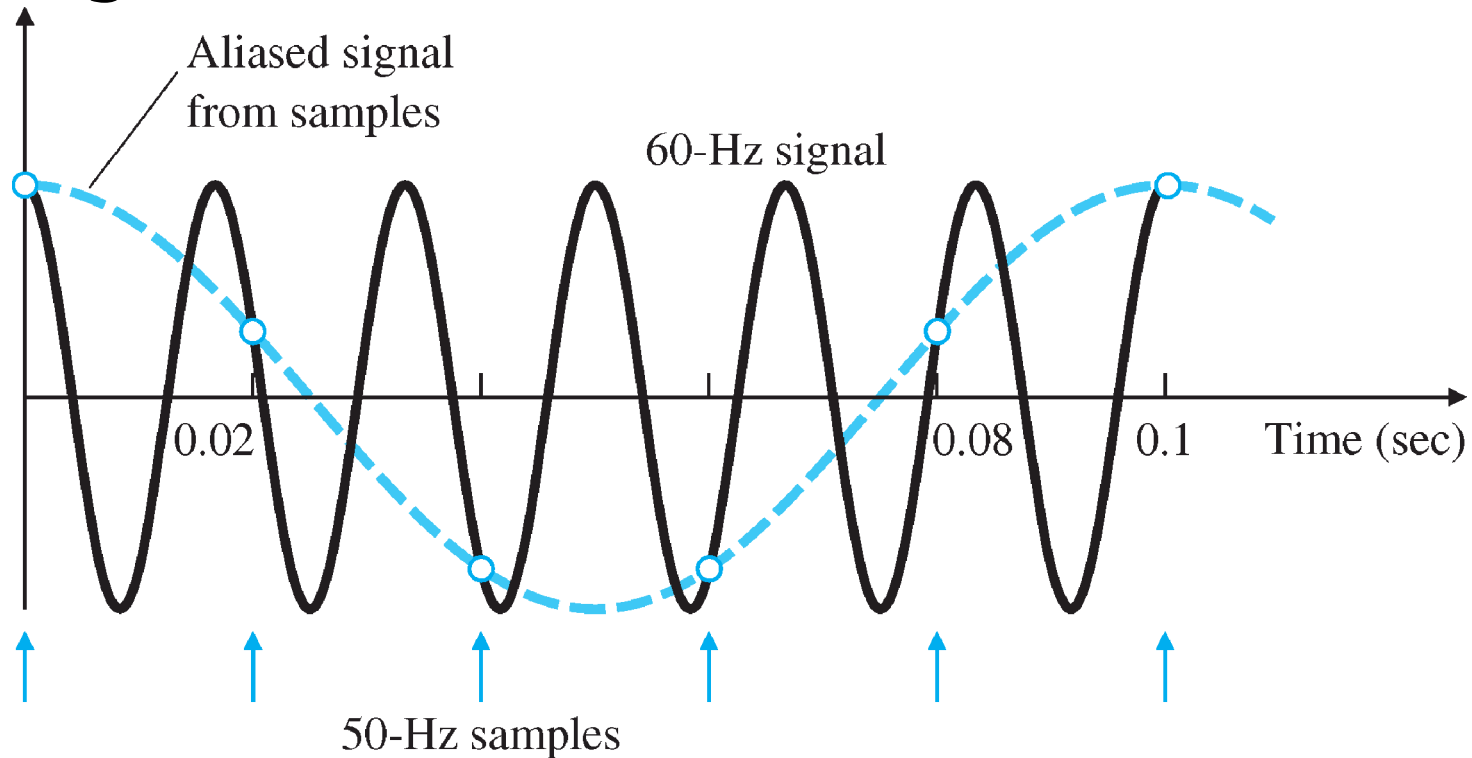
Fig. 2.15  
Analog Devices - Data Conversion Handbook, 2005



# Problemas del muestreo

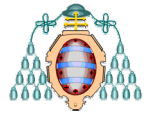
## ► Aliasing

Fig. 8.14  
Franklin, et al., 2006



Teorema de Nyquist–Shannon del muestreo: para que una señal muestreada pueda ser correctamente reconstruída no debe contener componentes de frecuencia superior a la mitad de la frecuencia de muestreo

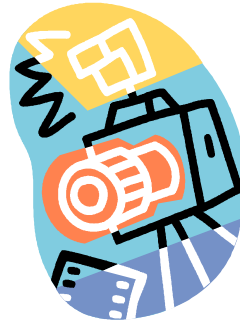
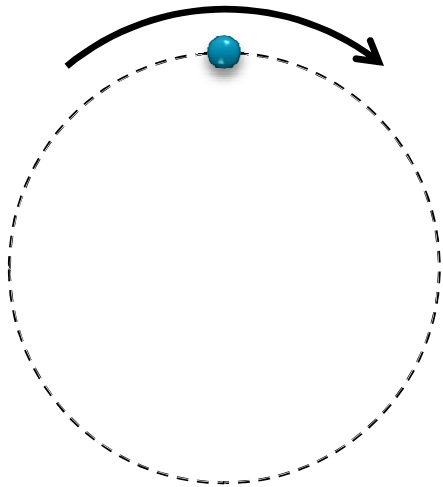




# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

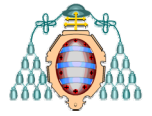


$$f_m = 10 \text{ Hz}, T_m = 0,1 \text{ s}$$



$$f_{Nyquist} = 5 > 0,625 \text{ Hz}$$

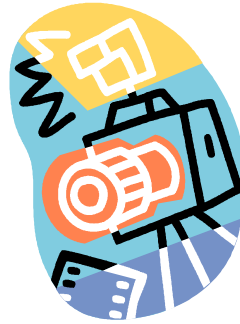
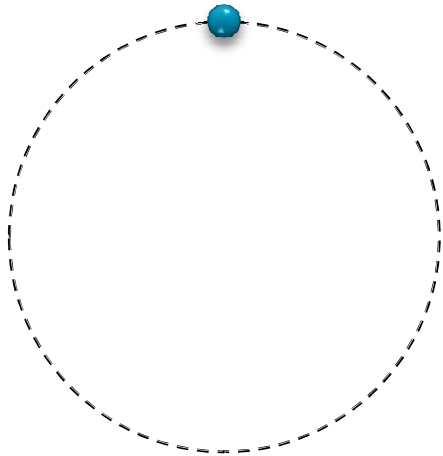
No hay problema de aliasing



# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

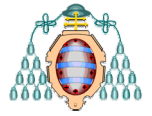


$$f_m = 10 \text{ Hz}, T_m = 0,1 \text{ s}$$



$$f_{Nyquist} = 5 > 0,625 \text{ Hz}$$

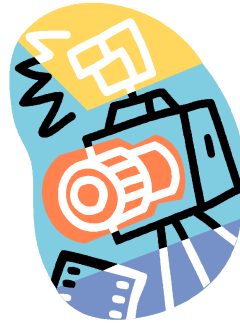
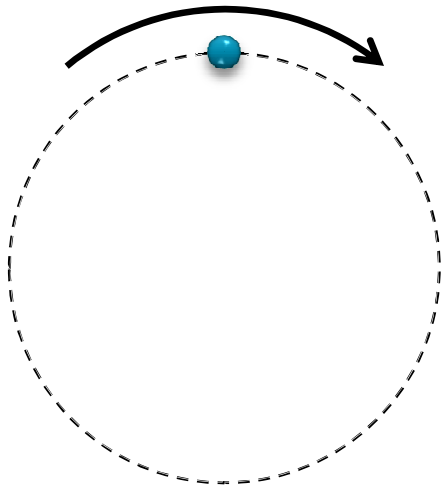
No hay problema de aliasing



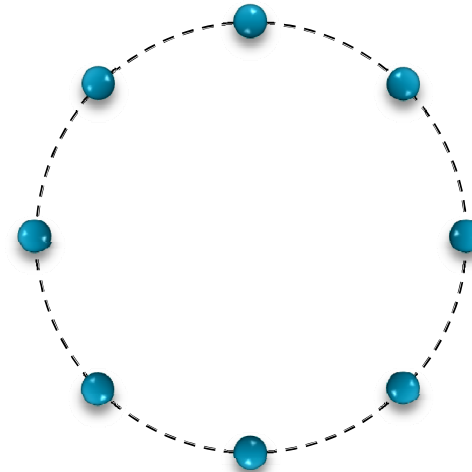
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

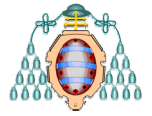


$$f_m = 5 \text{ Hz}, T_m = 0,2 \text{ s}$$



$$f_{Nyquist} = 2,5 > 0,625 \text{ Hz}$$

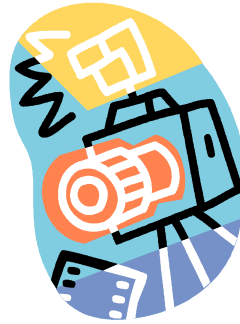
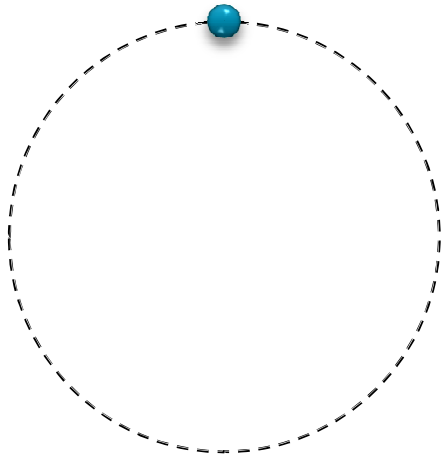
No hay problema de aliasing



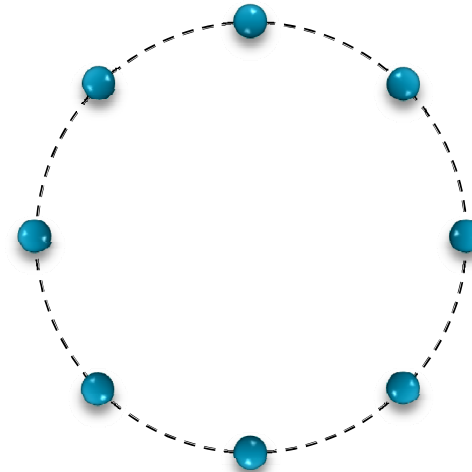
# Problemas del muestreo

## Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

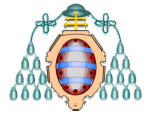


$$f_m = 5 \text{ Hz}, T_m = 0,2 \text{ s}$$



$$f_{Nyquist} = 2,5 > 0,625 \text{ Hz}$$

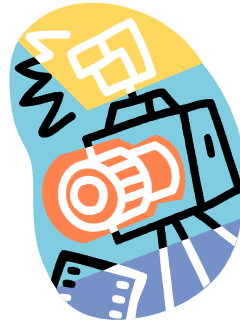
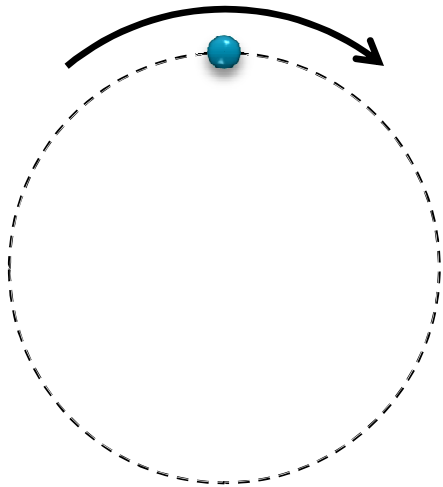
No hay problema de aliasing



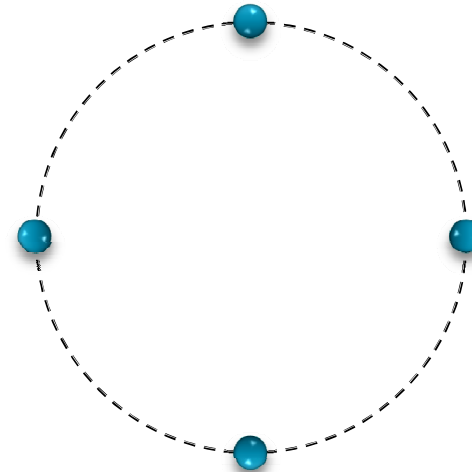
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

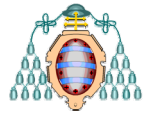


$$f_m = 2,5 \text{ Hz}, T_m = 0,4 \text{ s}$$



$$f_{Nyquist} = 1,125 > 0,625 \text{ Hz}$$

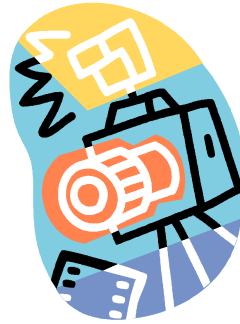
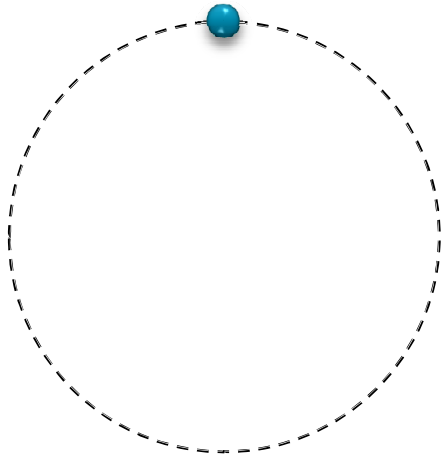
No hay problema de aliasing



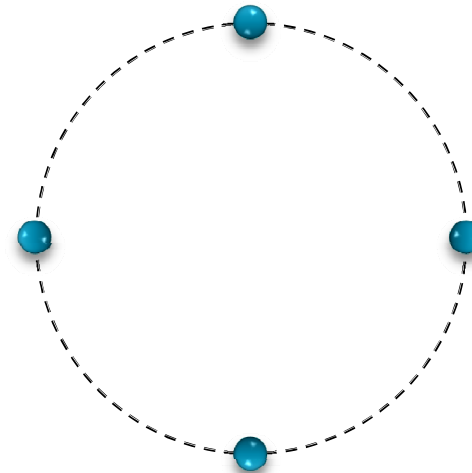
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

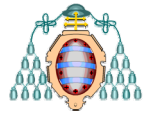


$$f_m = 2,5 \text{ Hz}, T_m = 0,4 \text{ s}$$



$$f_{Nyquist} = 1,25 > 0,625 \text{ Hz}$$

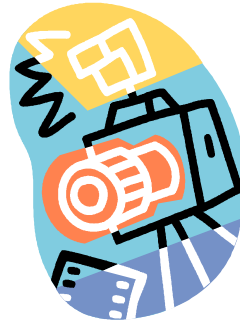
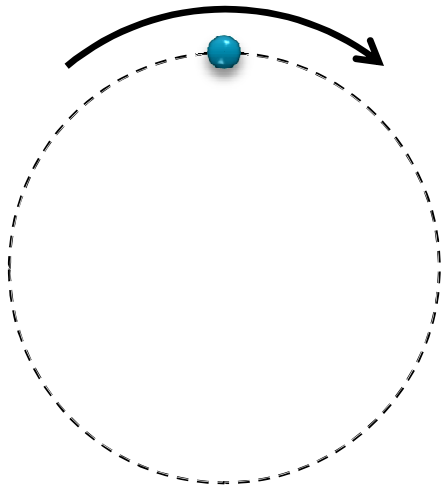
No hay problema de aliasing



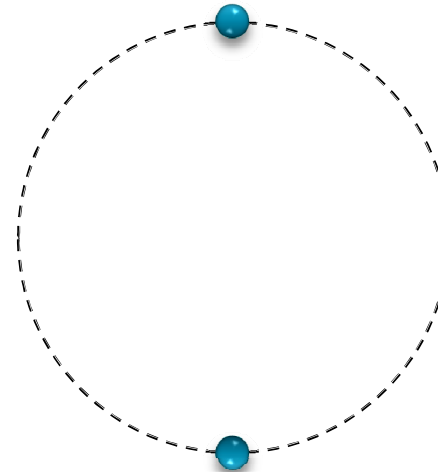
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

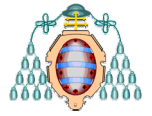


$$f_m = 1,25 \text{ Hz}, T_m = 0,8 \text{ s}$$



$$f_{Nyquist} = 0,625 = 0,625 \text{ Hz}$$

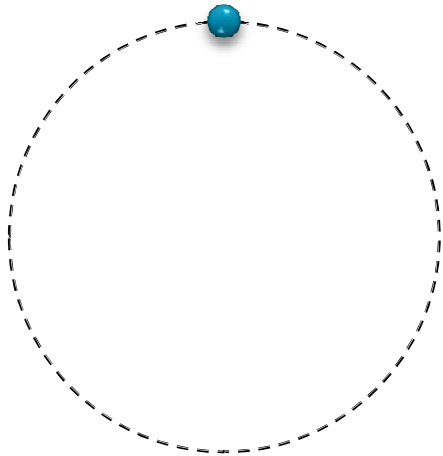
Comienza el problema del aliasing



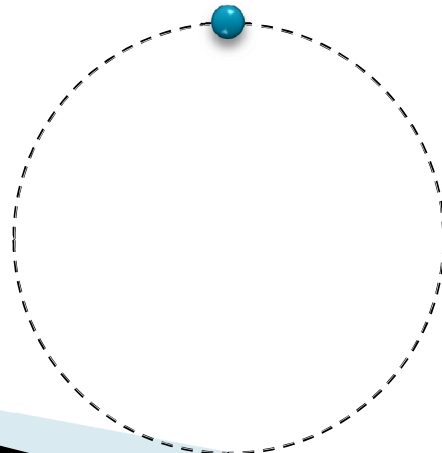
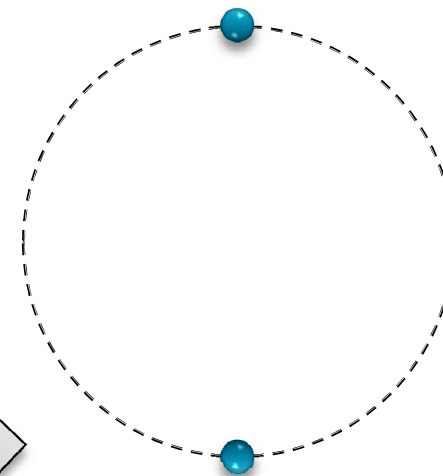
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

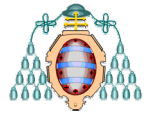


$$f_m = 1,25 \text{ Hz}, T_m = 0,8 \text{ s}$$



No se puede distinguir el sentido de giro

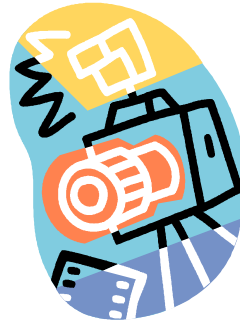
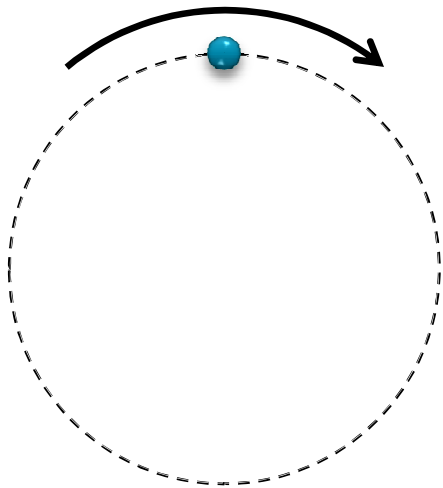




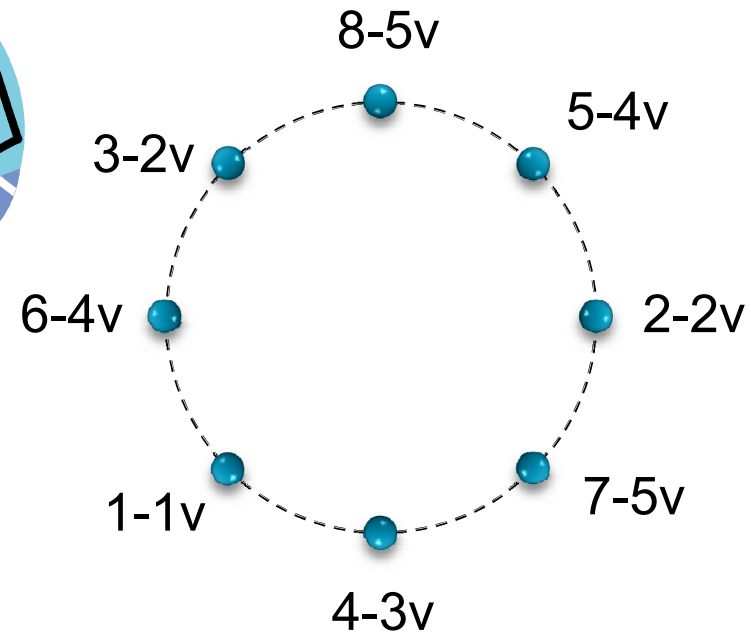
# Problemas del muestreo

## ► Aliasing

$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$

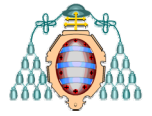


$$f_m = 1 \text{ Hz}, T_m = 1 \text{ s}$$



$$f_{Nyquist} = 0,5 < 0,625 \text{ Hz}$$

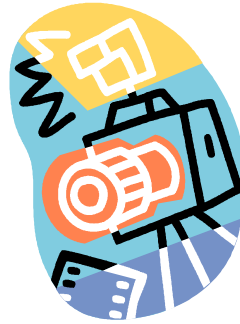
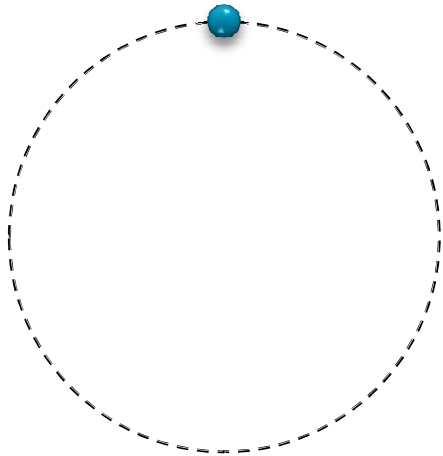
¡Aliasing!



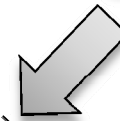
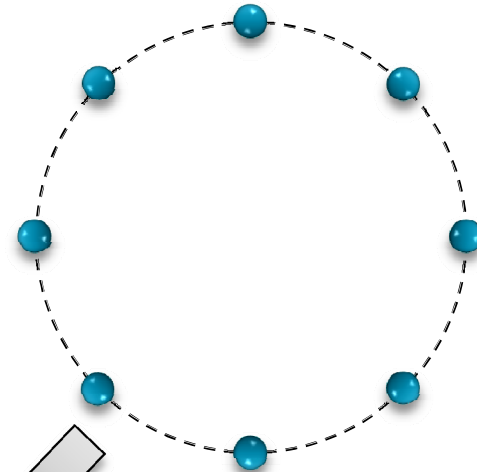
# Problemas del muestreo

## ► Aliasing

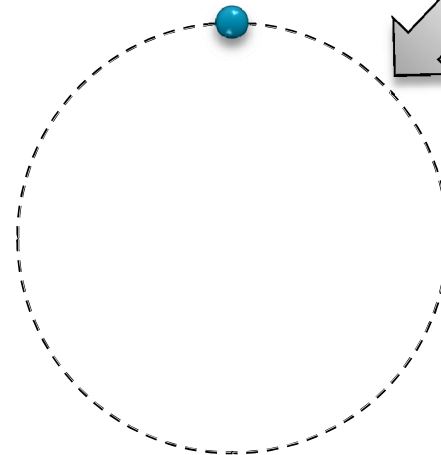
$$f = 0,625 \text{ Hz}, T = 1,6 \text{ s}$$



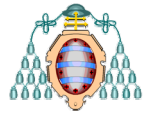
$$f_m = 1 \text{ Hz}, T_m = 1 \text{ s}$$



$$f = 0,375 \text{ Hz}, T = 2,67 \text{ s}$$



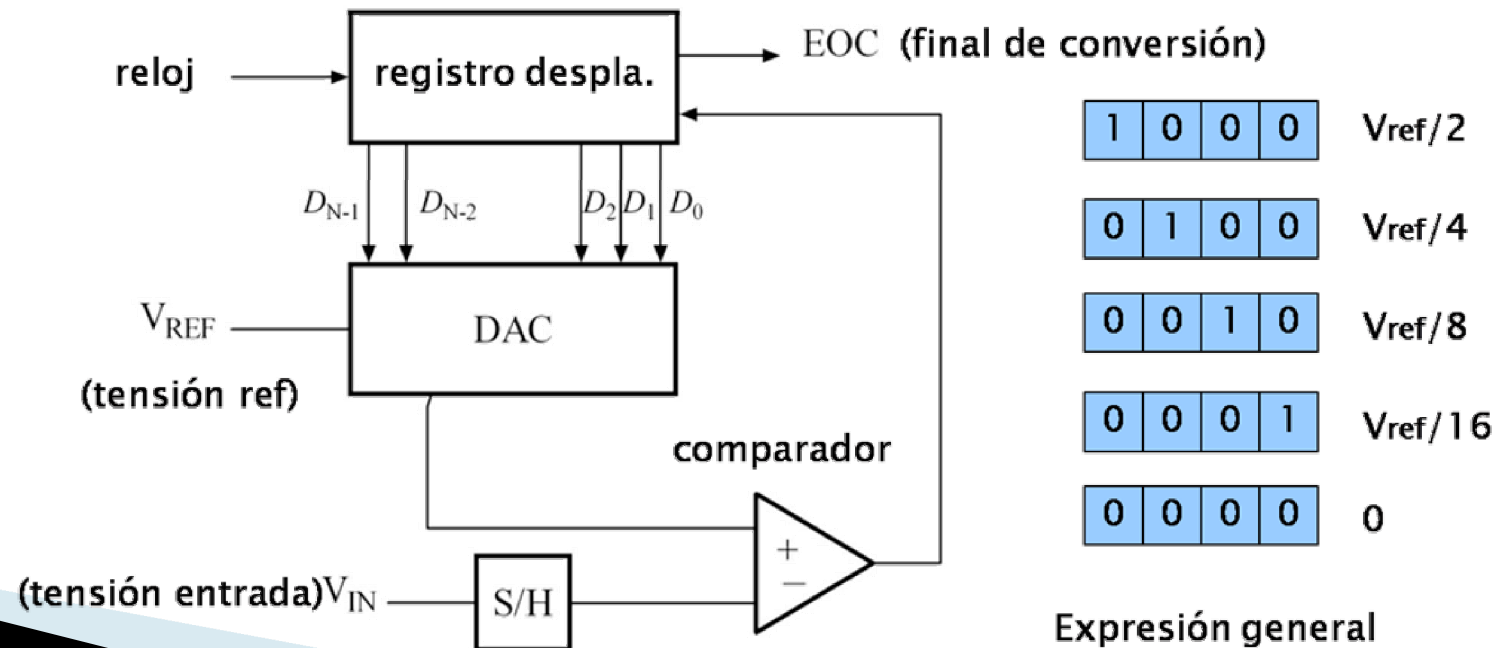
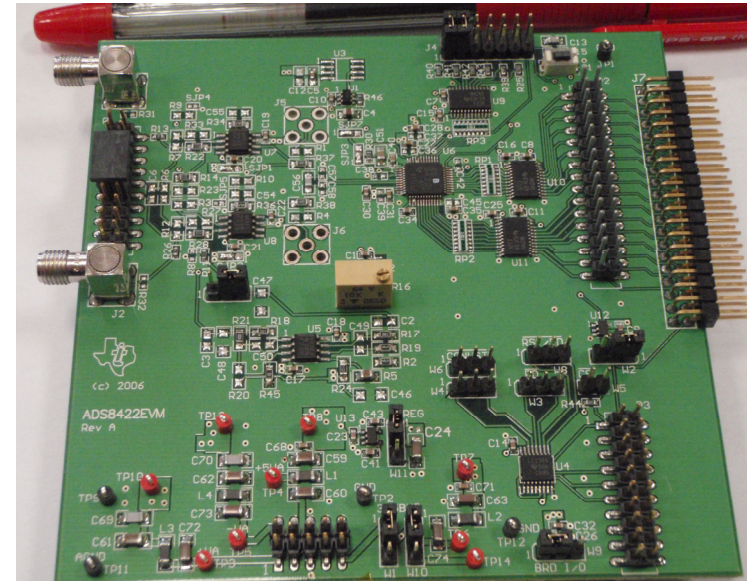
Se confunde la frecuencia

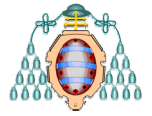


# Hardware de control digital

## ▶ Convertidores A/D

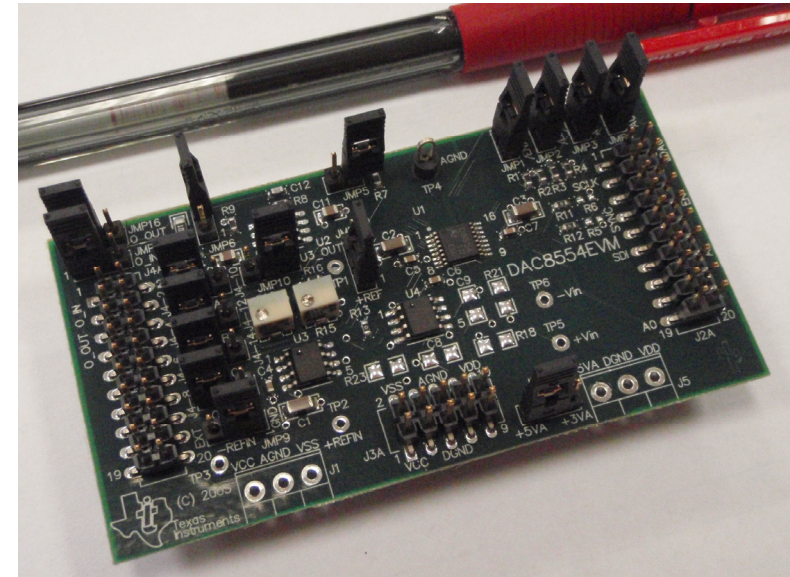
- Resolución: bits
- Tiempo de conversión
- Rango
- Precio



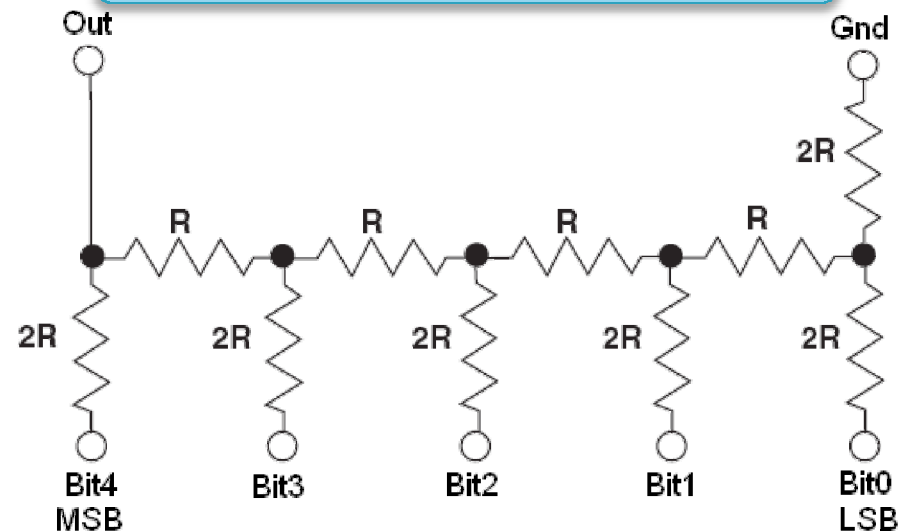


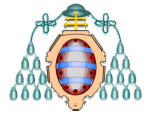
# Hardware de control digital

- ▶ Convertidores D/A
  - Resolución: bits
  - Rango
  - Precio
  - ~~Tiempo de conversión~~



Red de resistencias R-2R





# Hardware de control digital

## ► Filtros antialiasing

- Analógicos
- Butterworth de primer o segundo orden
- Frecuencia de corte
- Implementación: elementos pasivos, células de Sallen–Key

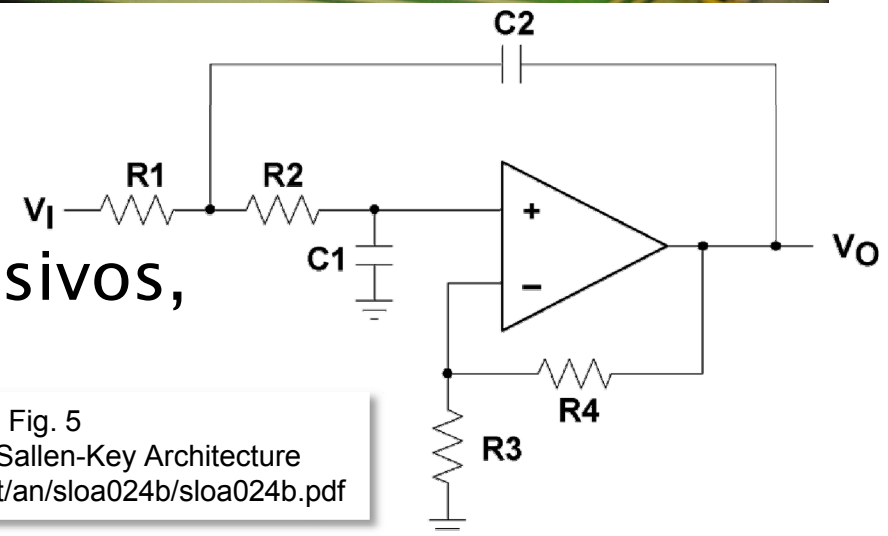
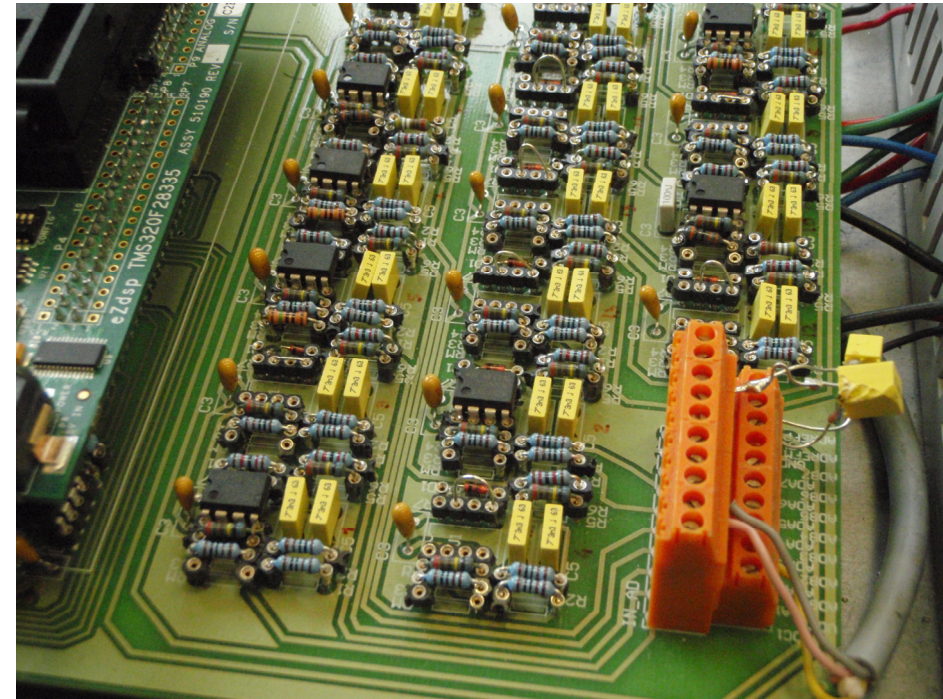
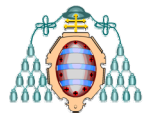


Fig. 5  
Analysis of the Sallen-Key Architecture  
<http://focus.ti.com/lit/an/sloa024b/sloa024b.pdf>



# Hardware de control digital

## ▶ Computador

- Arquitectura: microcontrolador, DSP, DSP controller, PC industrial...
- Velocidad: MHz, MIPS
- Precisión: 8 bit, 16 bit, 32 bit
- Coma fija o coma flotante
- Memoria de programa y de datos
- Periféricos adicionales: AD, comm.
- Precio

