A 14b 100MS/s DAC with Fully-Segmented Dynamic Element Matching

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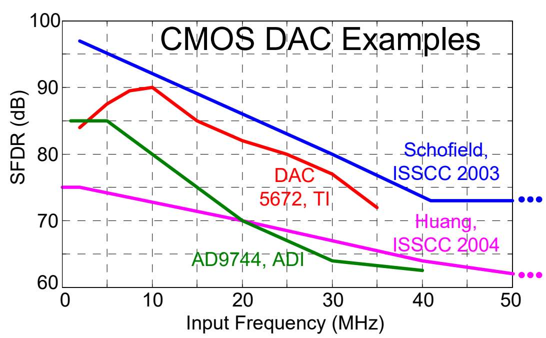
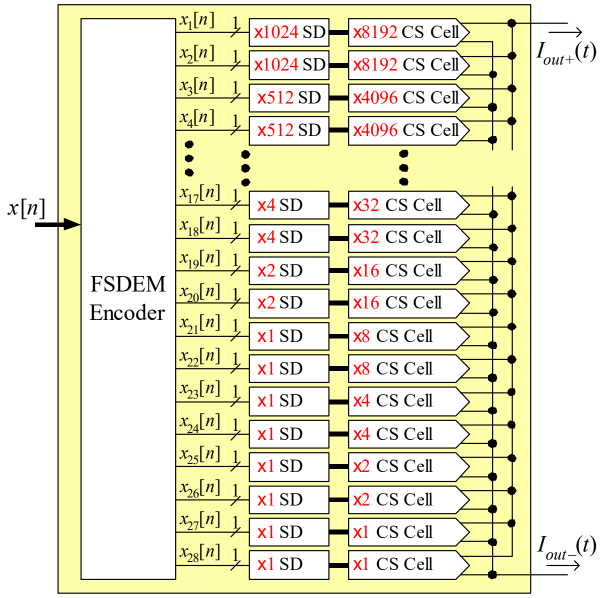
Conventional Nyquist-Rate DACs

- Segmentation with multiple MSB current steering (CS) cells
- Calibration, DEM, trimming, and/or special layout techniques applied to MSB CS cells only
- This does not eliminate non-linearity from CS cell pulse-shape mismatch, timing and glitch errors at high frequencies

⇒ SFDR tends to decrease with signal frequency:



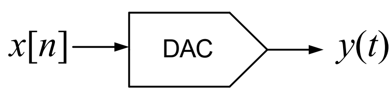
Simplified Diagram of This DAC



SD = Switch Driver, CS = Current Steering

- DEM with RZ output to scramble pulse-shape mismatch and allow smaller CS cells
- Fully Segmented DEM to avoid exponential hardware complexity

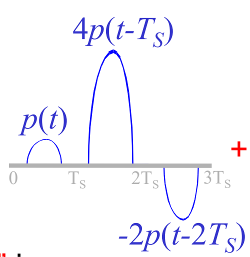
Meaning of DAC Linearity



Goal : Output pulse stream is linearly proportional to $x[n]$

Example:

$x[n]$: 1, 4, -2 $y(t)$ =



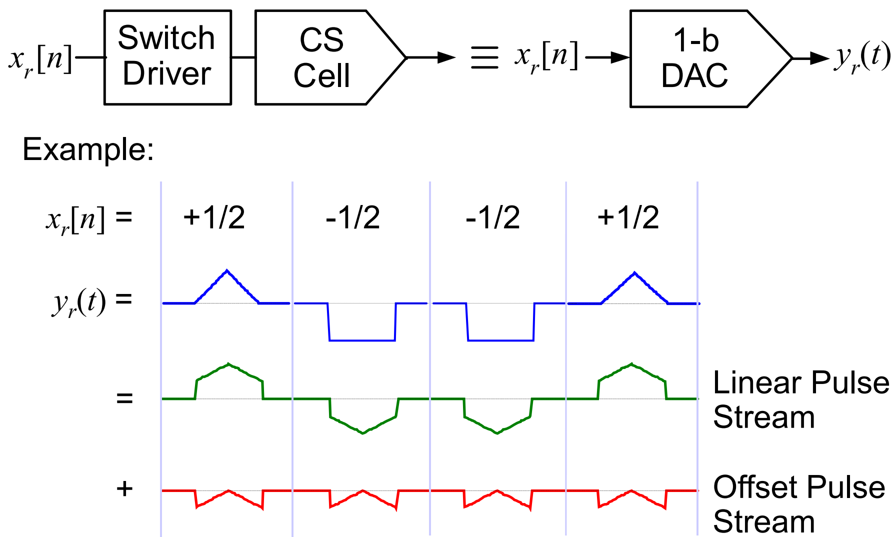
\+ "Other Stuff"

Have linearity if "Other Stuff" is:

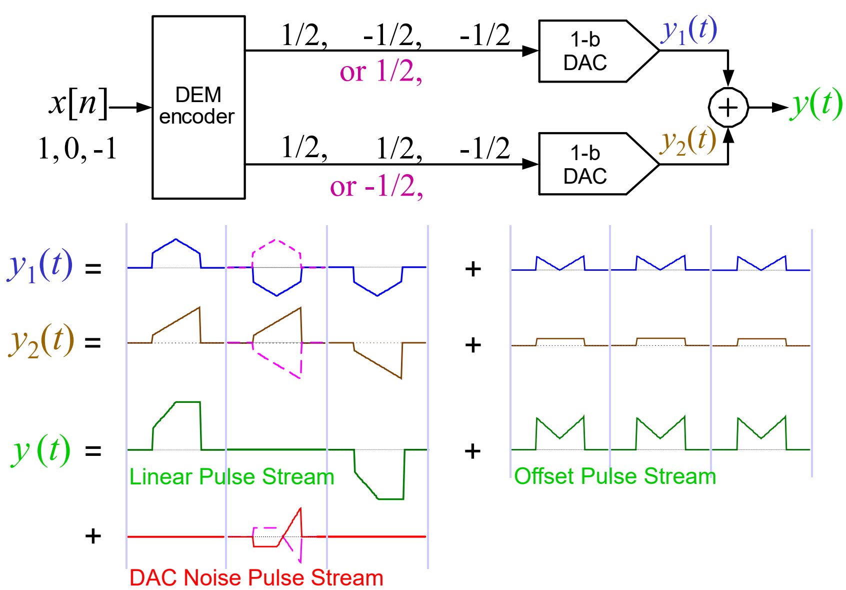
1) deterministic and independent of $x[n]$, or

2) random, spur-free, and uncorrelated with $x[n]$

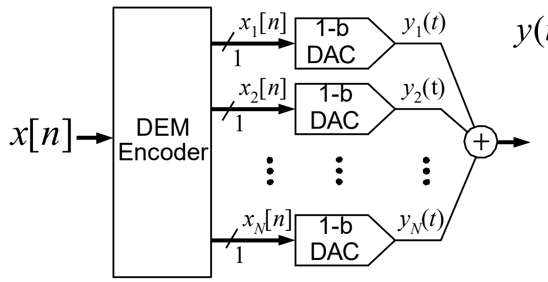
Behavior of r^{th} 1-bit DAC



3-Level DEM DAC Example



DEM Goal



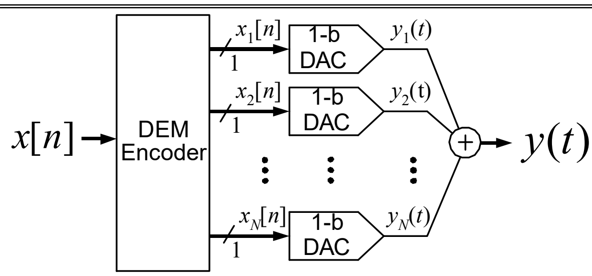
$y(t) = x[n]\alpha(t - nT_S)$
Linear Pulses
$+\beta(t - nT_S)$
Offset Pulses
$+e(n, t - nT_S)$
DAC noise Pulses

DEM Goal : Choose $x_i[n]$($\pm$1/2) such that

1) $$\sum_{i=1}^{N} x_i[n] = x[n]$$

2) DAC noise pulses are spur-free and uncorrelated with $x[n]$

How to achieve DEM Goal



DEM Goal achieved if [Welz, Galton, *TCAS II*, Dec 2002]

$$x_i[n] = m_i x[n] + \varepsilon_i[n]$$ (m_i=constant)

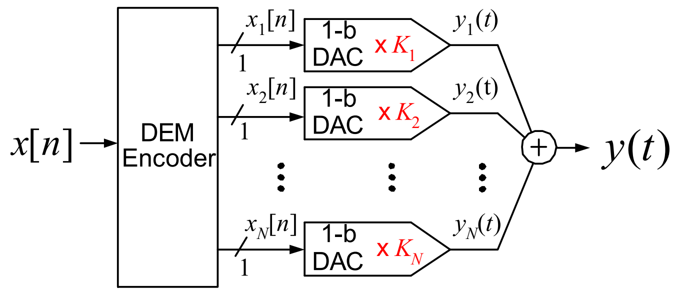
where

1) $\sum_{i=1}^{N} m_i = 1$ 2) $\sum_{i=1}^{N} \varepsilon_i[n] = 0$

3) $\varepsilon_i[n]$ is white and uncorrelated with $x[n]$ and $\varepsilon_j[n]$ for $i \neq j$

$\Rightarrow$ any leakage of $\varepsilon_i[n]$ due to mismatch will be spur-free!

DEM Goal with Segmentation



DEM Goal achieved if

$$x_i[n] = m_i x[n] + \varepsilon_i[n] \qquad (m_i\text{=constant})$$

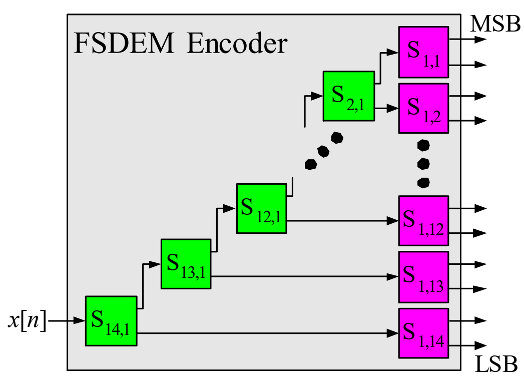
where

1) $\sum_{i=1}^{N} K_i m_i = 1$ 2) $\sum_{i=1}^{N} K_i \varepsilon_i[n] = 0$

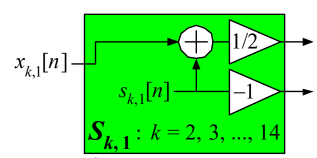
3) $\varepsilon_i[n]$ is well-behaved as before!

Details of FSDEM Encoder

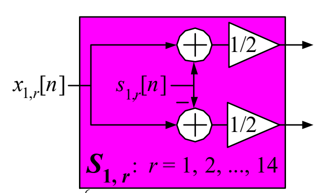
Can verify that the FSDEM encoder below satisfies conditions on last slide:



$d_1[n]$, ..., $d_{14}[n]$ are pseudo-random independent, white ± 1 sequences from LFSR

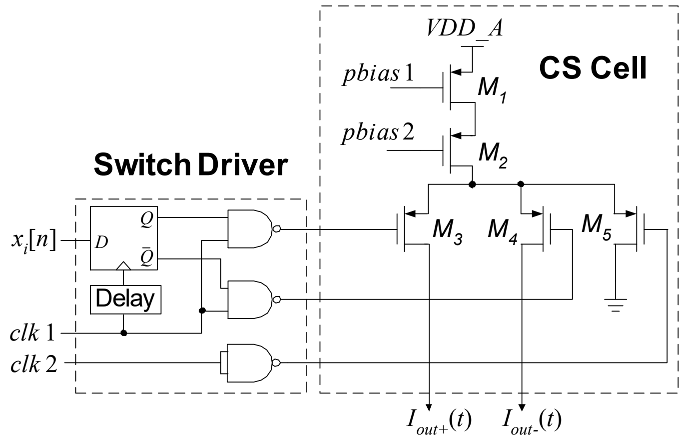


$$s_{k,1}[n] = \begin{cases} 0, & \text{if } x_{k,1}[n] = \text{even} \\ d_k[n], & \text{else} \end{cases}$$



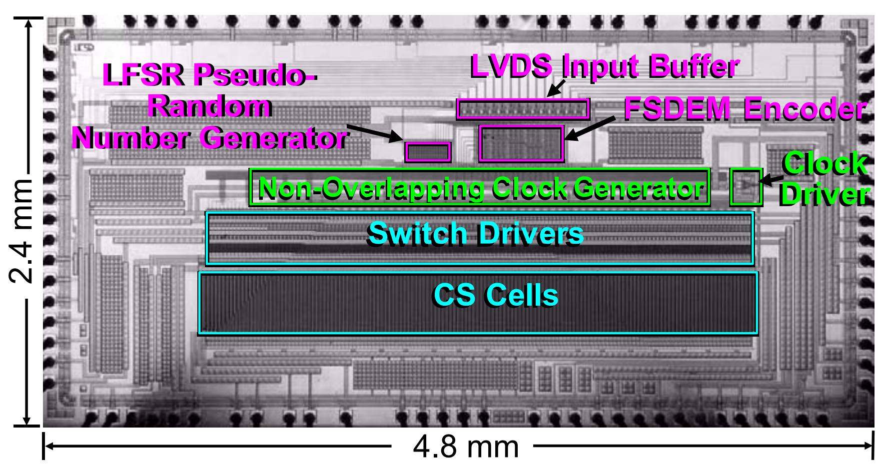
$$s_{1,r}[n] = \begin{cases} 0, & \text{if } x_{1,r}[n] = \text{odd} \\ d_1[n], & \text{else} \end{cases}$$

Circuit-Level Detail of DAC Cell

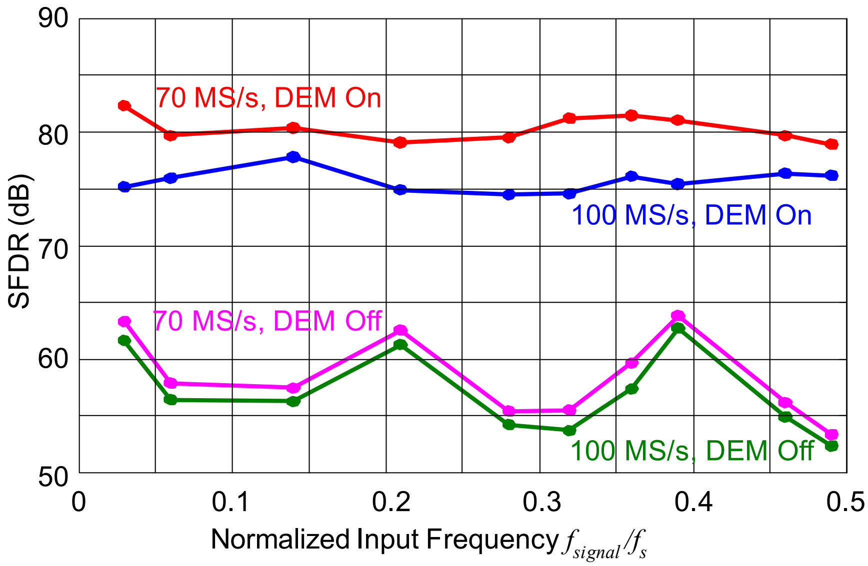


- Switch driver generates RZ switching-signals for CS Cell
- RZ switches in CS cell ensure data-independent transients
- Small transistors in CS cell for low parasitic capacitances

Die Photograph



Measured SFDR versus Frequency



Performance Table

Technology	TSMC 0.18 μm CMOS
Update Rate	100 MS/s
Package	QFN 64 with exposed paddle
Single-Tone SFDR @ 70 MS/s, 0 dBFS	78.9 to 82.3 dB across Nyquist
Single-Tone SFDR @ 100 MS/s, 0 dBFS	74.4 to 77.8 dB across Nyquist
Two-Tone SFDR @ 100 MS/s, -6 dBFS	82.1 dB, $f_{signal\ 1}$=13.97 MHz, $f_{signal\ 2}$=14.94 MHz 82.8 dB, $f_{signal\ 1}$=27.98 MHz, $f_{signal\ 2}$=28.95 MHz 80.6 dB, $f_{signal\ 1}$=45.99 MHz, $f_{signal\ 2}$=46.97 MHz
Full-Scale Current	16 mA
Supply Voltages	Analog: 1.8 V; Digital: 2.3 V
Current Consumption @ 100 MS/s	Analog: 30 mA; Digital: 53.5 mA
Area (including bond pads)	4.8 mm x 2.4 mm
Active Area	3.18 mm^2

Conclusion

- DEM with RZ output scrambles pulse-shape mismatch and allows smaller CS cells
- Fully Segmented DEM avoids exponential hardware complexity at the cost of increased CS cell current
- SFDR of >74 dB and >79 dB achieved across Nyquist band at 100 MS/s and 70 MS/s, respectively

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