AD converter power dissipation in communication systems

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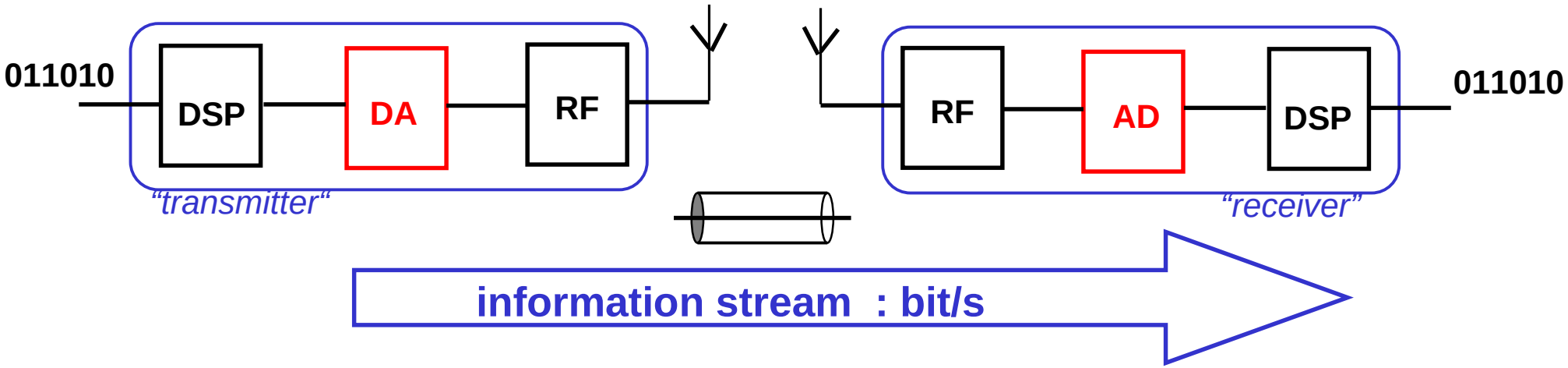
"Create better wired/wireless link"



optimising system is ...

maximise absolute datarate

minimise energy/bit

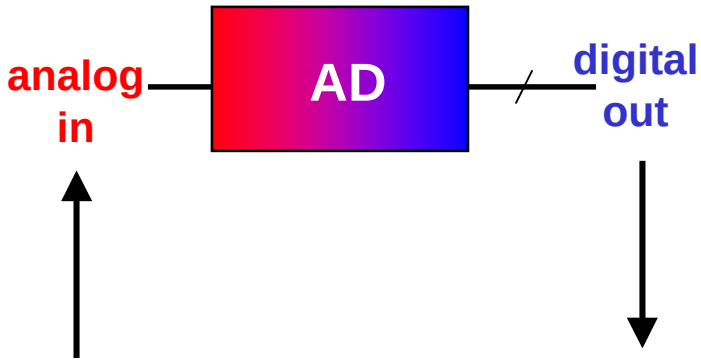
minimise $/bit ($ = hardware & operating cost)

maximise bit/s/Hz

Outline

- AD converters : power dissipation considerations
- Information theory (Shannon) in receiver
- Power/bit
- Some considerations on systems

AD : parameters

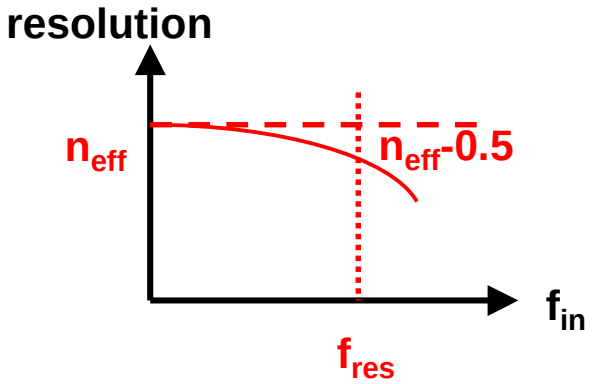


full scale
sine wave, f_{in}

Measured Signal to
Noise & Distortion

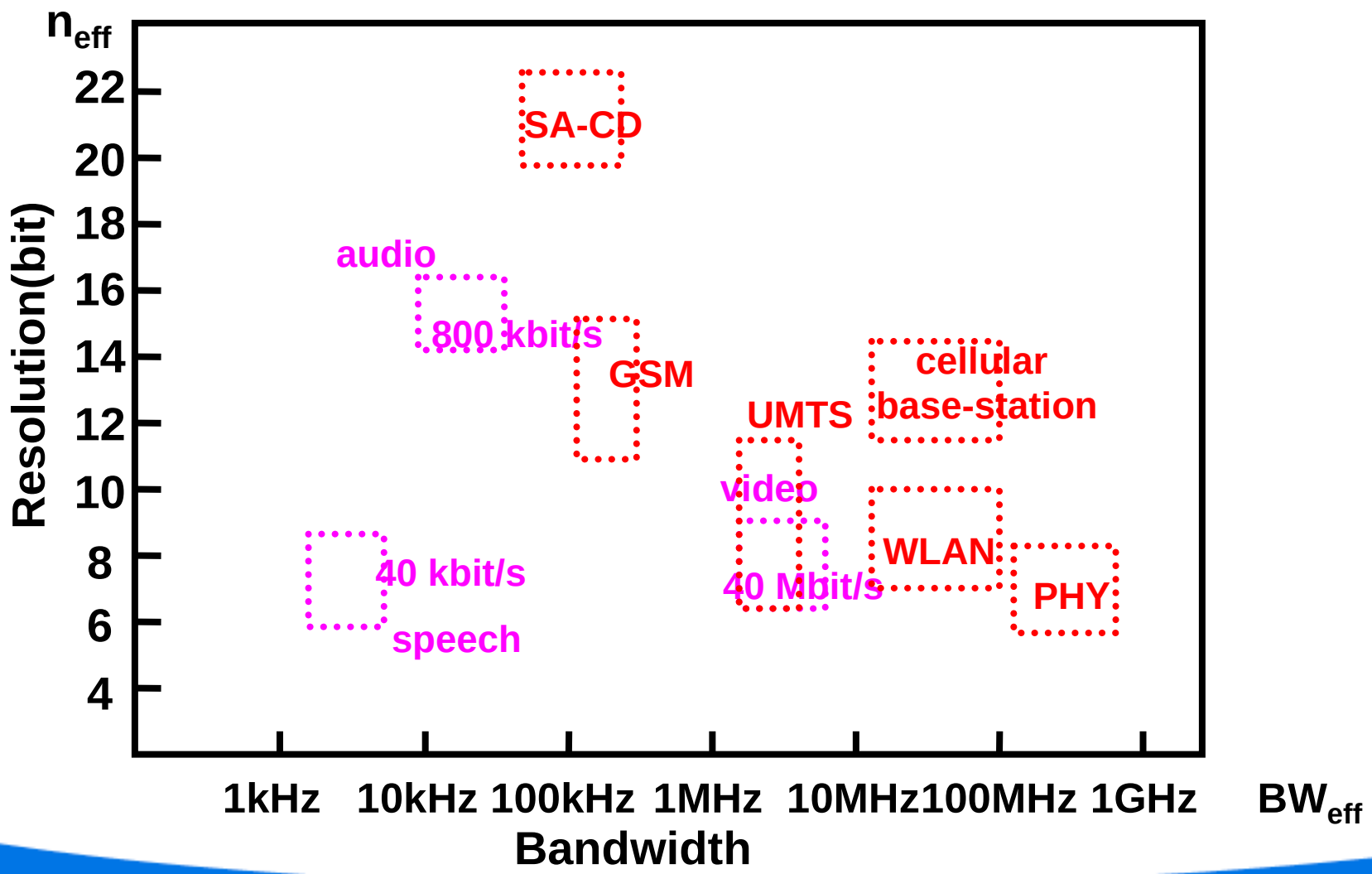
nominal resolution : n bit

sample rate : fs

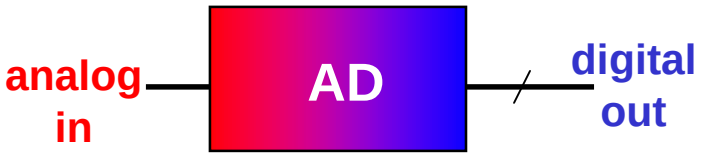


→ **Effective parameters: resolution n_{eff} and bandwidth BW_{eff}= min(fs/2, fres)**

AD parameters span decades !

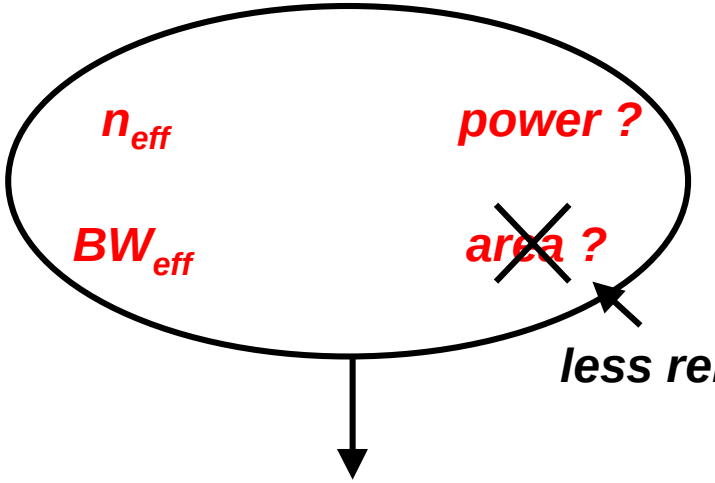


AD : power dissipation ?



resolution (n)

sample rate (fs)



f(architecture, technology, input range, ….)

less relevant: often < 1mm2 <<digital

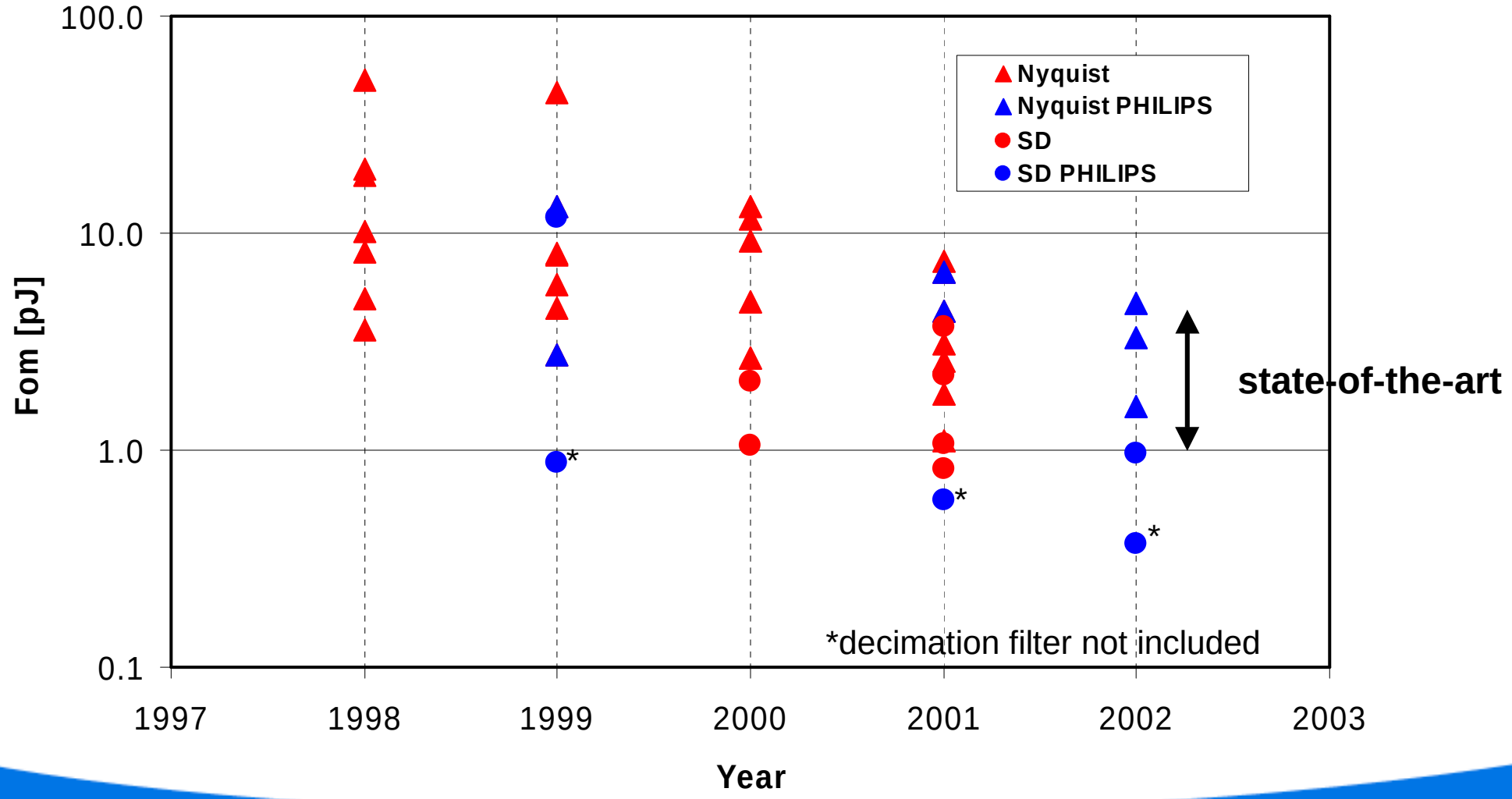
combine parameters in heuristic 'figure of merit' : JSSC => table

$Power / (2^{n}eff * 2\ BW_{eff}) = fom$

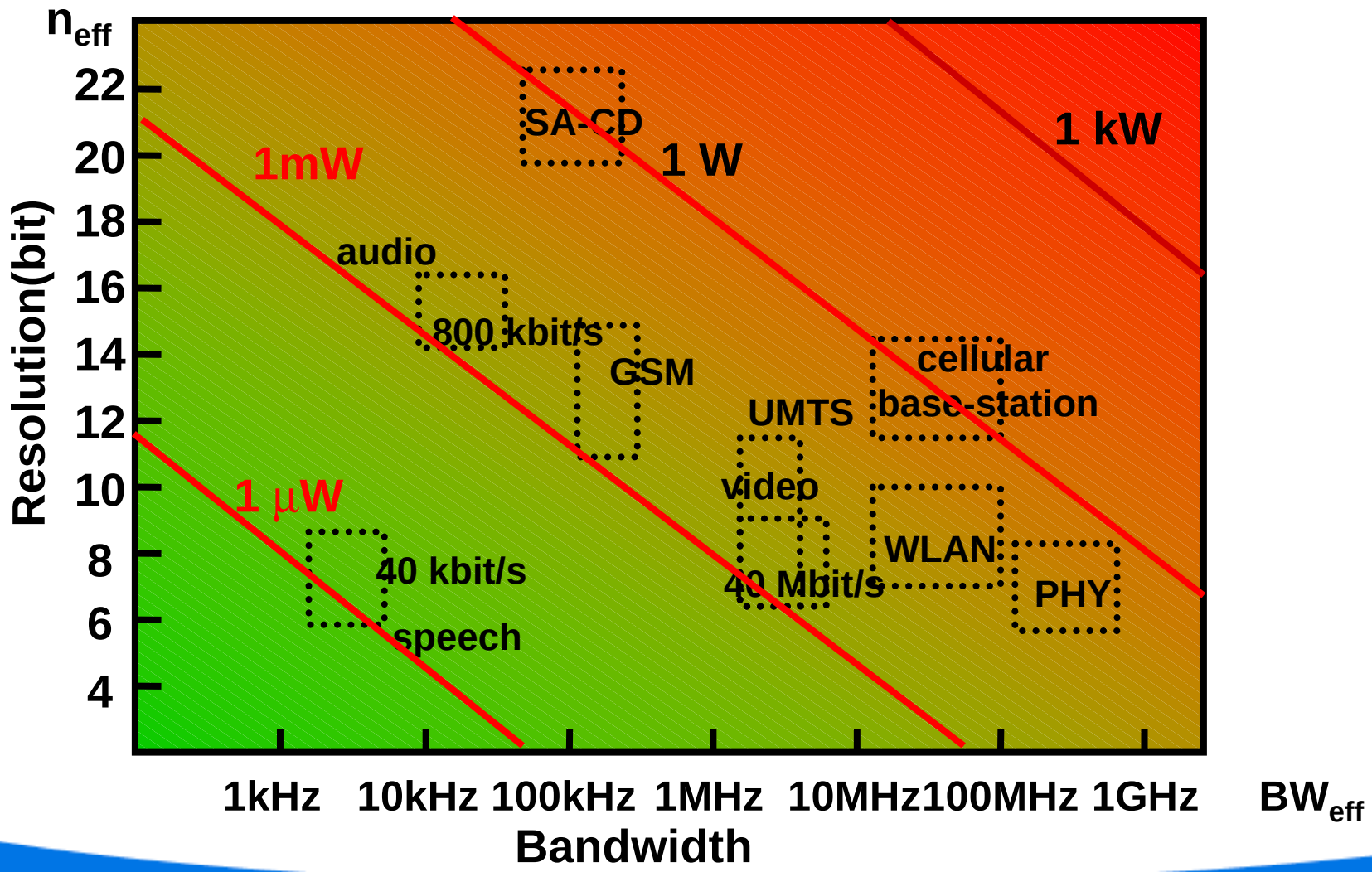
Reference	year	fs	n	power	enob0 SIN	Bwres	fom
		MS/s		mW	[bit]	MHz	pJ
Scholtens ISSCC02	2002	1600	6	328	5.7	660	4.8
Ploeg ISSCC01	2001	54	12	295	10.3	27	4.3
Abidi ISSCC01	2001	1300	6	500	5.7	650	7.4
Geelen ISSCC01	2001	1100	6	300	5.65	450	6.6
Park ISSCC01	2001	100	10	180	9.2	50	3.1
Kelly ISSCC01	2001	75	14	318	11.9	37.5	1.1
Moreland ISSCC00	2000	100	14	1250	12.2	50	2.7
Singer ISSCC00	2001	65	12	420	11.3	32.5	2.6
Pan JSSC00	2000	50	12	850	10.33	25	13.2
Choe JSSC00	2000	40	13	800	11.16	15	11.7
Brandt JSSC99	1999	20	10	75	9.7	10	4.5
Hoogzaad JSSC99	1999	40	10	65	9.2	20	2.8
Ploeg JSSC99	1999	25	10	195	9.2	12.5	13.3
Erdogan JSSC99	1999	0.125	12	16	11.5	0.0625	44.2
Opris JSSC98	1998	20	12	250	10.57	10	8.2
Ingino jSSC98	1998	10	12	338	10.84	5	18.4
Flynn JSSC98	1998	400	6	200	5.3	50	50.8
Tsukamoto JSSC98	1998	400	6	190	5.6	100	19.6
Veldhoven ISSCC02	2002	152	1	4	11.4	2	0.4
ETH ISSCC01	2001			11.5	13.66	0.2	2.2
Motorola ISSCC01	2001			5	13.66	0.18	1.1
Vleugels ISSCC01	2001			150	15.48	2	0.8
Geerts ISSCC00	2000			295	15.8	1.25	2.1
AKM ISSCC00	2000			270	16.65	1.25	1.1
Breems ISSCC99	1999	13	1	1.8	13.32	0.1	0.9
Zwan JSSCC99	1999	20	1	48	13.32	0.2	11.7

=> energy/conversion [pJ]

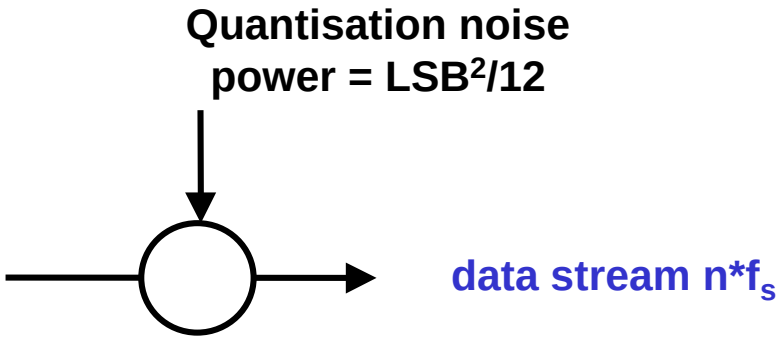
AD : figure of merit over time

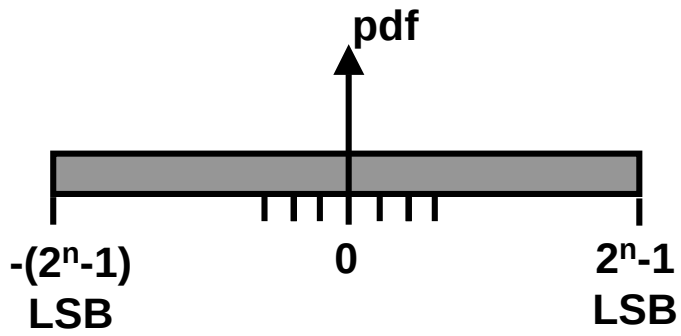


AD power dissipation based on 2pJ



AD & Shannon Information Theory



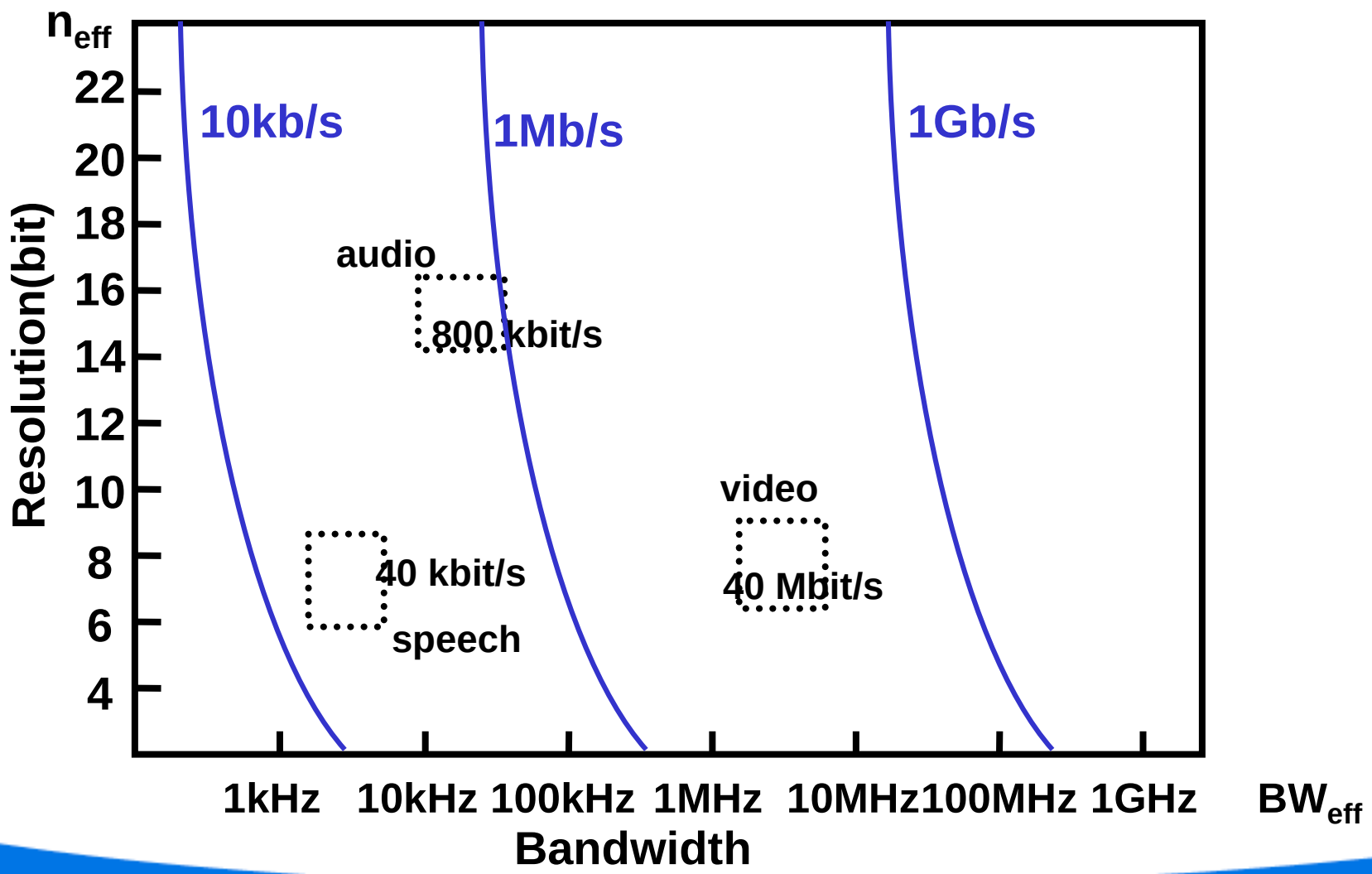


[Shannon] : Capacity=BW.$\log_2(1+S/N)$

$\cong$ fs/2 .$\log_2(2^{2n})$ = fs.n

Upper limit of information n . fs (ideal) => n_{eff} .2.BW_{eff}

Information capacity lines



power & information capacity in AD

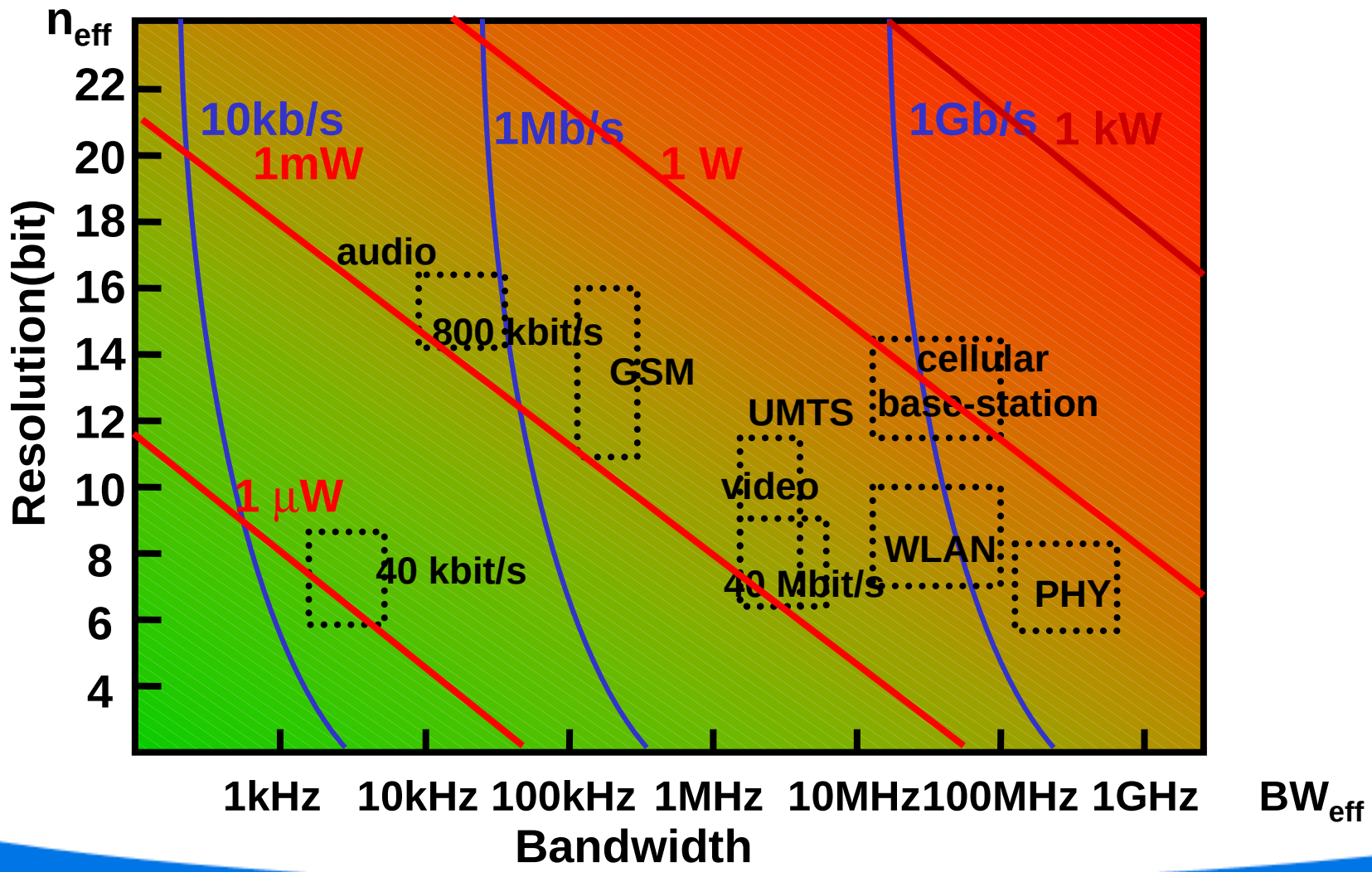
$$power = fom \cdot 2^{n_{eff}} \cdot 2.BW_{eff}$$

$$information\ capacity = n_{eff} \cdot 2.BW_{eff}$$

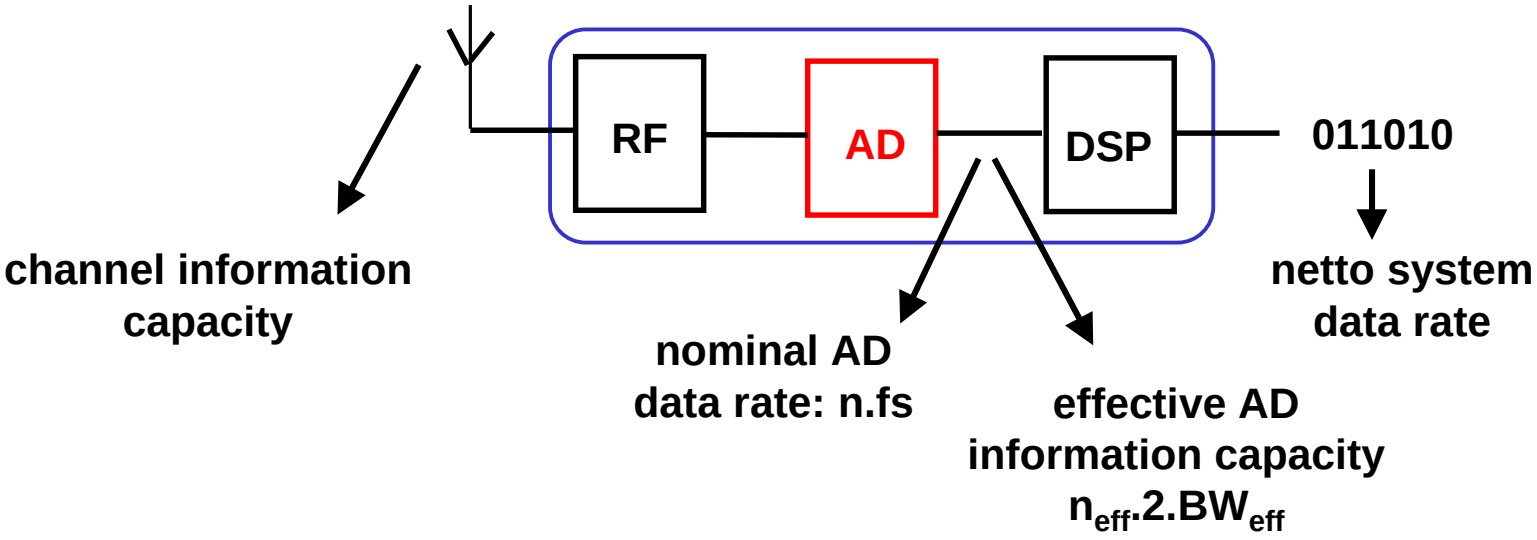
100Mbit/s :

A	B	C
10 bit 10 MS/s	5 bit 20 MS/s	two AD's
power =1	power =1/16	5 bit 10 MS/s
		power =1/16

All lines combined



Not all bits out of AD are information ..

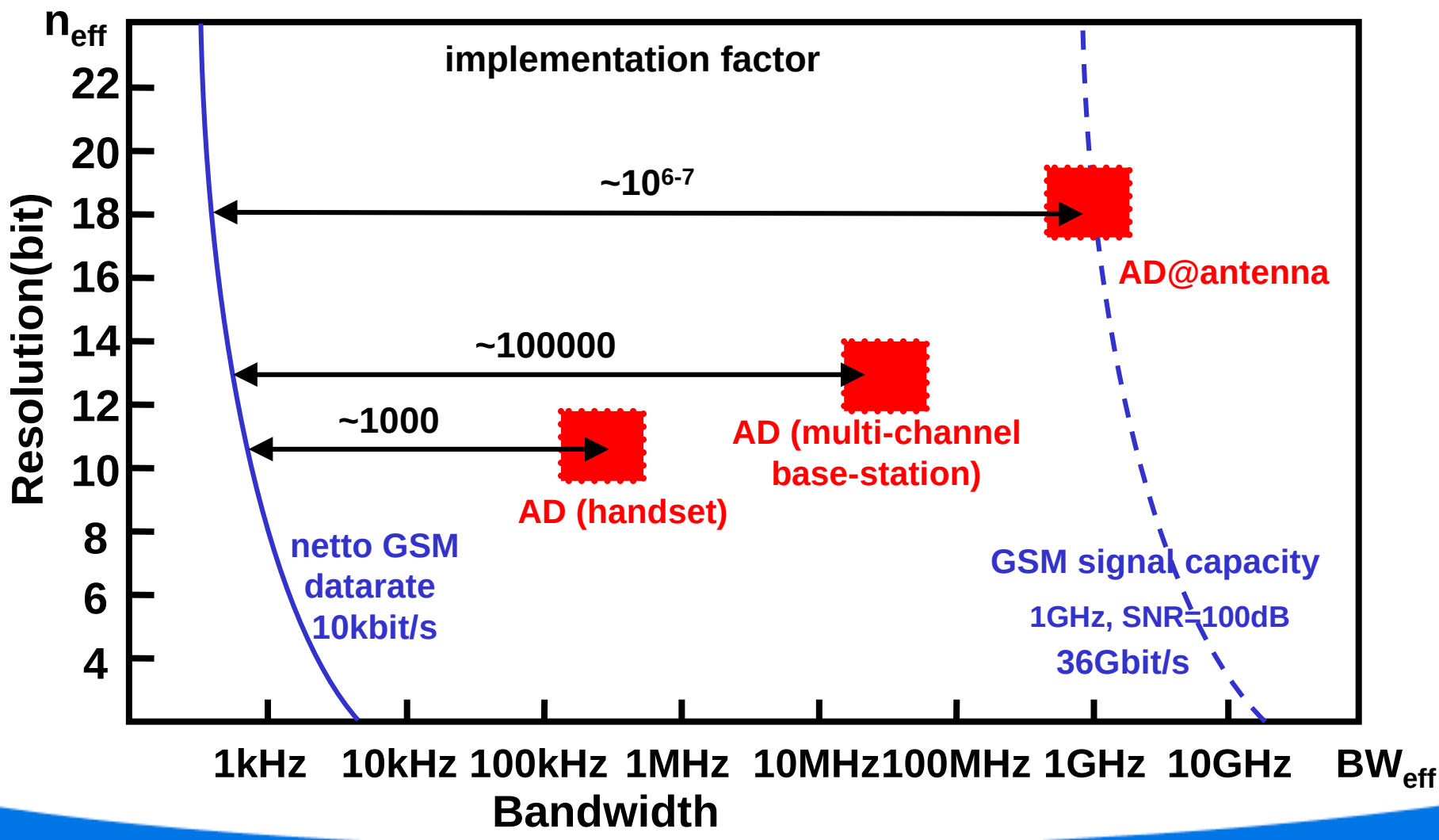


Definition : implementation factor = effective AD information capacity / netto system data rate

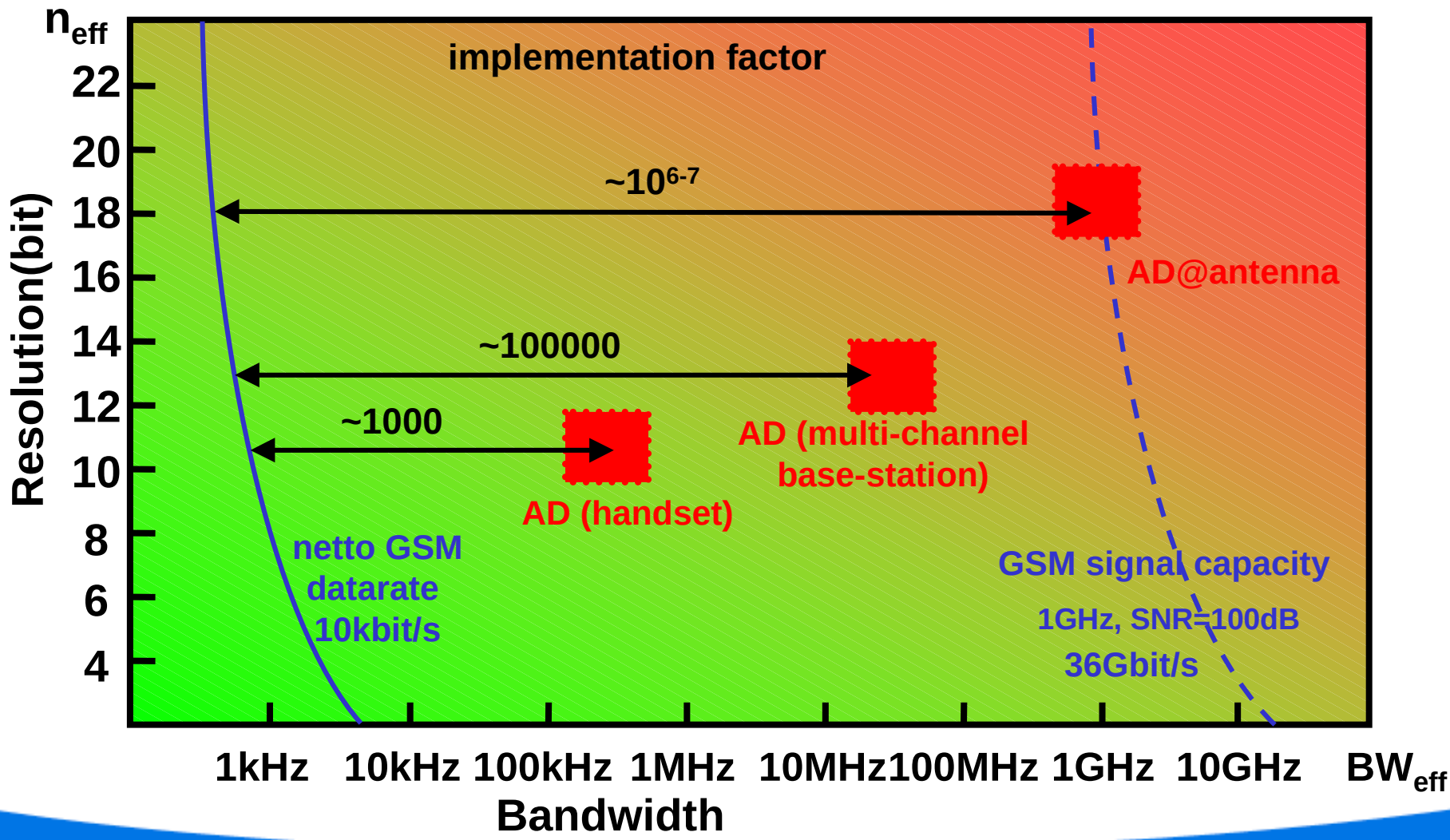
f(receiver architecture, system & standard choices, …)

implementation factor proportional to ‘digitalisation’ of receiver

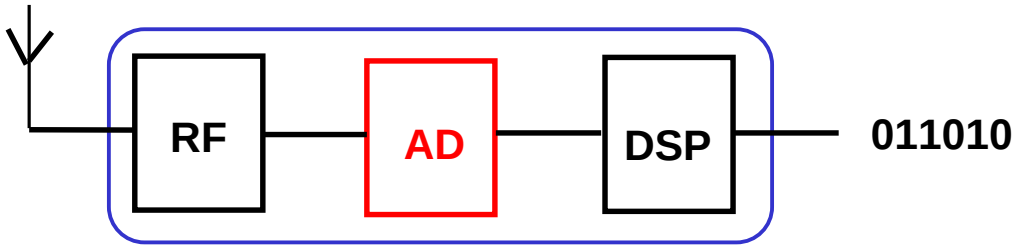
Implementation factor in graphics



Implementation factor in graphics



Calculation AD power in receiver

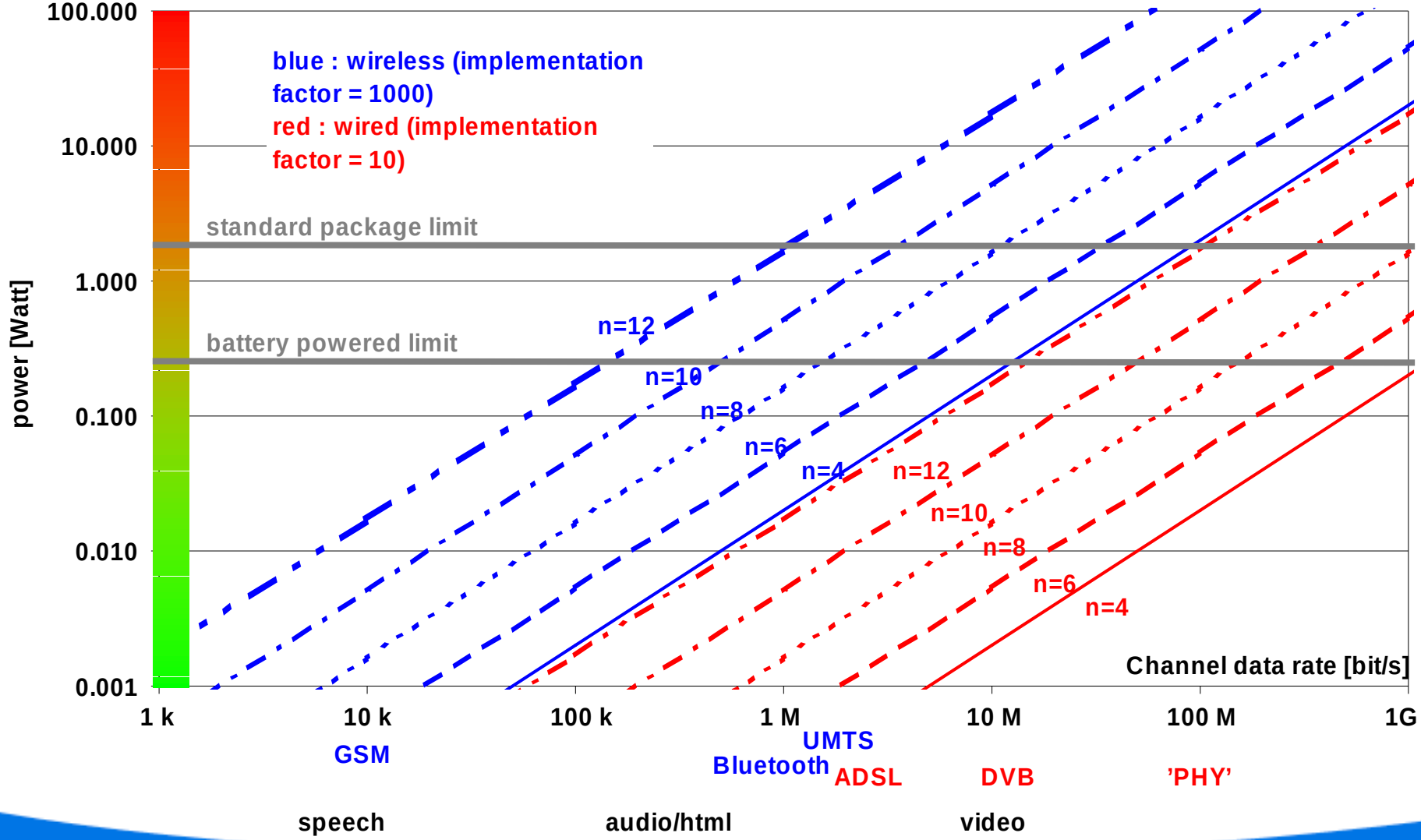


based on the netto data rate, the fom_{AD} and the implementation factor:

$$power_{AD} = \text{netto data rate} \cdot fom_{AD} \cdot implfactor \cdot 2 \cdot 2^n / n$$

- **system defined**
- **circuit design, physical limits**
- **receiver architecture**
- **system & architecture defined**

Channel AD power estimation @5pJ/conversionstep



Receiver architectures and implementation factor

Min implfactor 1 : maximal information conversion capacity in AD used

coding : not perfect random (‘crest factor’) 3 to 10

gain margin : factor 1 to 1000

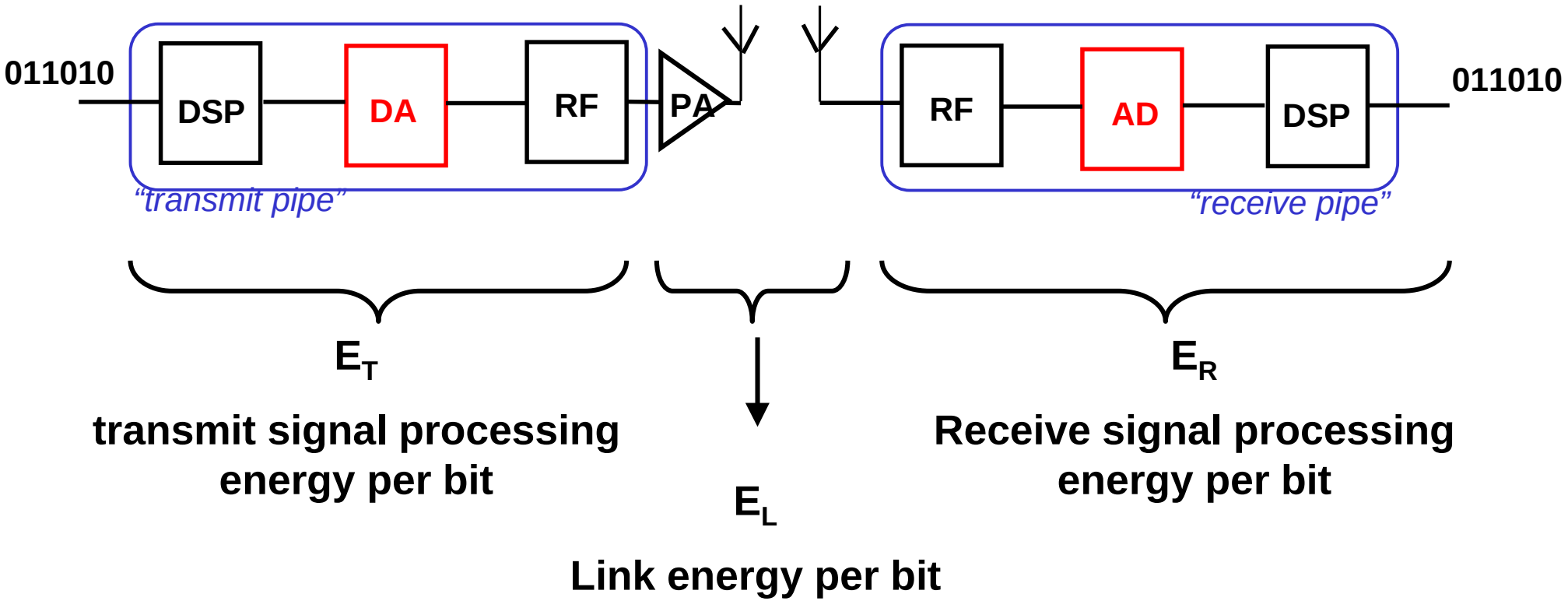
bandwidth margin (aliasing) : factor 2 to 5

channel selectivity : factor 5 to 100

band selectivity : factor 5 to 100

Max implfactor : AD @ antenna

Where does energy go ?



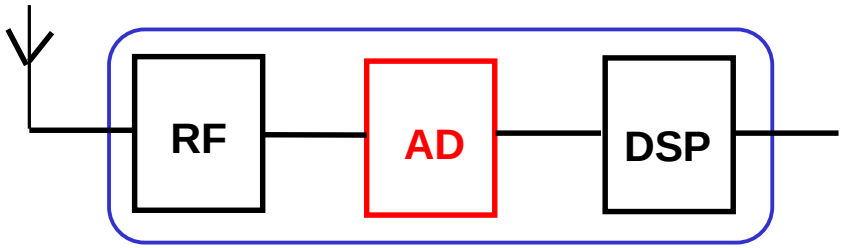
Values for E_T, E_L and E_R

	E_T [nJ/bit]	E_L[nJ/bit]	E_R[nJ/bit]
Bluetooth	150	1	170
GSM (0.2 Watt)	500-1000	2500	500-1000
WLAN 802.11	20-50	50	50
UWB*	250	0.001	250

*based on 5Watt, 10Mbit/s

=> E_T, E_L and E_R are functions of (bit rate, RF-frequency&BW , distance of link, coding scheme, IC technology implementation, .. …...)

E_R : how much in AD ?

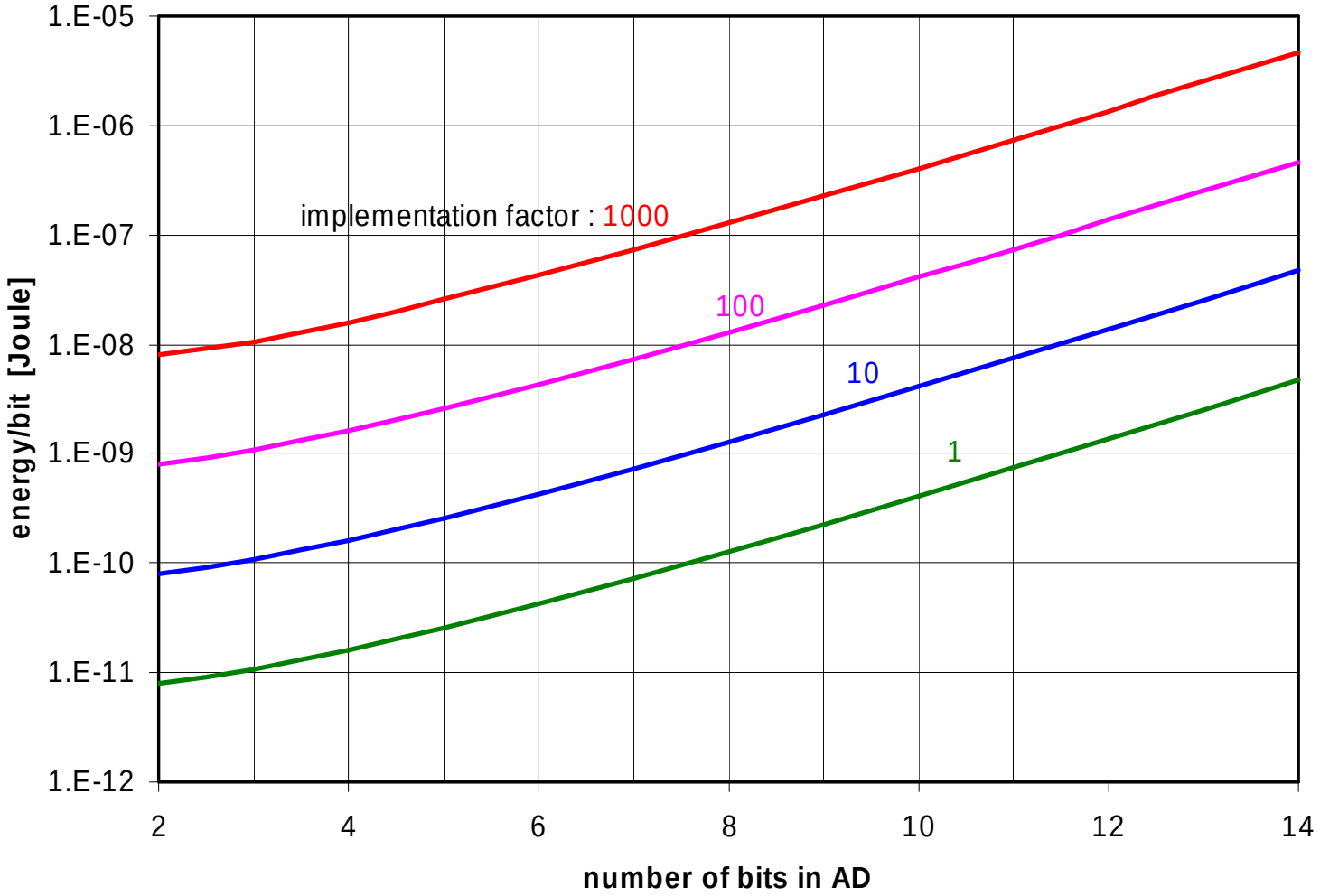


based on fom_{AD} = 2pJ/conversion, the contribution of an n-bit AD converter in E_R is :

$$E_R(AD) = fom_{AD} \cdot implfactor \cdot 2 \cdot 2^n / n$$

e.g. n=8, implfactor 100 => $E_R(AD)$= 12.8nJ/bit (n=10 => 41nJ/bit)

$E_R(AD)$ based on fomAD=2pJ



Summary : AD power in receiver

- proportional to data-rate if it comes from more BW (or multiple parallel channels)

- exponential to data-rate if it comes from more SNR

- proportional to implementation factor (receiver architecture, trade-off with RF front-end power and digital signal processing power !)

- proportional to ‘fom’ of AD (depends on the AD designer, 1 to 5 pJ is state of the art !)