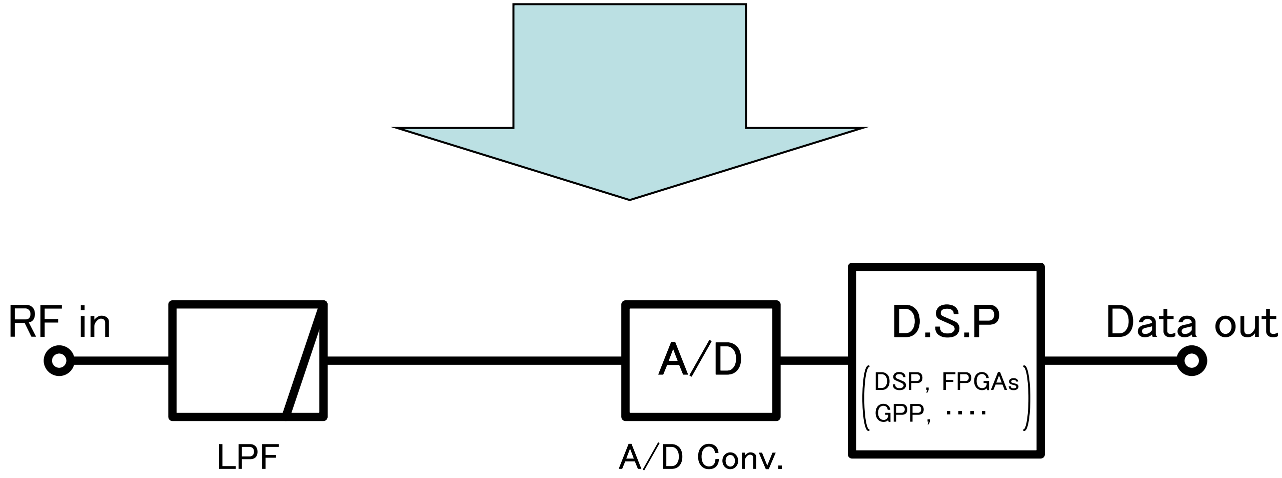
RF Sampling
Software Defined Radio
for HF Band

Outline

- Introduction
- Sensitivity (NF) of SDR
- NF analysis for ADC
- Analysis of bit-length for DSP
- Analysis and design for front-end
- Conclusion
- Q&A

What is an ideal SDR architecture?

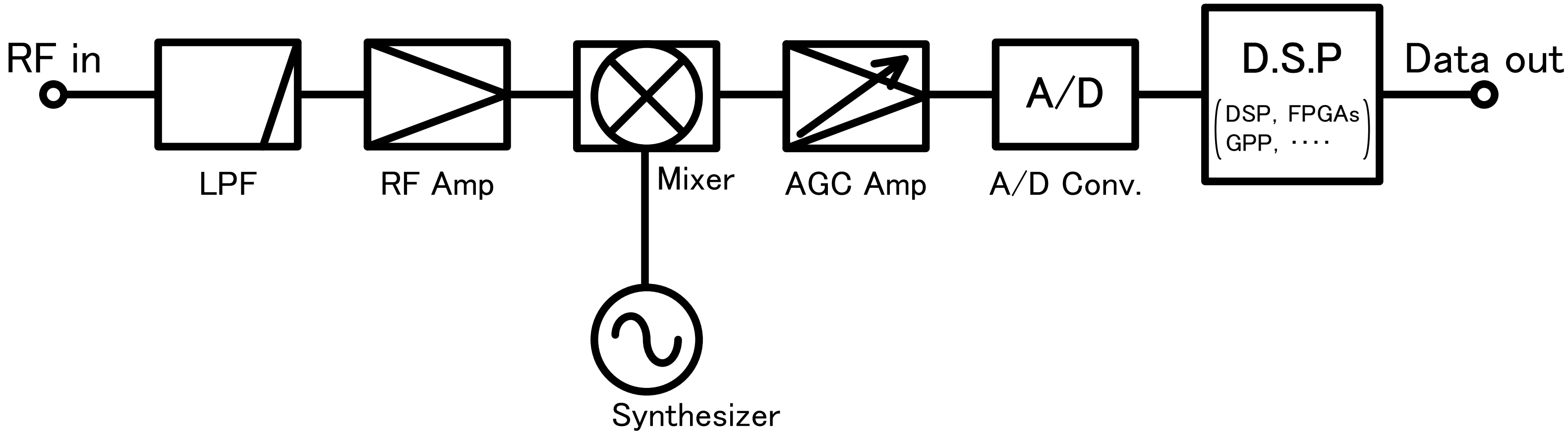


Depends on …

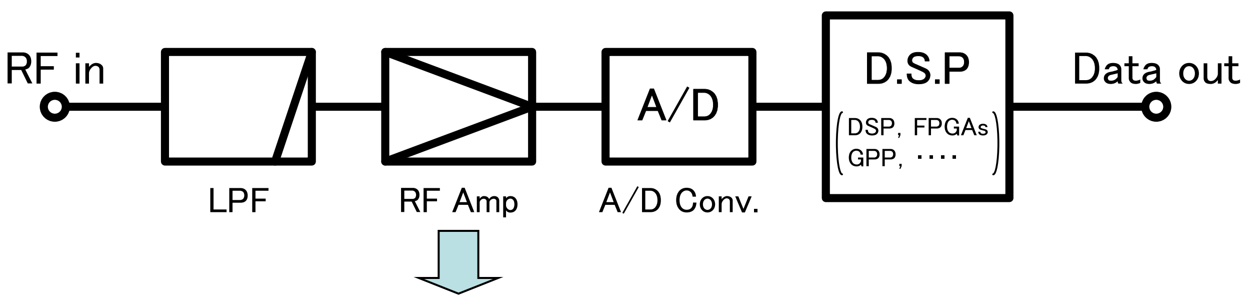
- **receiving frequency**
- **receiving band width**

Introduction ②

Current architecture of SDR is …



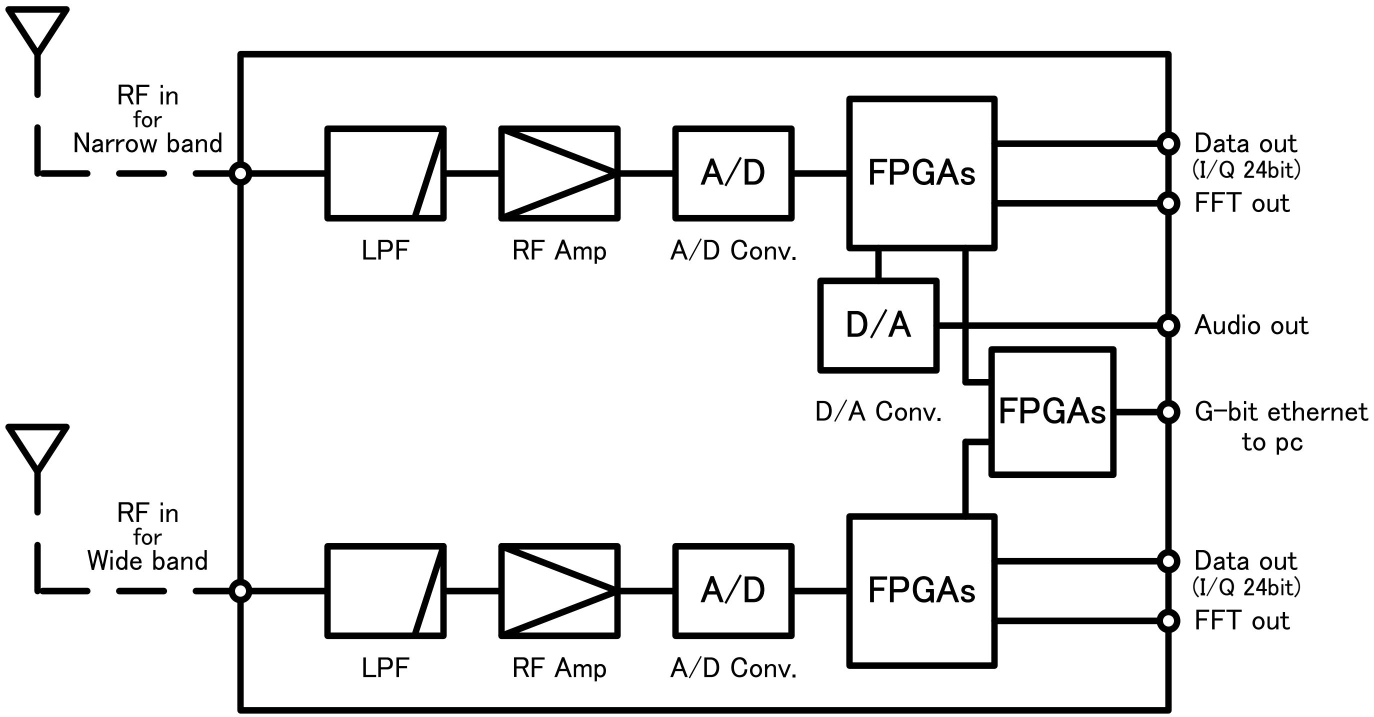
Progressive and realistic architecture of SDR is …



RF amplifiers are needed for keeping the NF.

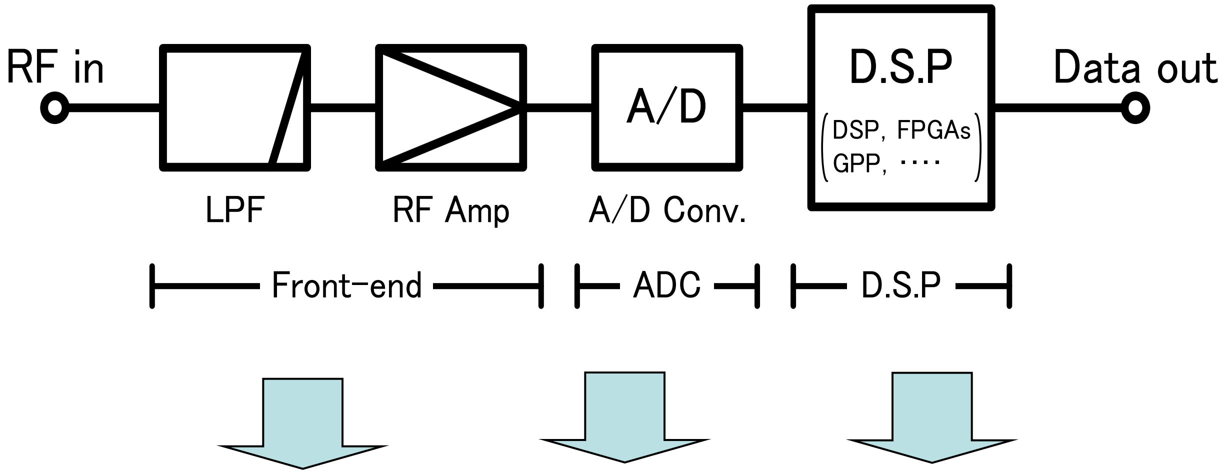
We propose

a realistic SDR for HF band with very high sensitivity & IPs.



- **no Analog Mixer (no image receptions)**
- **no Analog Synthesizer (no reciprocal mixing)**
- **no Analog AGC Circuits (no target reduction)**

How to establish the noise figure and design the appropriate RF amplifier…



NF **NF** **Quantization Error & Bit length**

Specification goal for SDR

High sensitivity mode

Sensitivity (NF)	NF : 8dB
IPs (IP3in & IP2in)	IP3in : +20dBm
	IP2in : +60dBm

Low distortion mode

Sensitivity (NF)	NF : 14dB
IPs (IP3in & IP2in)	IP3in : +30dBm
	IP2in : +70dBm

How to establish the NF of ADC?

Example of ADC characteristics

Resolution [bits]	16[bits]
Full-scale input swing voltage [V p-p]	2.75[V p-p]
Sampling frequency [MHz]	100[MHz]
Signal to quantization noise ratio S/N [dB]	81.1[dB]

$$\text{Amount of noise in ADC output}[\text{dBFS}]$$

$$= -S/N = -81.1[\text{dBFS}] \quad (1)$$

NF analysis for ADC ②

Amount of noise in 1Hz BW of ADC can be described as…

$$\text{Amount of noise in 1Hz BW of ADC output [dBFS]}$$
$$= \text{Amount of noise in ADC output [dBFS]}$$
$$- \text{Correction factor for 1Hz BW [dB]} \quad (2)$$

Correction factor for 1Hz BW can be described as…

$$\text{Correction factor for 1Hz Bandwidth [dB]}$$
$$= 10\log(\text{Nyquist bandwidth} / \text{1Hz bandwidth})$$
$$= 10\log(5e7) = 77.0\,[\text{dB}] \quad (3)$$

$$\text{Amount of noise in 1Hz BW of ADC}$$
$$= -81.1[\text{dBFS}] - 77[\text{dB}] = -158.1[\text{dBFS/Hz}] \quad (4)$$

NF Analysis for ADC ③

Convert to the RF level:

$$\text{full-scale voltage} = 2.75[\text{Vp-p}] = 0[\text{dBFS}] = 12.8[\text{dBm}] \quad (5)$$

By using equation (4), (5)
noise in 1Hz BW of ADC output converts to the RF level:

$$\text{noise in 1Hz BW of ADC output}$$

$$= 12.8[\text{dBm}] - 158.1[\text{dB}] = -145.3[\text{dBm}] \quad (6)$$

$$\text{thermal noise in 1Hz BW} = 10\log(kT)[\text{dBm}]$$

$$= 10\log((1.38\text{e-}23)\ (2.98\text{e}2)) = 10\log(4.11\text{e-}18)$$

$$= 173.9[\text{dBm}] \quad (8)$$

Where k = Boltzmann’s constant, 1.38e-23
T = absolute temperature, K (298 K)

NF Analysis for ADC ④

NF of ADC is designated as:

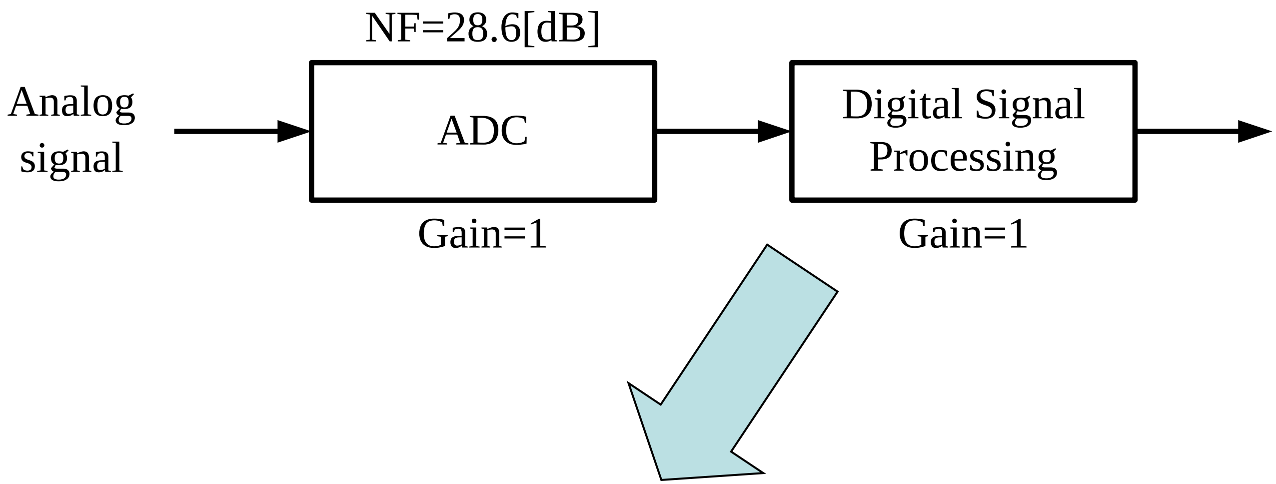
$$\text{NF of ADC} = \text{ADC noise component in 1Hz BW} - \text{thermal noise in 1Hz BW}$$

$$= -145.3[\text{dBm}] - (-173.9[\text{dBm}]) = 28.6[\text{dB}] \quad (9)$$

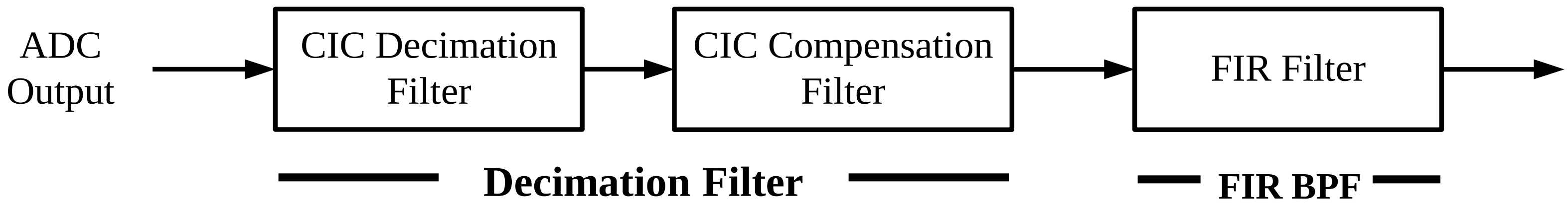
From equation (9),
NF of ADC can be assumed to be 28.6dB.

Analysis of the bit length for DSP ①

Process of Digital Signal Processing



Principal flow diagram of digital signal processing



Analysis of the bit length for DSP ②

Analysis of noise in the digital filter.

$$\text{In-band noise of the filter}$$
$$= \text{inband noise of ADC output} + \text{quantizaton noise of itself} \quad (10)$$

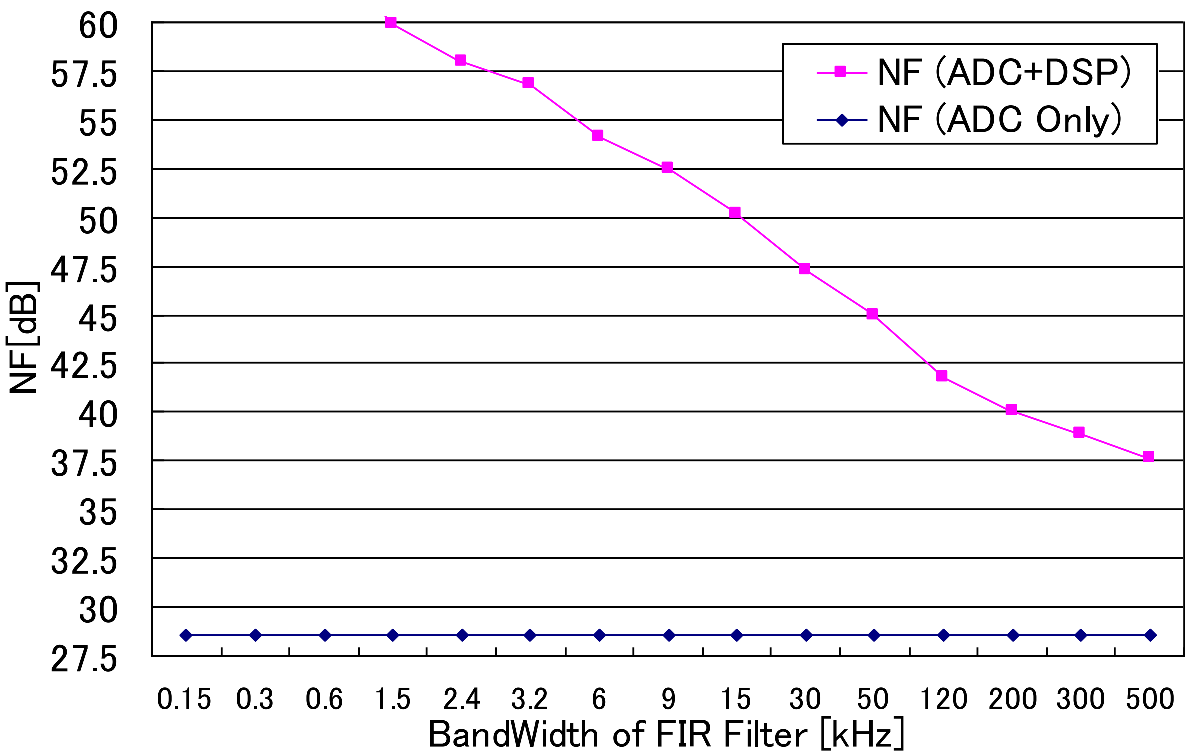
$$\text{Out-band noise of the filter}$$
$$= \text{outband quantization noise of it} \quad (11)$$

$$\text{Amount of noise in the filter output}$$
$$= \text{inband noise of the filter} + \text{outband noise of the filter} \quad (12)$$

Analysis of the bit length for DSP ③

NF calculation of 16bit decimation filter and 16bit FIR filter

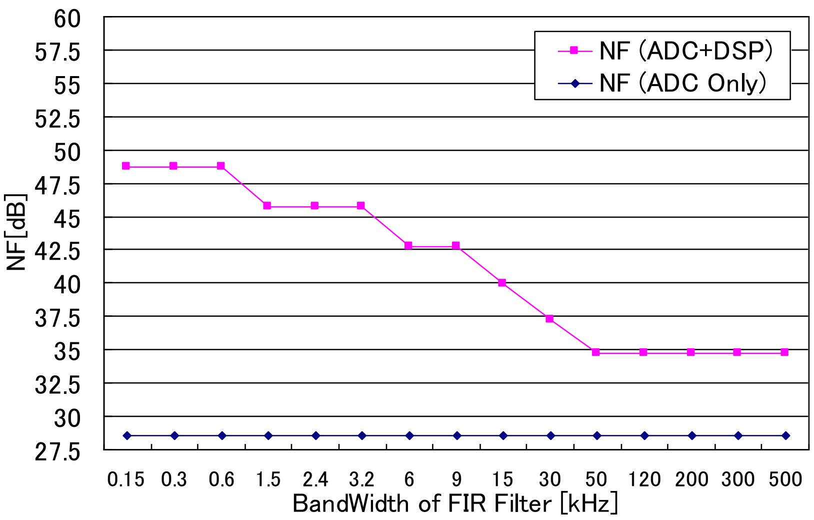
Decimation filters bit length: 16bit
FIR filters bit length: 16bit



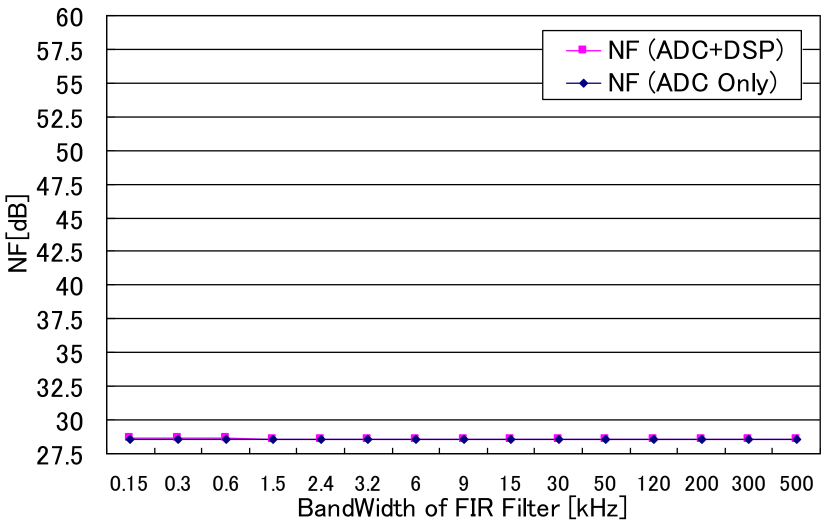
Analysis of the bit length for DSP ④

Calculation of the good length bit for **decimation filters**

Decimation filters bit length: 16bit
FIR filters bit length: 32bit



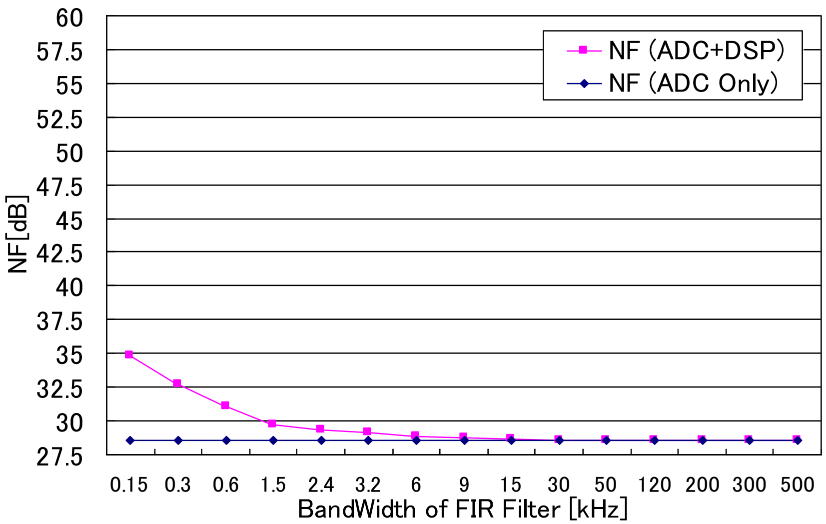
Decimation filters bit length: 22bit
FIR filters bit length: 32bit



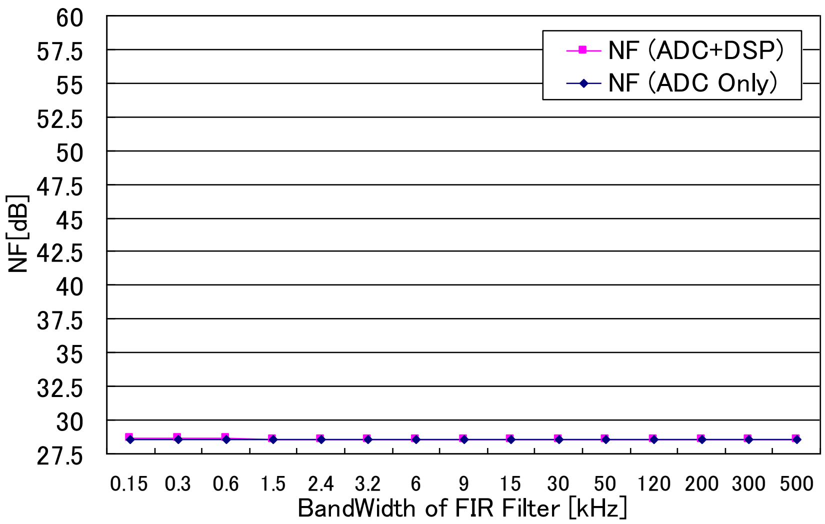
Analysis of the bit length for DSP ⑤

Calculation of the good length bit for <u>**FIR filters**</u>

Decimation filters bit length: 32bit
FIR filters bit length: 22bit



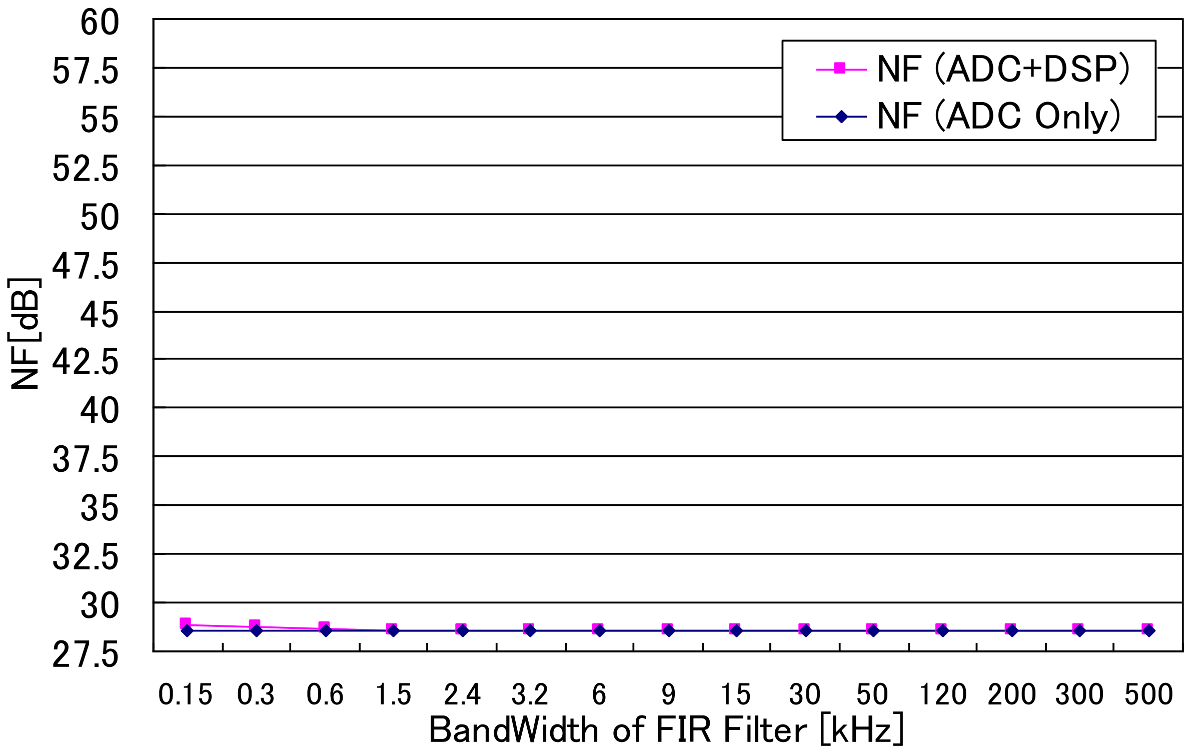
Decimation filters bit length: 32bit
FIR filters bit length: 25bit



Analysis of the bit length for DSP ⑥

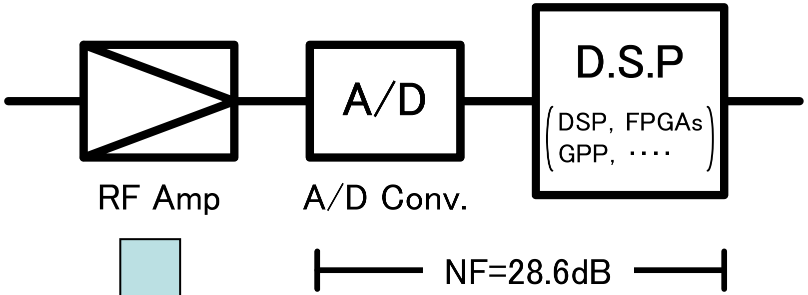
NF calculation of 22bit decimation filter and 25bit FIR filter

Decimation filters bit length: 22bit
FIR filters bit length: 25bit



Analysis and design for front-end ①

Calculating the NF and gain for front-end in order to keep receivers NF of 8dB.



NF=
Gain=
IP3=
IP2=

NF for front-end [dB]	Necessary gain for front-end [dB]
0	21.3434046
1	21.5605299
2	21.8502767
3	22.2448863
4	22.7988092
4.5	23.1642654
5	23.6146253
5.5	24.1826455
<u>6</u>	<u>24.9232352</u>
6.5	25.9393661
7	27.4622541
7.5	30.2297457

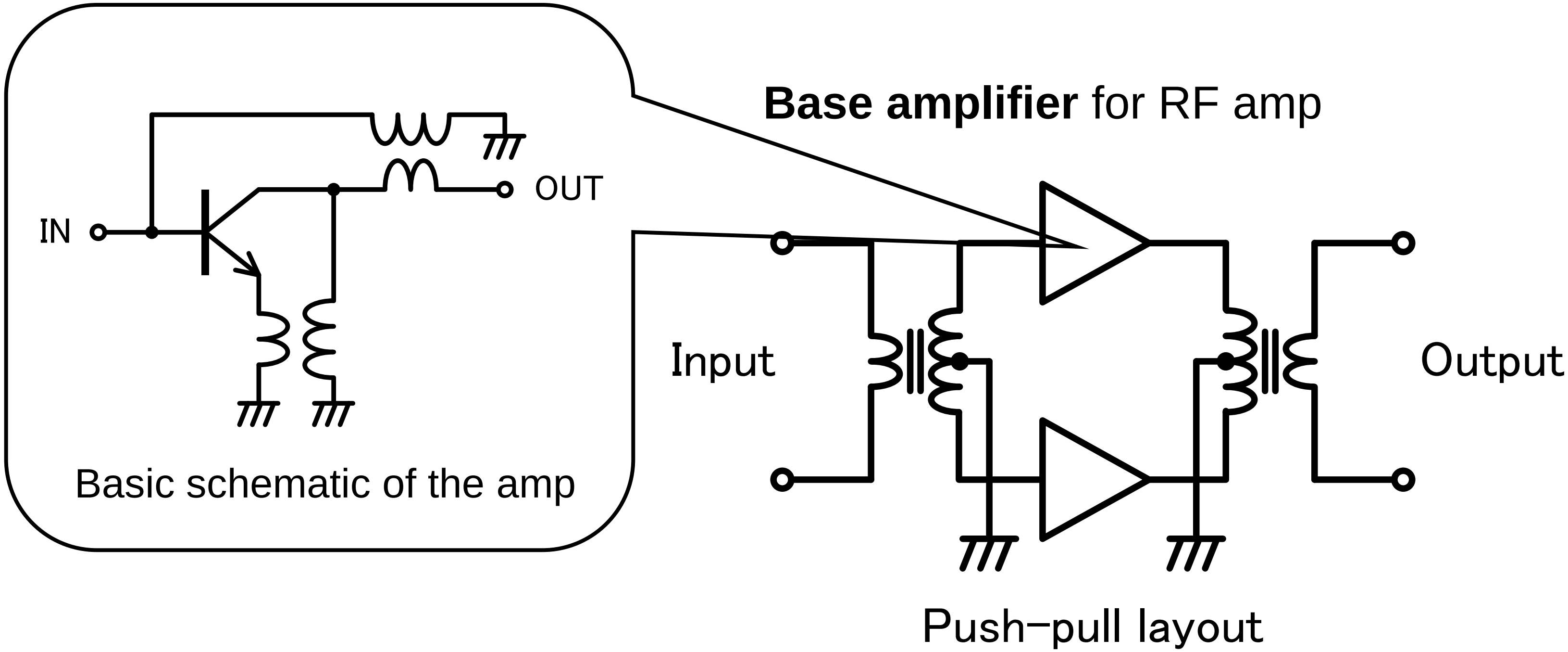
Specification goal for SDR

Sensitivity (NF)	NF : 8dB
IPs (IP3in & IP2in)	IP3in : +20dBm
	IP2in : +60dBm

Sensitivity (NF)	NF : 14dB
IPs (IP3in & IP2in)	IP3in : +30dBm
	IP2in : +70dBm

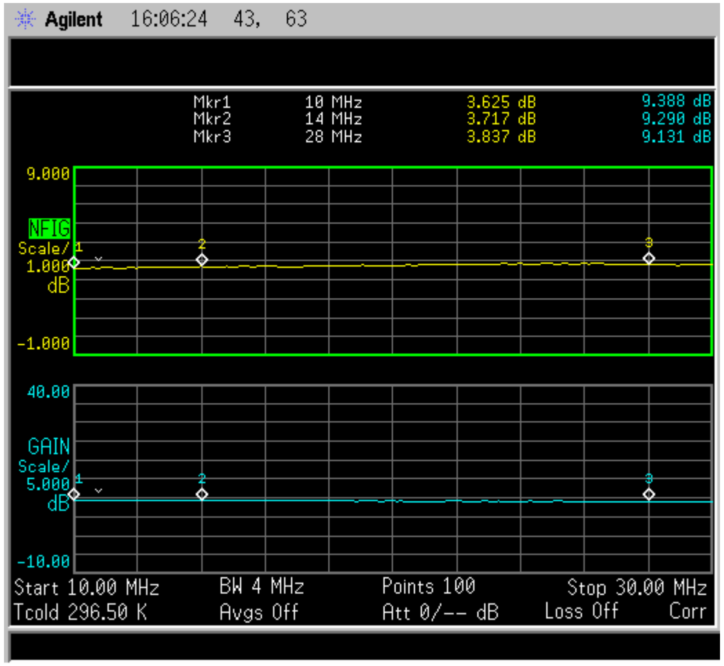
Analysis and design for front-end ②

Amplifier Design



Gain	9.2dB @14MHz
NF	3.7dB @14MHz
IP3in	45.9dBm @14MHz
IP2in	82.2dBm @14MHz

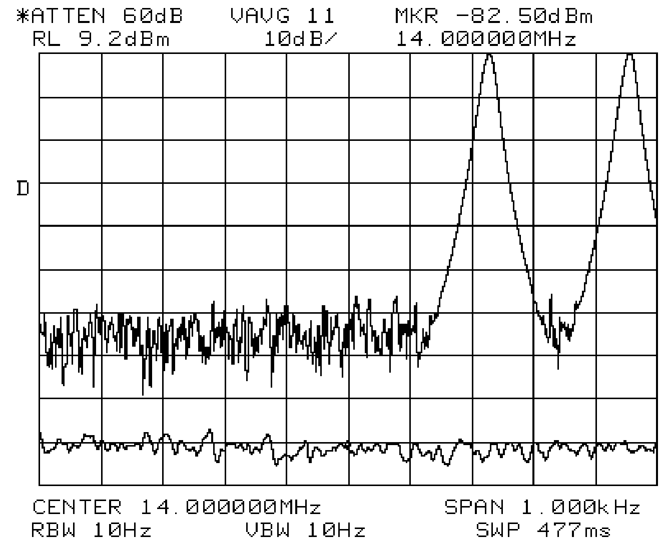
Analysis and design for front-end ③



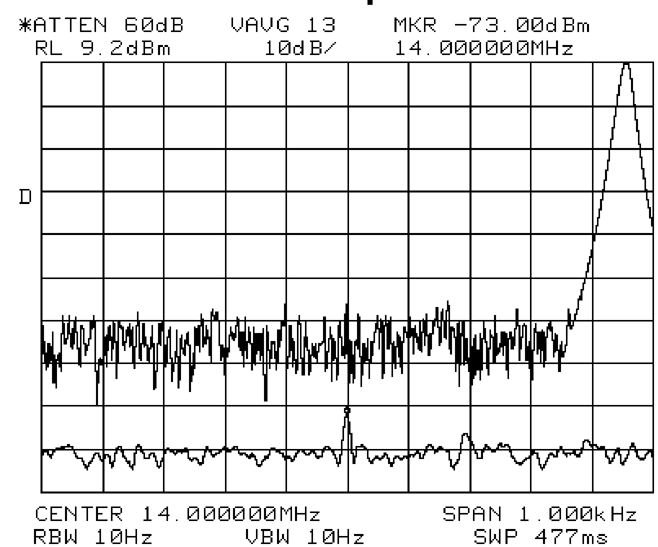
NF=3.7dB @14MHz

Gain=9.2dB @14MHz

IP3 of the base amplifier



IP2 of the base amplifier



The IP3in

$$= \frac{\text{Two tone level} - \text{IMD level}}{2} + \text{Intput}$$

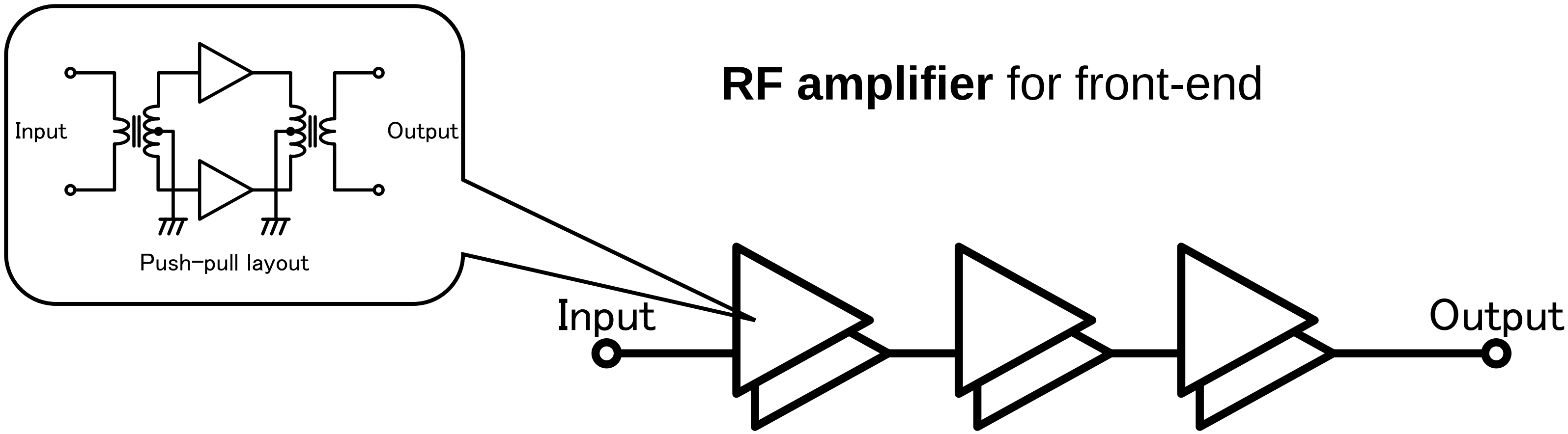
$$= \frac{9.2\,[\text{dBm}] - (-82.50[\text{dBm}])}{2} + 0\,[\text{dBm}] = 45.85\ [\text{dBm}] \quad (14)$$

The IP2in

$$= (\text{Two tone level} - \text{IMD level}) + \text{Intput}$$

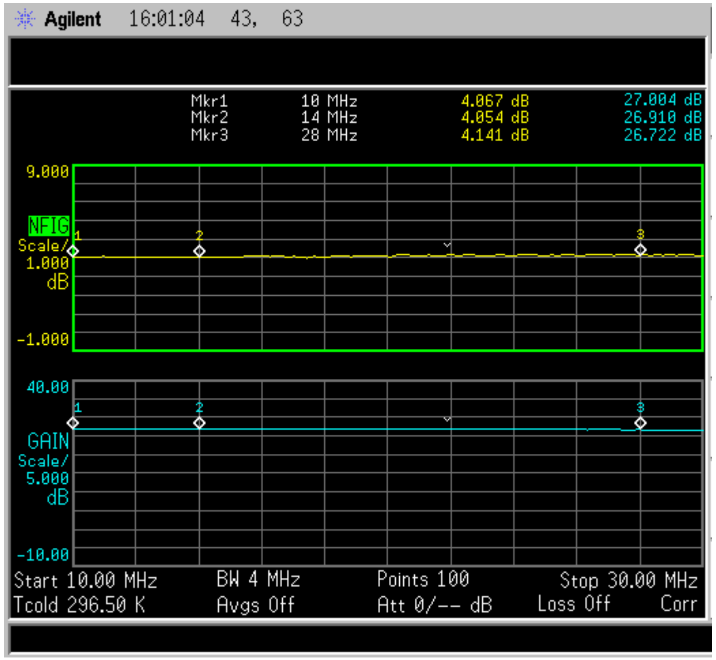
$$= 9.2\,[\text{dBm}] - (-73.00\ [\text{dBm}]) + 0\,[\text{dBm}] = 82.2\ [\text{dBm}] \quad (16)$$

Amplifier Design



Gain	26dB @14MHz
NF	4.1dB @14MHz
IP3in	+27.9dBm @14MHz
IP2in	+71.1dBm @14MHz

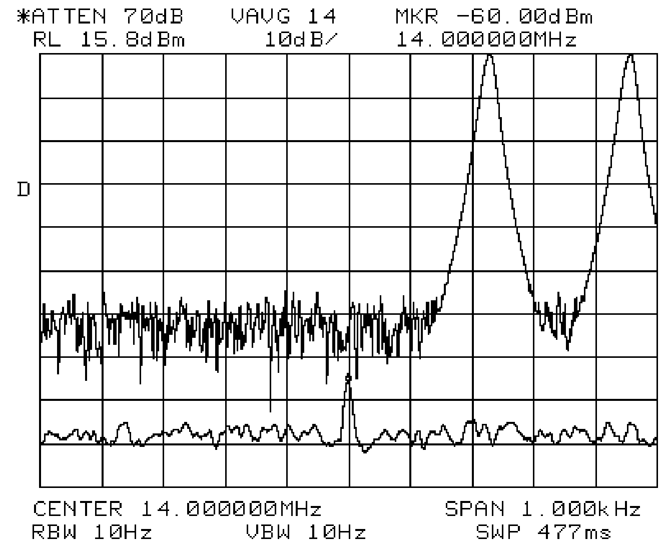
Analysis and design for front-end ⑤



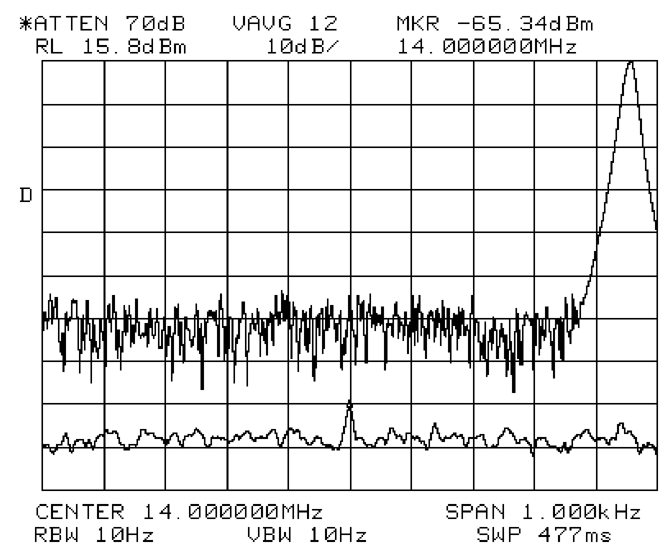
NF=4.1dB @14MHz

Gain=26dB @14MHz

IP3 of the RF amplifier



IP2 of the RF amplifier



The IP3in

$$= \frac{\text{Two tone level - IMD level}}{2} + \text{Intput}$$

$$= \frac{15.8\,[\text{dBm}] - (-60.0\,[\text{dBm}])}{2} + (\ \ 10)\,[\text{dBm}] = 27.9\ [\text{dBm}] \quad (17)$$

The IP2in

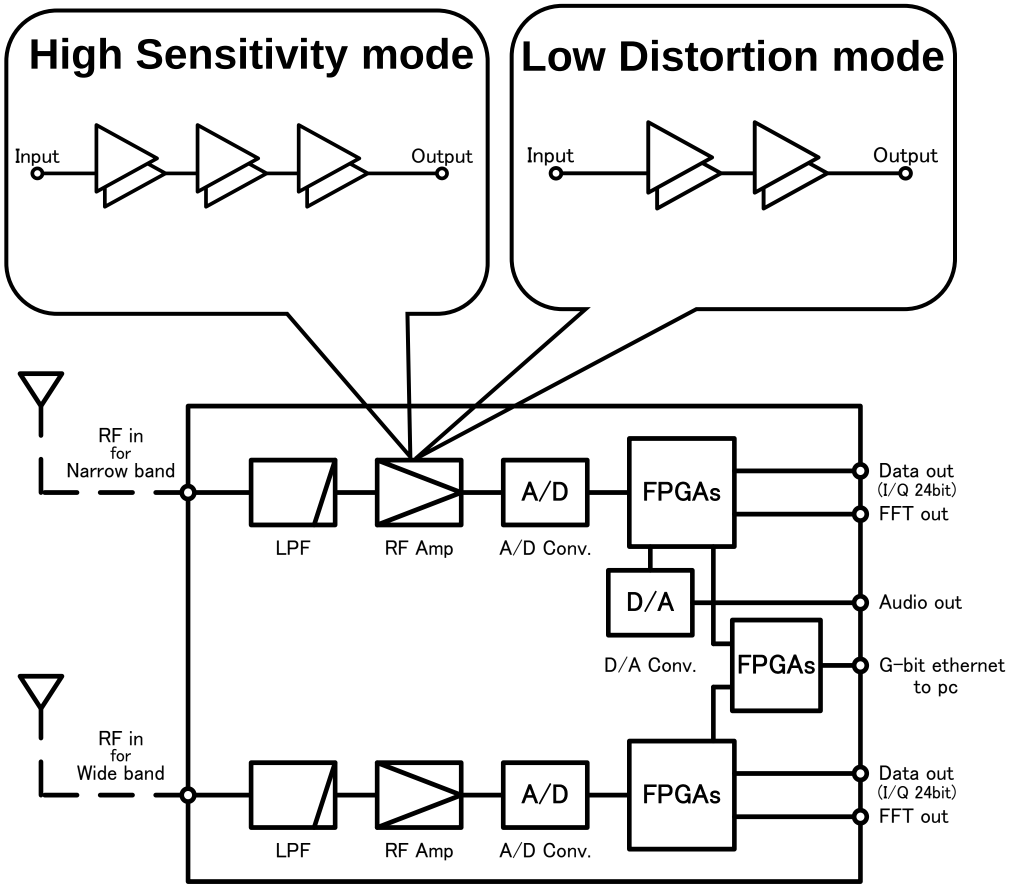
$$= (\text{Two tone level - IMD level}) + \text{Intput}$$

$$= 15.8\,[\text{dBm}] - (-65.3\ [\text{dBm}]) + (\ \ 10)\,[\text{dBm}] = 71.1\ [\text{dBm}] \quad (18)$$

Conclusion

Performance characteristics of the SDR

Frequency Range	500kHz to 30MHz
NF (high sensitivity mode)	8.0dB (typ)
NF (low distortion mode)	14.0 dB (typ)
IP3(in-band) (high sensitivity)	+23dBm (typ)
IP3(in-band) (low distortion)	+30dBm (typ)
IP2(in-band) (high sensitivity)	+70dBm (typ)
IP2(in-band) (low distortion)	+80dBm (typ)
Receiving band width (wide)	1.25MHz to 10MHz
Receiving band width (narrow)	150Hz to 500kHz
Signal linearity	>130dB
RF limit level for receiving	-13dBm
IQ data output (Max)	24bit each



Thank you !

Any questions ?