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Design of Fully Differential OpAmps for GHz Range Applications

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Outline

- **Motivation**
- **Influence of delay on OpAmp Stability**
- **Comparison PNP/NPN with BiCMOS RF OpAmp**
- **Low voltage PNP/NPN OpAmp topology**
- **Simulation results**
- **Conclusions**

Motivation

- OpAmps are frequently used as RF blocks of Communication system in MHz range

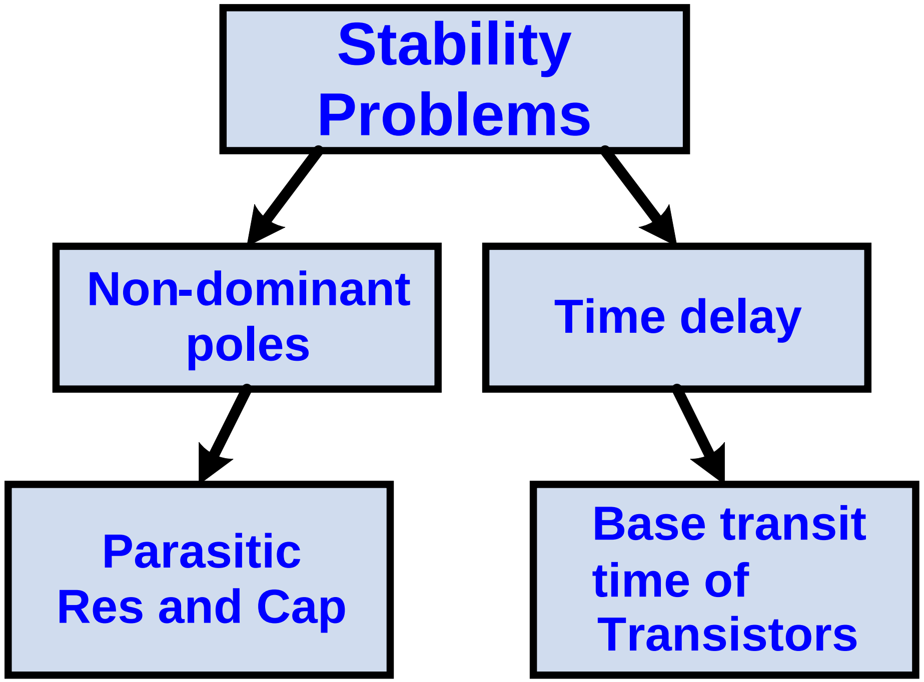
- It is attractive to extend OpAmp operation frequencies to GHz range

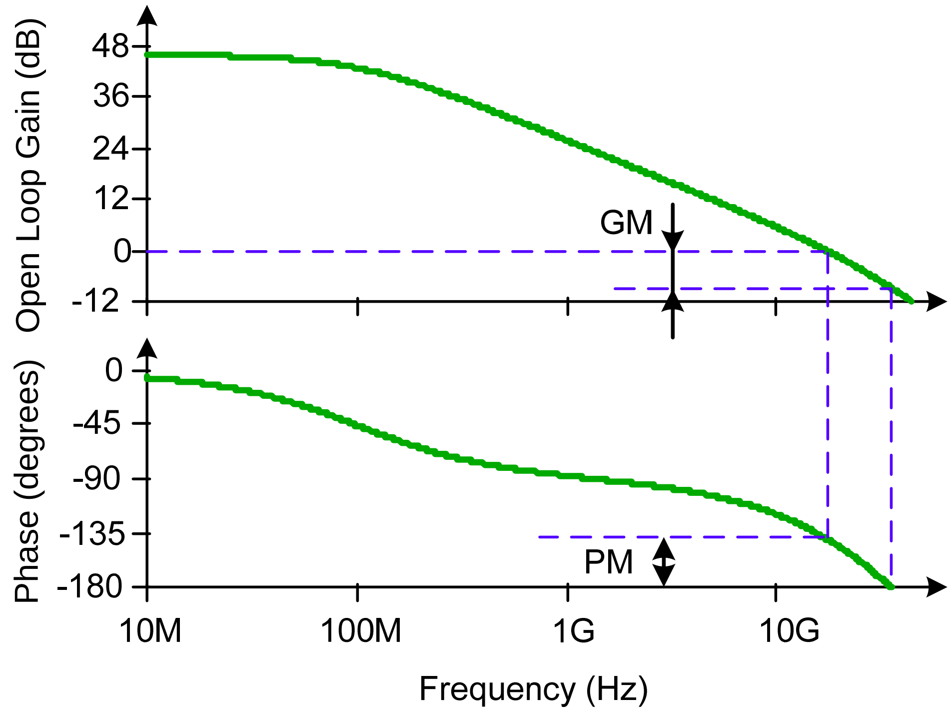
- The main OpAmp parameters for design RF blocks are Unity Gain Bandwidth (UGB) and Phase Margin (PM)

- Topologies comparison and development required

Stability of an OpAmp

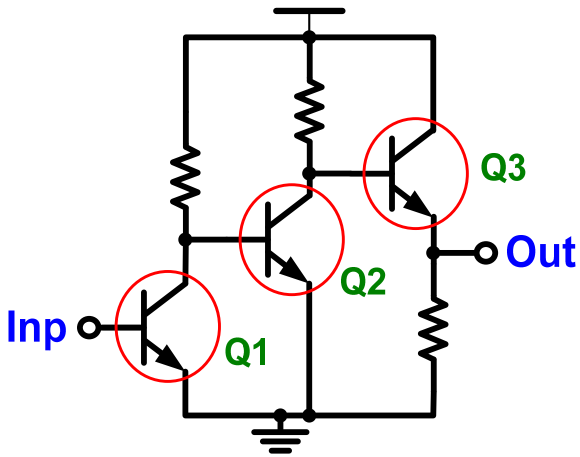
To build up an RF block (amplifier, filter and etc.) we introduce a negative feedback and **stability issue arises**



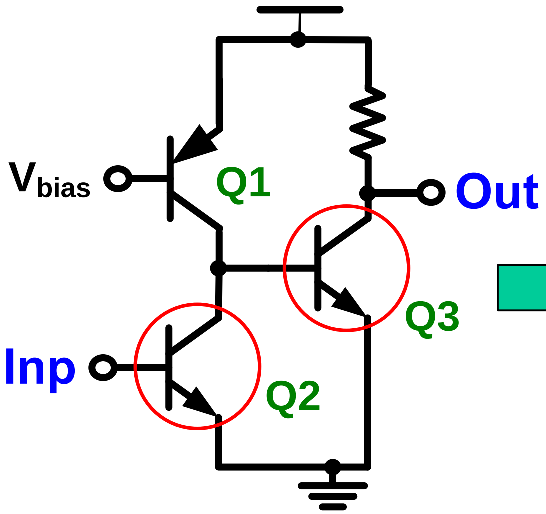


In case the feedback factor of unity, to get stable operation we have to satisfy conditions **PM>45** degrees and **GM>6dB**

“Electrical Length”

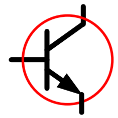


EL=3

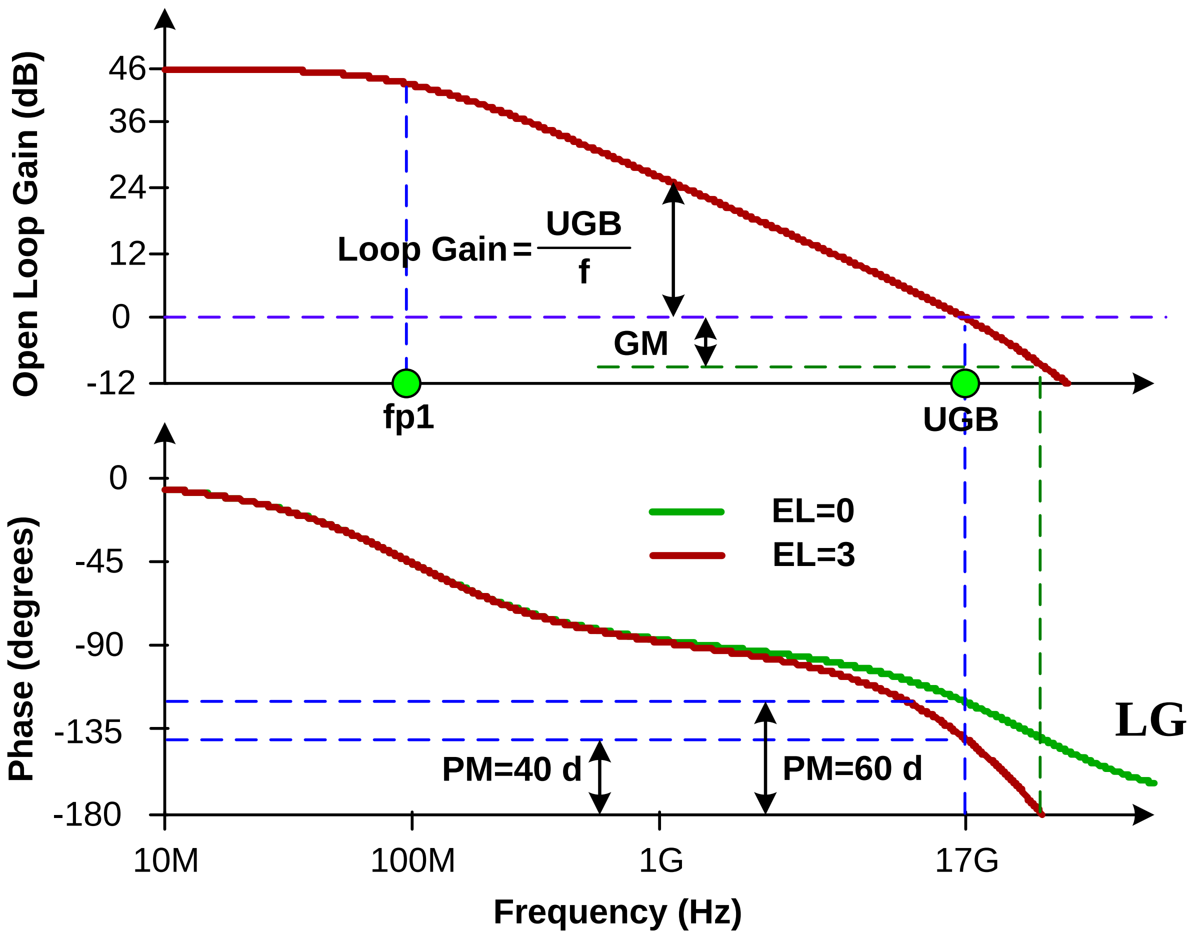


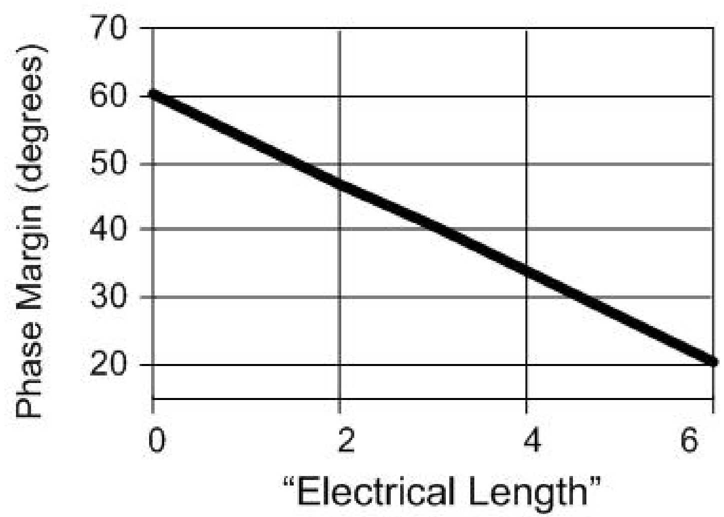
EL=2

Delay time is $EL \bullet \frac{1}{\omega_T} = EL \bullet \tau_B$

“Electrical Length” is the number of transistors taking part in the signal processing 

Delay influence on Phase Margin





$$LG = A_{OL} \times B \Big|_{B=1} = A_{OL} \Big| \approx \frac{UGB}{f}$$

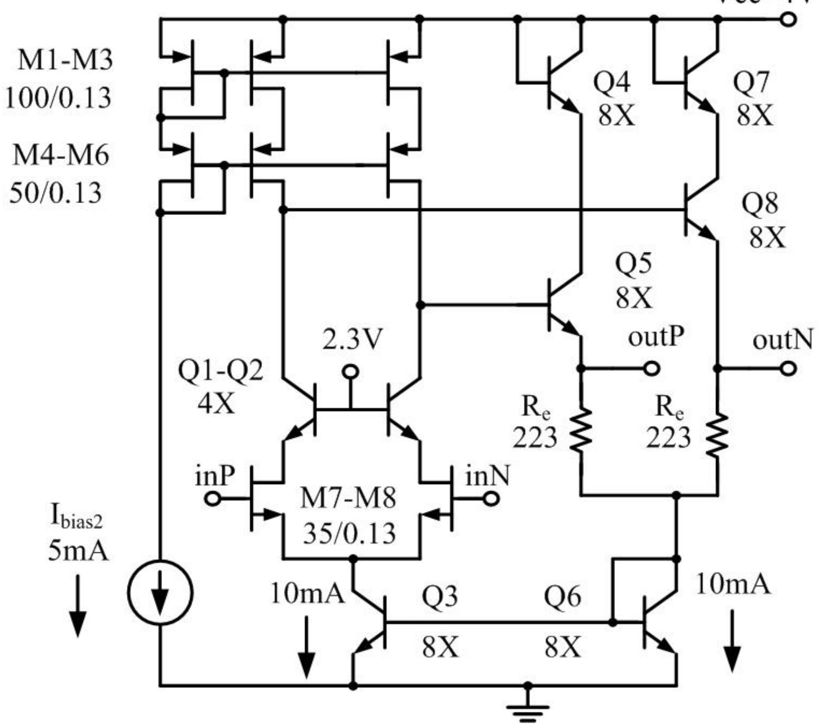
$fp1 > f > UGB$

Roll Off=20dB/dec

$$A_{OL} = \frac{200}{(1+s/2\pi\cdot 100\cdot 10^6)(1+s/2\pi\cdot 30\cdot 10^9)}\cdot e^{-s\cdot EL/2\pi\cdot 150\cdot 10^9}$$

Comparison PNP / NPN with BiCMOS RF OpAmp

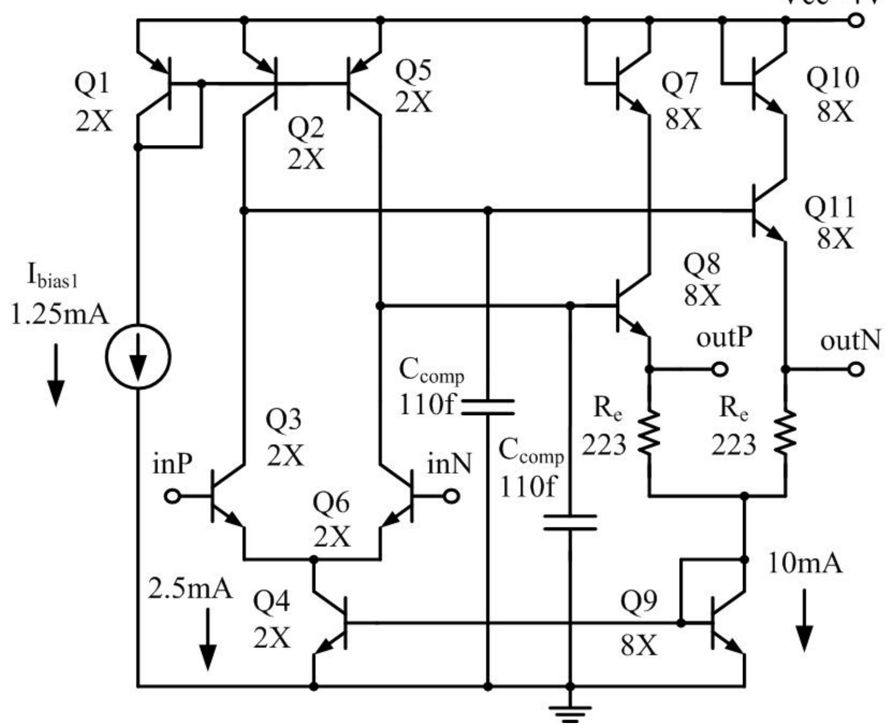
BiCMOS RF OpAmp



$$C_{inp}=C_{gs}=WLC_{ox}$$

EL=3

PNP/NPN RF OpAmp



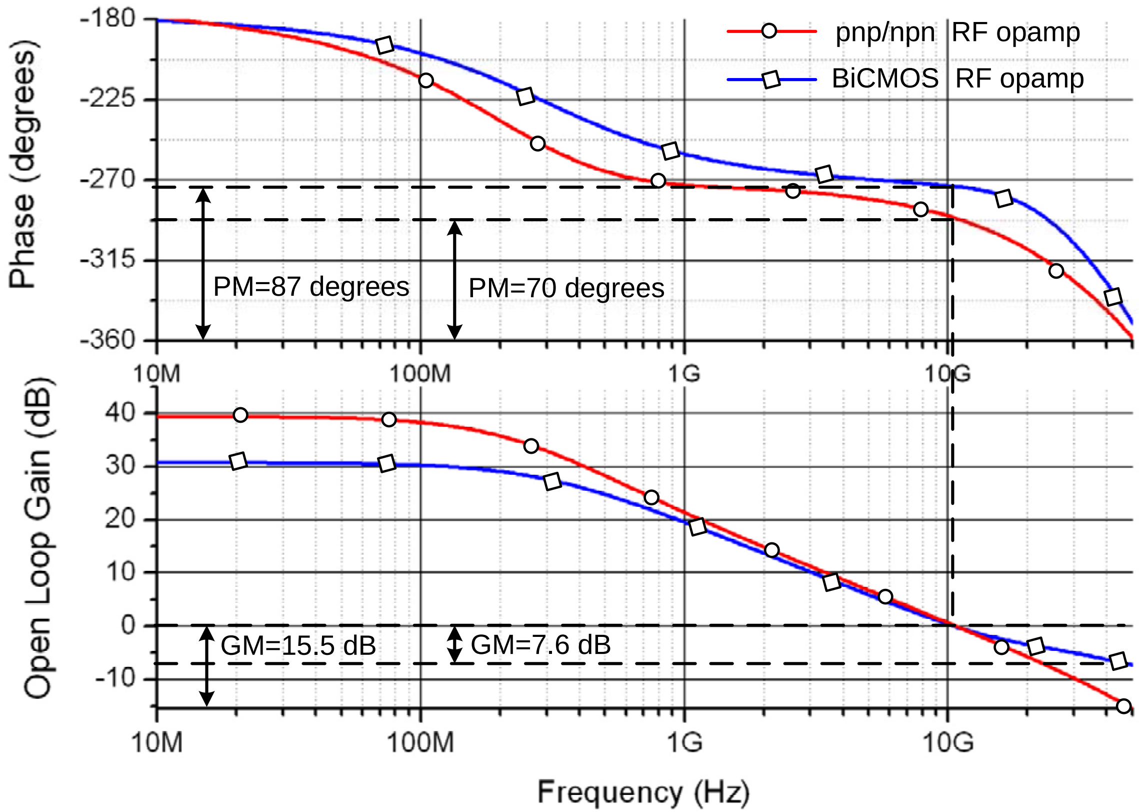
$$C_{inp}=C_{be}=\tau_b \frac{I_e}{V_T}$$

EL=2

S.P. Voinigescu, et al., "Design Methodology and Applications of SiGe BiCMOS Cascode Opamps with up to 37-GHz Unity Gain Bandwidth," IEEE CSICS, Techn. Digest, pp.283-286, Nov. 2005.

This work

Comparison PNP / NPN with BiCMOS RF OpAmp



BiCMOS OpAmp has better PM=87 degrees and

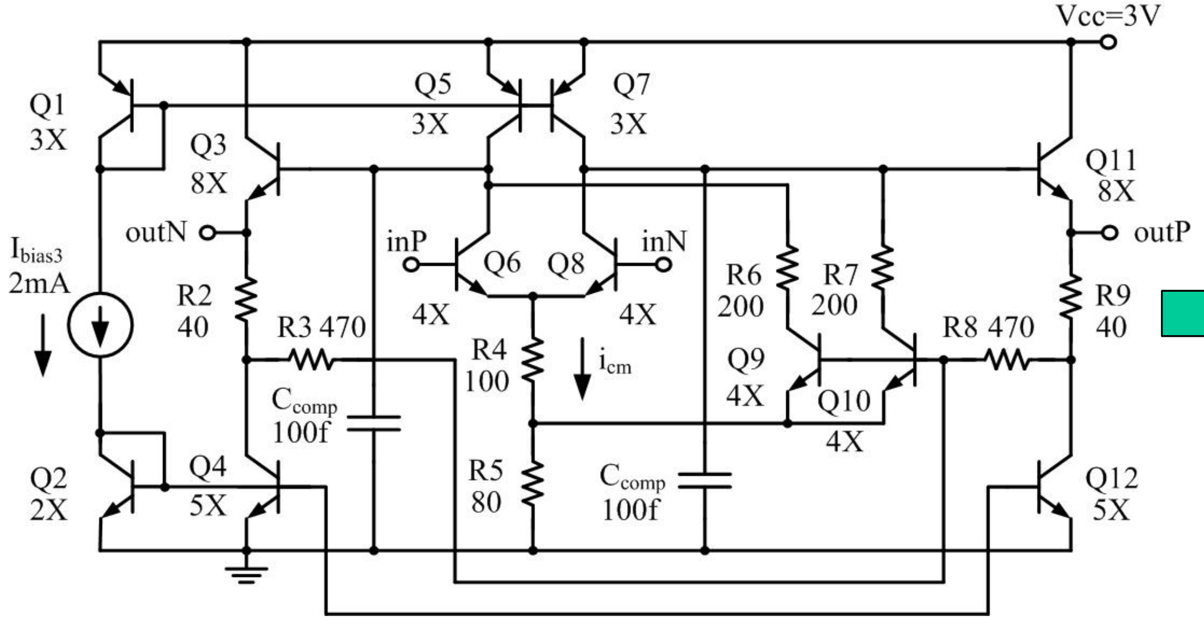
PNP/NPN OpAmp has better GM=15 dB

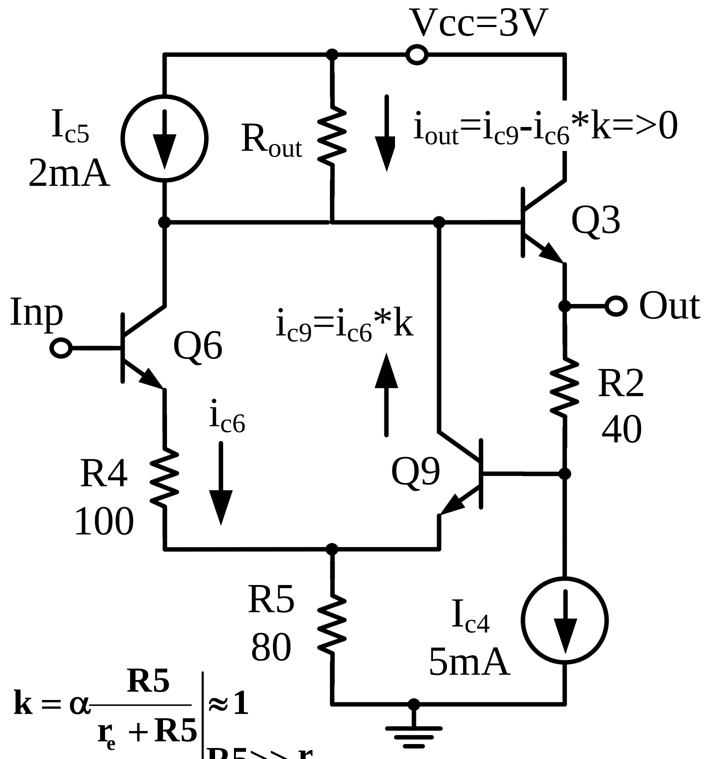
RF opamp	Parameters and Units				
	SE UGB, GHz	*PM, degrees*	*GM, dB*	*DC Gain, dB*	*Iq, mA*
PNP/NPN	**10.7**	**70**	**-15.5**	**39.4**	**12.5**
BiCMOS	**10.7**	**87**	**-7.6**	**30.8**	**20**

The MOSFET models of BiCMOS OpAmp are preliminary

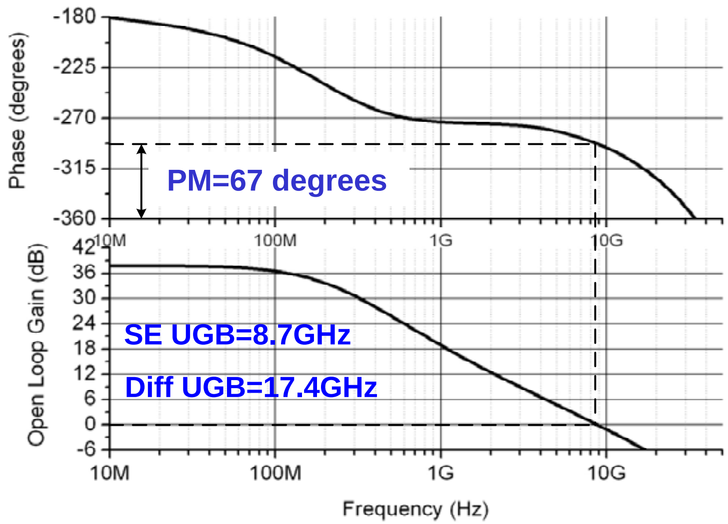
The Supply Voltage of the OpAmps is 4 V

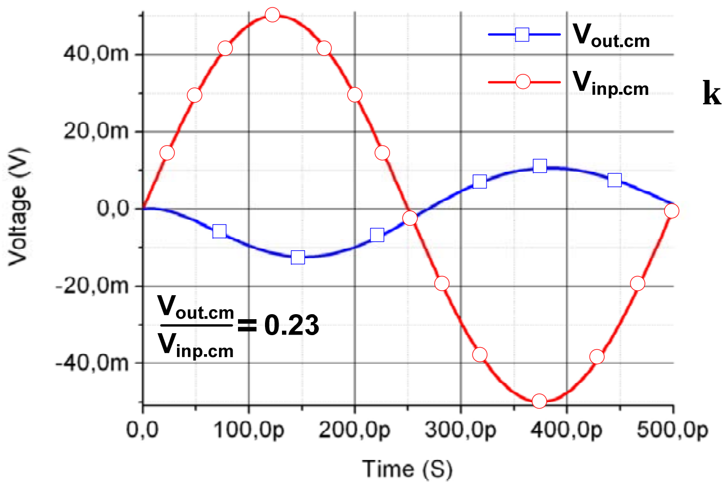
New Low Voltage OpAmp Topology





$$k = \alpha \frac{R5}{r_e + R5} \bigg|_{\substack{R5 \gg r_e \\ \alpha \approx 1}} \approx 1$$

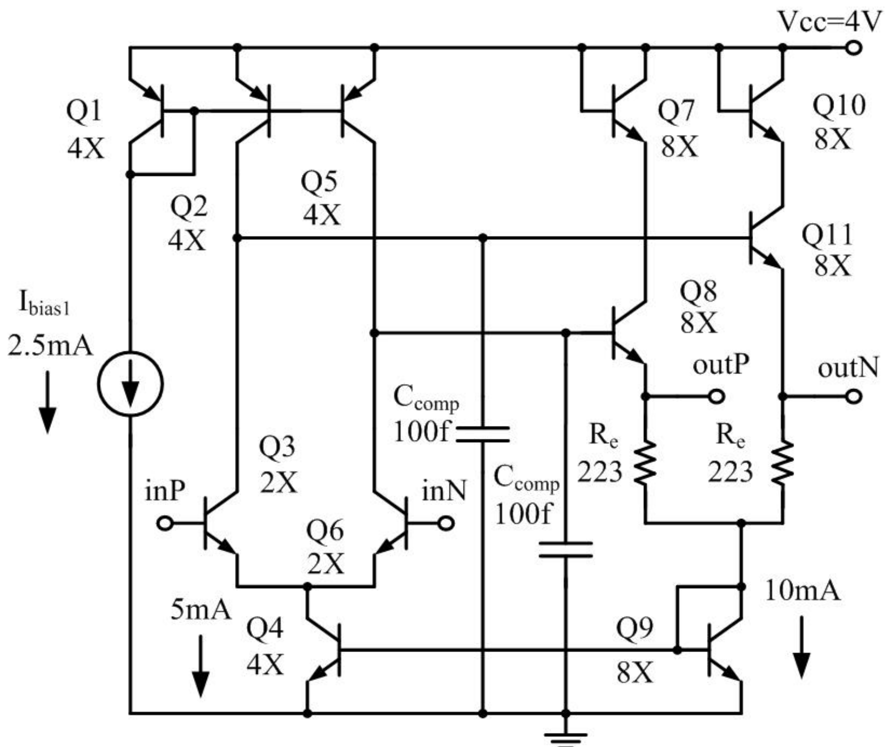


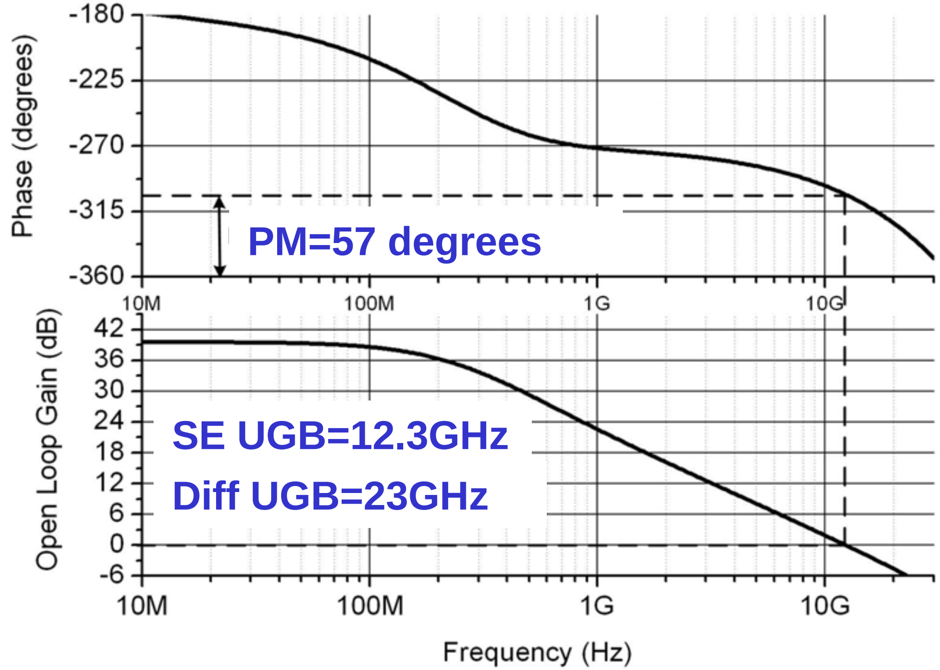


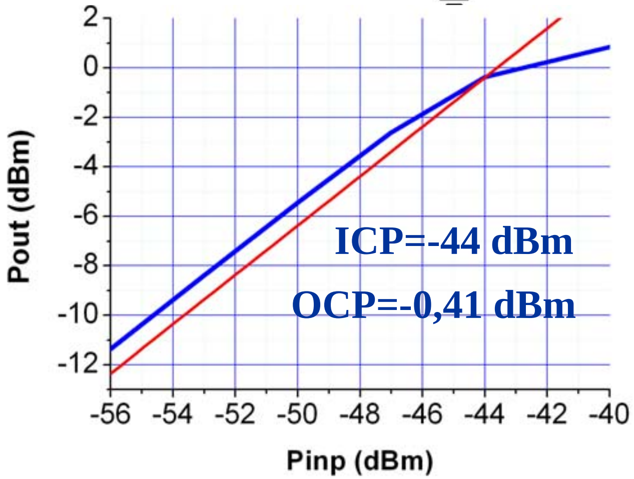
Equivalent half-circuit for common-mode signal

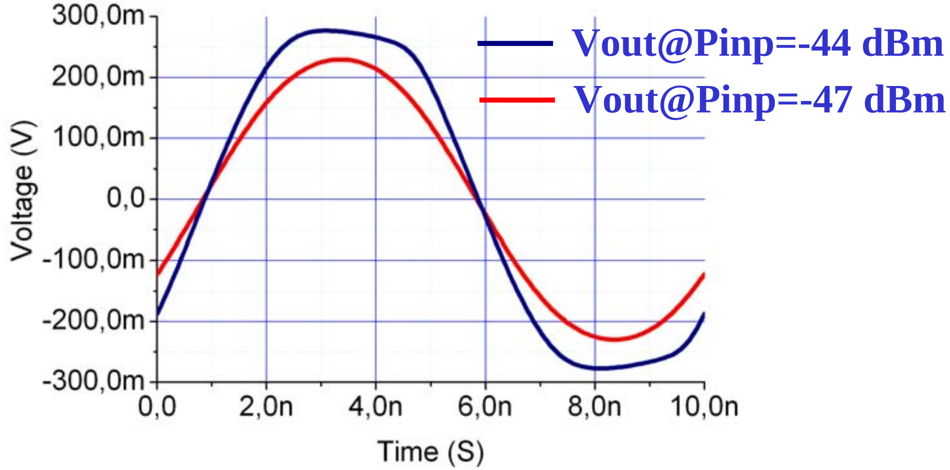
Diff Vout=890 mVp-p

Characteristics of the PNP / NPN OpAmp

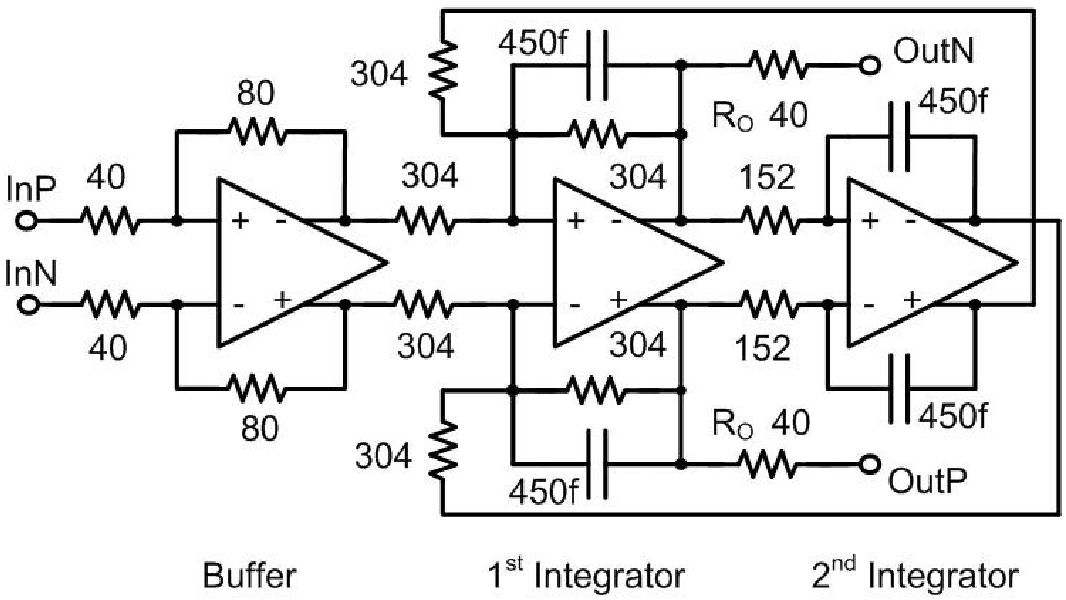


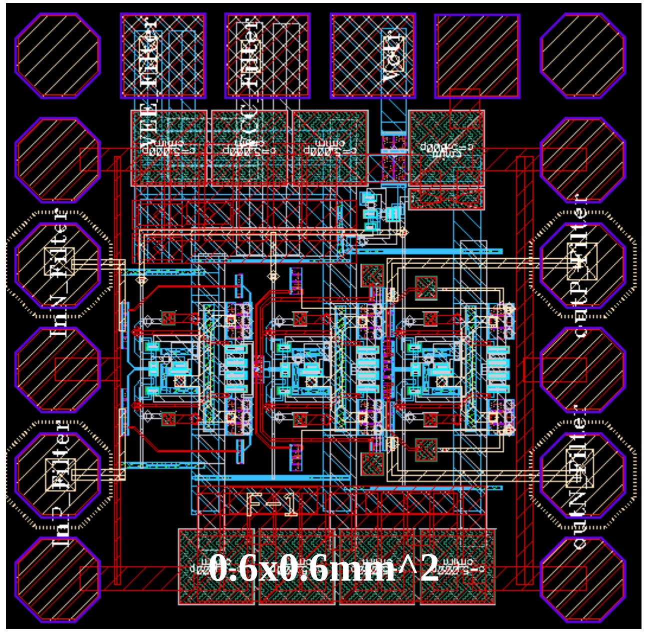




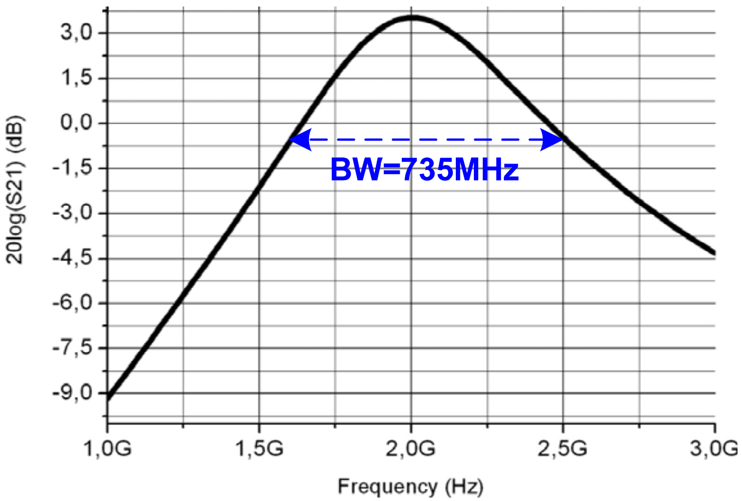


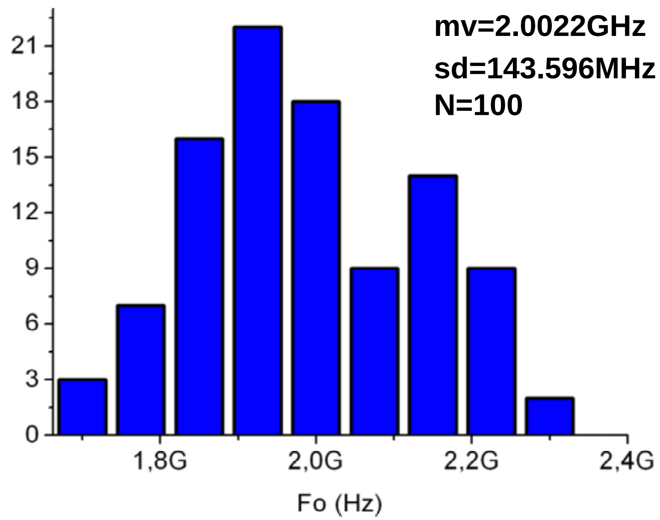
2GHz bandpass Filter

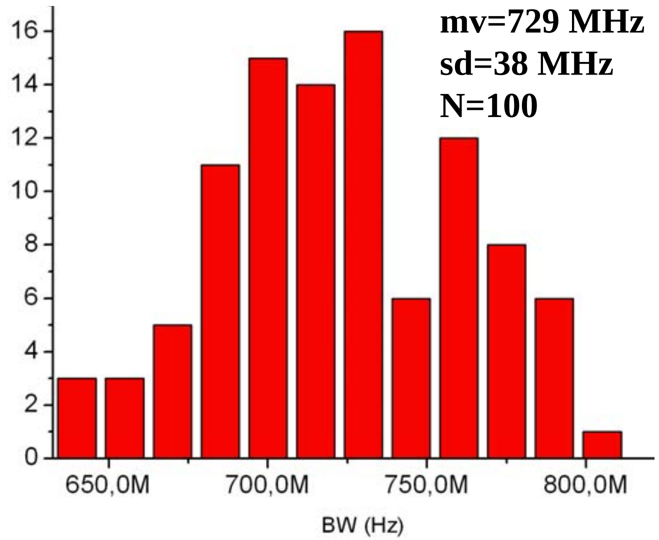




ICP=-7dBm OCP=-4.3dBm NF=21.6dB







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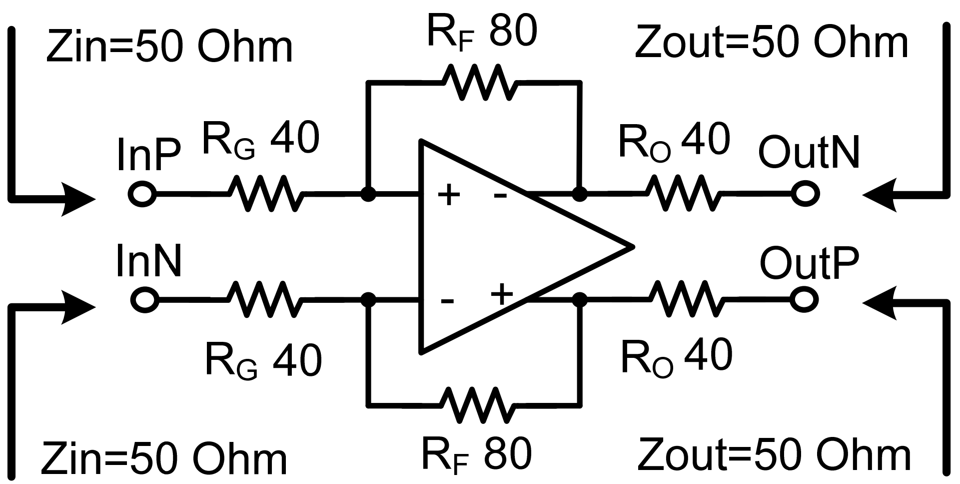
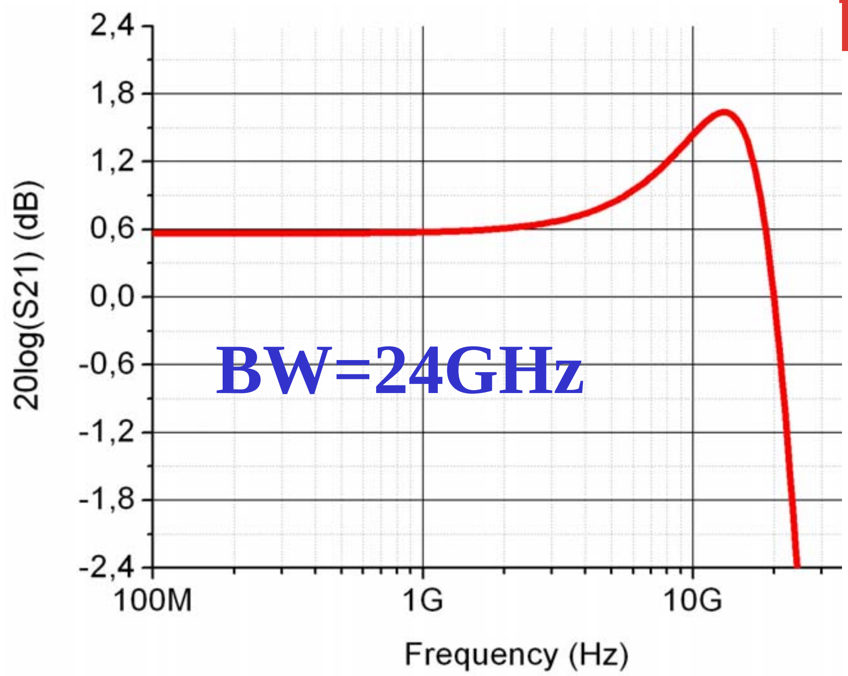
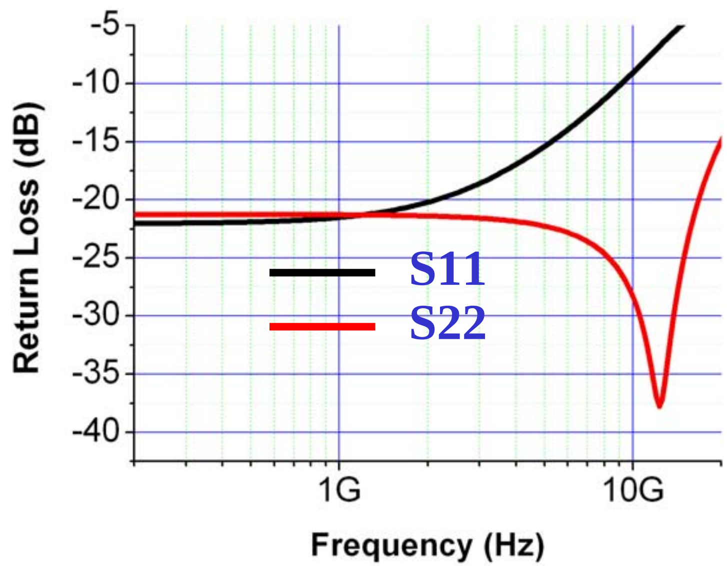
Line Driver







OCP=-3.2dBm

Vout.max=430mVp-p

NF=12.5 dB

$$Zin = R_G + \left.\frac{R_F}{LG}\right|_{LG>>1} \Rightarrow R_G$$

LG degrades with frequency. That’s why input return loss degrades at high frequency where LG is too small

Conclusions

- **An RF OpAmp for GHz-range applications with unity feedback should be realized with minimum “Electrical Length” circuit for stable operation**

- **BiCMOS and PNP/NPN RF OpAmp topologies comparison has been presented. Appropriate topology can be chosen according to the application requirements (consumption current, supply voltage, DC open loop gain, cost)**

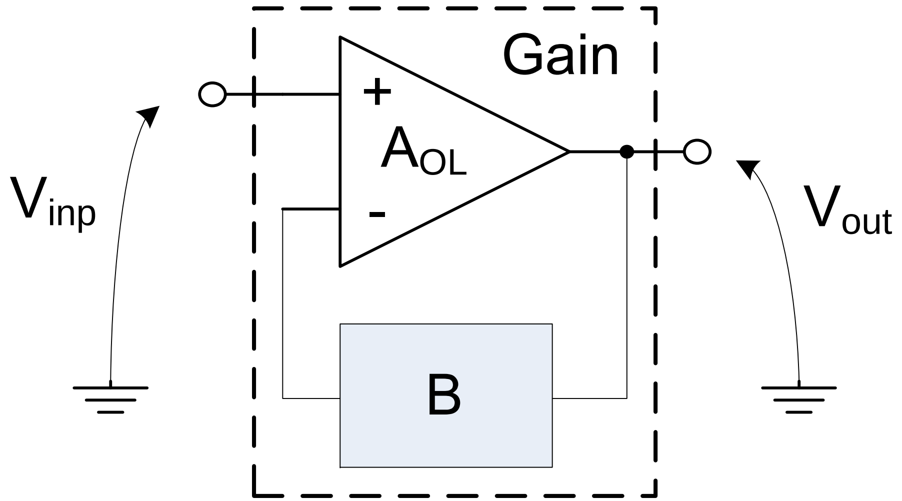
- **A low voltage RF OpAmp topology has been presented for supply voltage 3 V**

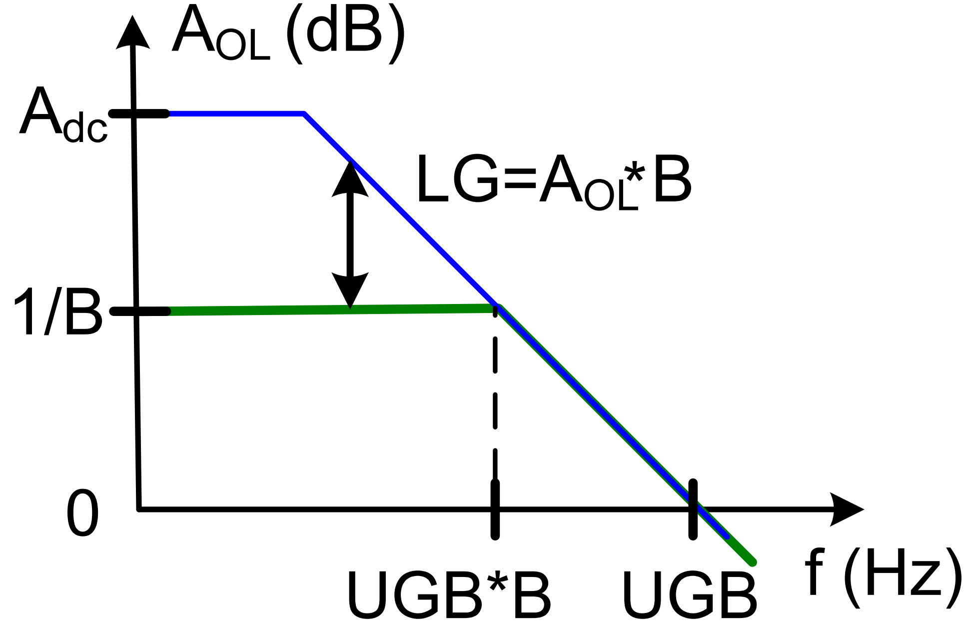
- **Application of RF OpAmp for design of a 2G bandpass Filter and a Line Driver with BW=24GHz has been demonstrated**

THANK YOU!!!

Signal Conditioning Accuracy

$$\text{Gain}=\frac{LG}{LG+1}*\frac{1}{B}\Bigg|_{LG>>1}\approx\frac{1}{B}$$





For B=1 ⇒ $LG=\frac{UGB}{f_s}$ ⇒ UGB should be a few times higher than f_s