EE4-17 High Performance Analogue Electronics

1.
(a) (Theory)

The mixer downconverts the high frequency RF signal to an intermediate frequency.

(b) (Theory)

If we are trying to select one particular frequency channel from the complete RF spectrum we need a bandpass filter to reject any unwanted frequencies. Generally this filter has to be narrowband, and high Q filters are difficult to design at high frequencies. This problem is compounded if the input signal frequency is variable. A tuneable, high Q bandpass filter with a constant bandwidth is now required.
A solution is to downconvert the input signal to an intermediate frequency (IF), and a bandpass IF filter is then used to select the wanted signal. The design of the bandpass IF filter is eased since it doesn't have to be tuneable, and the IF frequency is much lower than the input RF signal.

(c) (application of theory)

Advantage: The generation of a purely sinusoidal signal is impossible. It can only be approximated with a certain level of distortion. The lower this level is the more difficult it becomes, whereas a square wave can just be generated with a clock. The linearity of the mixer block is not as important anymore, since the signal itself is nonlinear.,

Disadvantage: Distortion. The output of the mixer has now many other frequency components.

A filter at the output can eliminate up to certain extend the distortion harmonics.

(c) (theory)

Multiplier, Gilbert cell, mixer.
The L and C constitute a bandpass filter to filter out the undesired distortion components of the signal which are generated if the latter is mixed with a signal that is not a pure sinewave.

2.

(a) (New theory)

$V_{out(max)}=V_{in(min)}-V_T$

(b) (New theory)

The bottom transistor in the triode region to eliminate the second order term from the current equation. The top transistor does not really matter since it will always be in saturation. The output transistor must be kept in saturation so that the two p-type transistors work together as a current mirror.

(c) (New theory)

In the circuit in (b) the drain voltage is going to unavoidable change with the input voltage which is going to generate distortion harmonics. This can only be mitigated up to certain extend by oversizing the top transistor. In the circuit in (c) however, the drain voltage remains constant thanks to the feedback amplifier which improves distortion.

The disadvantage of the configuration in (c) is the larger number of transistors, as well as the need to design an amplifier with a significantly higher bandwidth than the transconductor.

(d) (New theory)

$$I_{out}=\beta[(V_{in}-V_T)V_{REF}-V_{REF}^2/2]$$

The amplifier keeps the bottom transistor in the triode region, and the drain voltage almost constant hence minimizing distortion.

(e) (New theory)

The most obvious advantage is that it requires less numbers of stacked transistors and hence can operate at a lower power supply voltage.

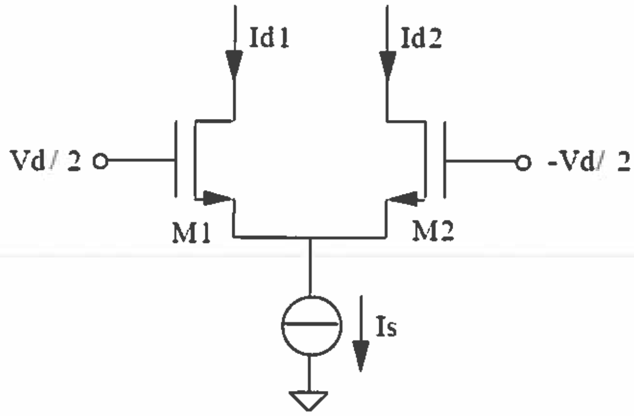
(f) (New theory)

The drain voltage goes to the positive terminal. V_{REF} to the negative. This is how the feedback would be effective on keeping the drain voltage constant and equal to V_{REF}.

(g) (New theory)

The answer is Figure 3(d).

3.
(a) (Theory)



(b) (Application of theory)

$$I_{out} = 2I_{bias}\tanh\left(\frac{V_{in}}{2\eta U_T}\right)$$

$$I_{out} = 2I_{bias}\tanh\left(\frac{V_{in}}{2U_T}\right)$$

(Top expression for MOS and bottom for bipolar)

The difference in the η parameter.

Lower power consumption and higher input impedance.

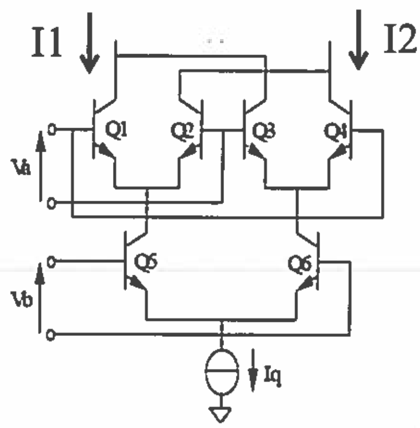
(c) (Theory)

One possibility is to increase the area of the input transistors to reduce Flicker noise. Also, by using a cross-coupled topology with scaled area so that the third order harmonics cancel out.

(d) (Application of theory)

Transistor M1 is not operating in weak inversion. The circuit has saturated.

(e) (Theory)



The output is given by the difference between the two currents I1 and I2.

4.

(a) (Theory)

In a MOSFET, there are two main sources of noise:

(i) *Thermal noise* due to the resistance of the channel:

$$ind^2 = \frac{8kTgm\Delta f}{3} \ A^2$$

This noise source can also be represented by an equivalent channel resistance rd = 3/2gm.

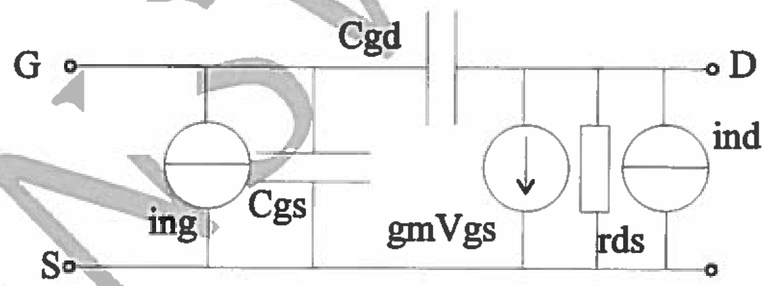
(ii) *Flicker (1/f) noise* in series with the gate:

$$vng^2 = \frac{k_f\Delta f}{CoxWLf} \ V^2$$

k_f is a flicker noise coefficient which is process dependent. Note that the 1/f noise is inversely proportional to gate area, thus bigger devices are less noisy.

(b) (Theory)

Equivalent noise model:



(c) (Theory)

$$vn^2 = \frac{8kT}{3gm}\left(1+\frac{f_l}{f}\right) \ V^2$$

($f_l = 3gmk_f/8kTWLCox$)

(d) (Application of theory)

It is the same circuit as in (c) but without the capacitors and with different parameter values.

- gm represent the transconductance of M1
- Vgs=Vin
- rds=1/(gm2+gds1+gds2+G_D) with numbers referring to the corresponding transistors and G_D=1/R_D.
- ing remains the same.
- ind is the sum of the thermal noises of transistors 1 and 2 (expression given in (a) but substituting subscripts), as well as the thermal noise of RD (=4kT/RD).
- S is grounded
- D is v_{out}.
- G is v_{in}.

(e) (Application of theory)

Thermal:

$$\overline{V^2_{n,in}} = 4kT\frac{2}{3}\left(\frac{g_{m2}}{g^2_{m1}} + \frac{1}{g_{m1}}\right) + \frac{4kT}{g^2_{m1}R_D}$$

Flicker:

$$\overline{V^2_{n,in}} = \frac{1}{C_{ox}}\left[\frac{K_p g^2_{m2}}{(WL)_2 g^2_{m1}} + \frac{K_N}{(WL)_1}\right]\frac{1}{f}$$

(f) (Application of theory)

$$\overline{V^2_{n,out}} = A^2\overline{V^2_{n,in}}$$

Where A is the voltage gain of the circuit given by:

A=g_{m1}[1/(g_{m2}+G_D+g_{ds1}+g_{ds2})]

And:

$$\overline{V^2_{n,in}} = 4kT\frac{2}{3}\left(\frac{g_{m2}}{g^2_{m1}} + \frac{1}{g_{m1}}\right) + \frac{1}{C_{ox}}\left[\frac{K_p g^2_{m2}}{(WL)_2 g^2_{m1}} + \frac{K_N}{(WL)_1}\right]\frac{1}{f} + \frac{4kT}{g^2_{m1}R_D}$$

(g) Increase the gm of the input transistor by for example increasing the area, while keeping the current constant so that g_{m2} does not increase too.