1. EE4-17 High Performance Analogue Electronics

(a) (Theory)

Noise factor is defined as the total output (or input) noise power of the system divided by the output (or input) noise power due to the source alone.

$$\text{Noise factor } F = \frac{Psys + Pni}{Pni}$$

$$SNR_{in} = \frac{Psig}{Pni} \qquad SNR_{out} = \frac{Psig}{Pni + Psys}$$

$$\frac{SNR_{in}}{SNR_{out}} = \frac{Pni + Psys}{Pni} = \text{noise factor } F$$

$$NF\,(dB) = SNR_{in}\,(dB) - SNR_{out}\,(dB)$$

We require a certain $SNR_{out} = SNR_{det}$ at the detector in order to recover the signal. Thus:

$$SNR_{in}\,(dB) = SNR_{det}\,(dB) + NF$$

$$SNR_{in}\,(dB) = Psig\,(dB) - Pni\,(dB)$$

We define the sensitivity of the system as the minimum input signal that we can successfully detect:

$$\text{Sensitivity} = Psig\,(dB) = SNR_{in}\,(dB) + Pni\,(dB)$$

$$= Pni\,(dB) + NF + SNR_{det}\,(dB)$$

(b) (Application of Theory)

Because the equivalent noise at the input gets divided by the product of the gains of previous blocks, so if previous blocks have gain larger than one the equivalent input noise of the corresponding block gets reduced.

(c) (Application of theory)

$$F = \frac{vnt^2}{G1G2G3G4vns^2} = F1 + (F2-1)/G1 + (F3-1)/G1G2 + (F4-1)/G1G2G3$$

(d) (New theory)

For that bandwidth the Flicker noise is negligible. Also, if there are no leakages there is no shot noise. In summary, the only noise contributors are:

1- The thermal noise due to the channel resistance, which can be written as:

$$i_{nd}^2 = \frac{8}{3} kT g_m \frac{A^2}{Hz}$$

2- The noise of the source, which is given by:

$$v_s^2 = 4kT R_S \frac{V^2}{Hz}$$

3- The noise of the load, which is:

$$v_L^2 = 4kT R_L \frac{V^2}{Hz}$$

The thermal noise of the transistor can be transferred back to the input dividing by the square of the transconductace, i.e.:

$$\frac{8}{3} \frac{kT}{g_m} \frac{V^2}{Hz}$$

The thermal noise of the load can be transferred back to the input dividing by the power gain:

$$\frac{4kT}{g_m^2 \cdot R_L} \frac{V^2}{Hz}$$

The total noise is the sum of all the contributors:

$$v_{eq}^2 = 4kT \left(R_S + \frac{1}{g_m^2 \cdot R_L} + \frac{2}{3 g_m} \right) V^2/Hz$$

(e) (Application of theory)

Any answer based on extracting conclusions from the equation obtained in (d).

2.

(a) (Theory)

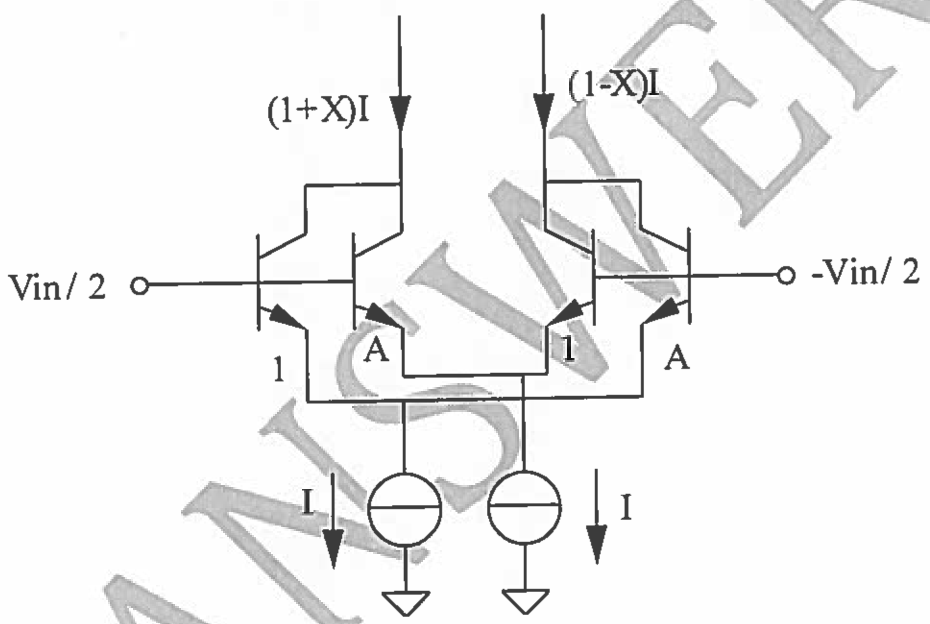
Because it has an increased linearity since in differential configurations even order harmonics disappear.

(b) (Theory)

A single transistor can act as a transconductor since there is a dependency between the current and the voltage in the different terminals. (Based on this multiple answers are valid on this question depending on the transistor is chosen).

The performance of a single transistor (whichever is chosen) can be improved by creating a differential pair. This improves distortion.

Two differential pairs can also be combined to further improve distortion. For example:



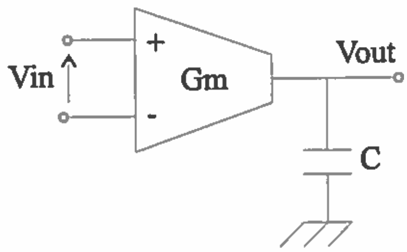
A disadvantage of adding more transistors is the increase in area The additional potential disadvantages depend on the topology you have chosen to answer this question. In the topology given in the example a disadvantage is the reduction of the transconductance for the same biasing current (ie. associated power consumption).

(c) (New theory)

Just by loading the two output branches equally, and taking the voltages as the outputs.

(d) (Application of theory)

A Gm-C Single-ended integrator can be built as:



where $\dfrac{Vout}{Vin} = \dfrac{Gm}{sC}$

Based on this: Gm/C=1/10.

And the solution of this problem can be found by selecting any transconductor topology, that gives the relationship above.

For example, if a MOS differential pair is chosen, the transconductance is given by:

$gm = \dfrac{\partial Iout}{\partial Vd} = \sqrt{2\beta Is}$. This is the same as the transconductance of the input transistor.
Hence, C has to be 20nF.

(e) (Application of theory)

The input referred noise of the transconductor on its own in that band is white, since any Flicker noise is negligible. However, when the capacitor is added the noise is shaped. The relationship between the noise in the two bands will be given by:

$$\frac{\text{Noise (new)}}{\text{Noise (original)}} = \frac{\int_{100kHz}^{200kHz} \frac{1}{f^2}\, df}{\int_{100kHz}^{150kHz} \frac{1}{f^2}\, df} = \frac{1/200 - 1/100}{\frac{1}{150} - \frac{1}{100}} =$$

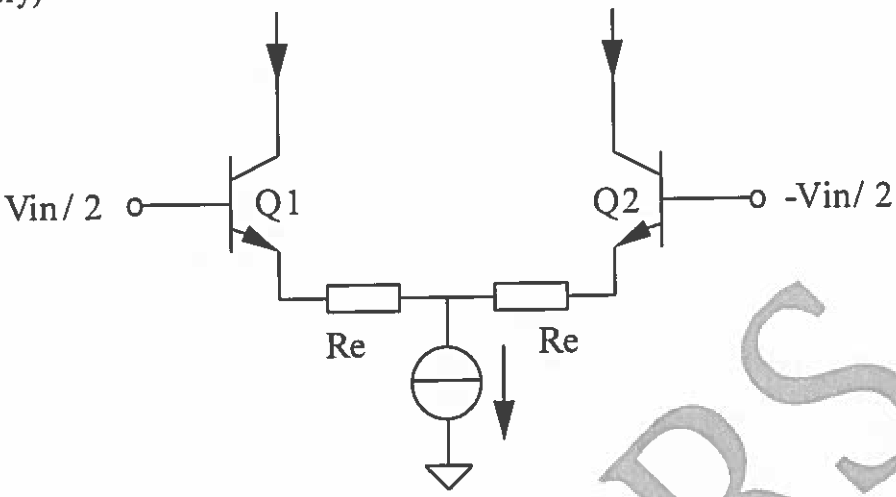
$$= 1.5$$

Noise (new) = 1.5 Noise (original) = 6 μV^2

or 2.45 μVrms

3.

(a) (Theory)



(b) (Application of theory)

1kΩ in order to reduce the thermal noise of the circuit.

(c) (Application of theory)

Under those assumptions, only Flicker noise, given by:

$$vng^2 = \frac{k_f}{CoxWLf} \ V^2/Hz$$

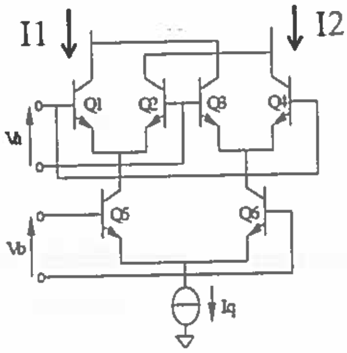
(d) (Application of theory)

Under those assumptions, the noise is caused by the resistors, it is thermal and proportional to R. Therefore, in the first case is 100 times bigger and in the second 1000.

(e) (Application of theory)

With passive resistors no since there are no two different input terminals that would result in multiplication.

(f) (Theory)



(g) (Application of theory)

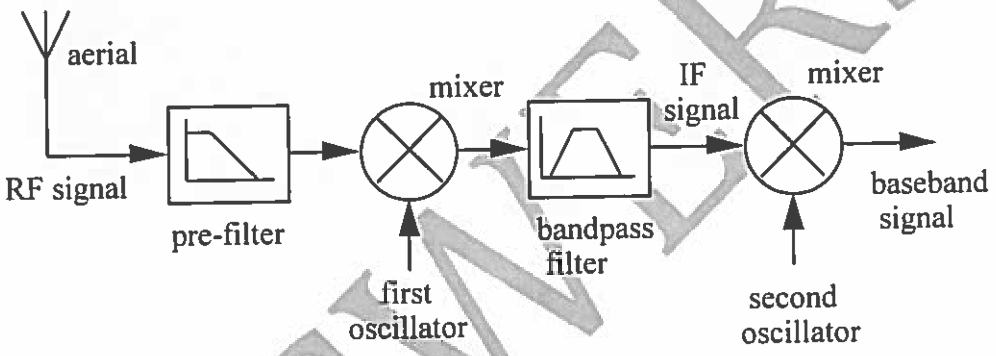
I would make the area big to reduce Flicker noise.

4.

(a) (Theory)

If we are trying to select one particular frequency channel from the complete RF spectrum, then 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 (i.e. the signal is transmitted in one of a number of possible channels, each with the same bandwidth). A tuneable, high Q bandpass filter with constant bandwidth is now required.

The solution is to use a superhet receiver (supersonic heterodyne). This system downconverts 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 centre frequency is much lower than the input RF signal.



The downconversion is performed by 'mixing' (multiplying) the RF input signal (f_{RF}) with a local oscillator signal (f_{LO}), such that the resulting output is at the required IF frequency (f_{IF}).

Received RF signal = $2A\cos[(f_{RF})t + \theta]$ Local oscillator signal LO = $\cos(f_{LO})t$

Mixer output $= 2A\cos(f_{LO})t\cos[(f_{RF})t + \theta]$

$= A\cos[(f_{LO} - f_{RF})t - \theta] + A\cos[(f_{LO} + f_{RF}) + \theta]$

i.e. sum and difference components

The sum components are at a very high frequency and are removed by filtering. The difference frequency component is a replica of the RF component in terms of amplitude and phase, but is shifted down to an intermediate frequency (IF):

$$f_{IF} = f_{LO} - f_{RF}$$

The oscillator frequency f_{LO} is often tuneable to ensure that a range of input RF frequencies can be selected.

(b) (Application of theory)
11.295MHz and 11.305MHz

(c) (Application of theory)

A quarter of the wavelength (3.125cm)

(d) (Theory)

In a direct conversion receiver, a single local oscillator is used whose frequency is equal to the RF carrier frequency, and thus the IF = 0 Hz. No bandpass filtering is required as the signal is converted directly to baseband. In addition, there is no image signal, thus no image filtering is needed. All signal filtering is at baseband frequencies, and therefore can be performed on-chip. This means that a single-chip receiver is feasible using direct conversion.

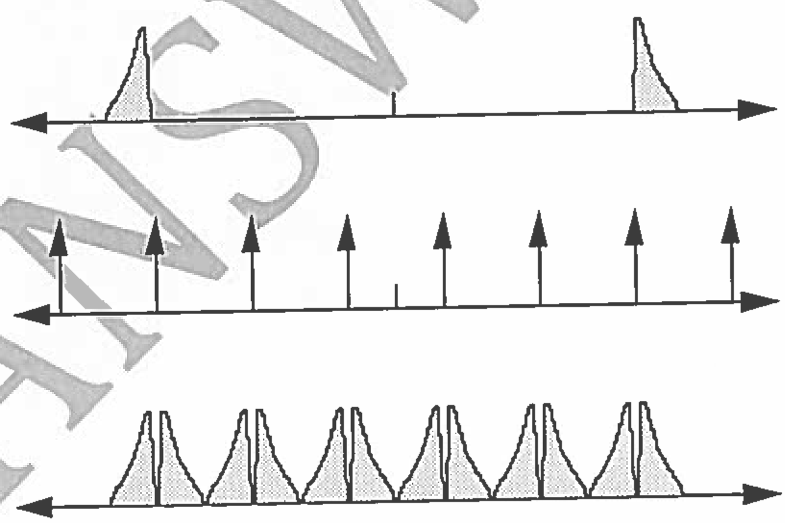
The main drawback with direct conversion architectures is their susceptibility to LO 're-radiation' which is picked up by the antenna. After mixing, this leads to dc offsets in the receiver, which will directly corrupt any dc information in the signal.

(e) (Theory)

To remove spurious.

(f) (Theory)

Subsampling receivers work by sampling the RF signal at a frequency lower than twice the maximum input frequency, but larger than two times the signal bandwidth. This guarantees that aliasing will not occur. The "replicas" of the signal resulting from the sampling process contain the baseband signal. One of the low frequency ones is then digitized directly.



The main drawback with this technique is the aliasing of noise, since subsampling by a factor m effectively multiplies the downconverted noise power of the sampling circuit by a factor 2m, since this noise is not band-limited.