INITIATION TO HIGH FREQUENCY ELECTRONICS

1. Objectives.

The goal of this work is to study some functional blocks commonly used in radio transmissions.

2. Devices to study.

- Filter with two coupled LC resonators.
- Input and output impedances of a MOS transistor.
- One typical quartz oscillator.
- A one transistor tuned amplifier.
- Several mixers.

3. Bibliography.

[1] Circuits et systèmes électroniques, Prof. M. Declercq.

[2] Traité d'électricité volume VIII, Électronique, Prof. R. Dessoulavy et J.-D. Chatelain, PPR.

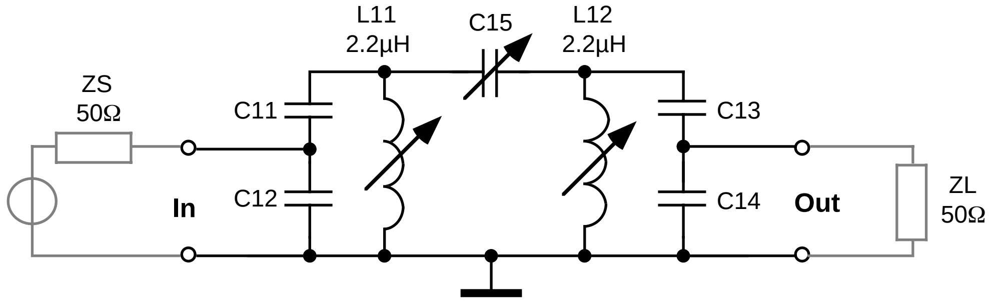
[3] Schematics of the board "Initiation à la HF" in appendix.

[4] Data sheets of the components on the intranet.

[5] Circuits et techniques HF et VHF, Prof. C. Enz & Dr. C. Dehollain.

4. LC filter with two coupled LC resonators.

4.1. Description.



This filter is made of two parallel LC resonator with capacitive coupling. The capacitive dividers at both access is used for impedance transformation.

4.2. Theoretical forecasts.

4.2.1. Why is there two capacitive dividers one at each access, when only one is necessary at the side of the lowest impedance, on the source or the load ?

4.2.2. How to deal with a complex impedance at the source or the load ?

4.2.3. The coupling is made by the adjustable capacitor C15. Estimate the optimum value of C15. Sketch the frequency response of the filter for different values around this optimum.

4.2.4. Which parameters will limit the quality factor of the filter ?

4.2.5. Which is the order of this filter ?

4.2.6. What is the slope (dB/dec.) of the frequency response of this filter at low frequency (under the resonant frequency) respectively at high frequency (above the resonant frequency) ?

4.2.7. Are there other coupling methods ? Discuss pro and con.

4.2.8. Calculates the values of C11, C12, C13, C14 and C15 to obtain a -3 dB band pass from 13 MHz to 15 MHz with optimum flat shape with 50 Ω source and load.

4.3. Measurements and tuning.

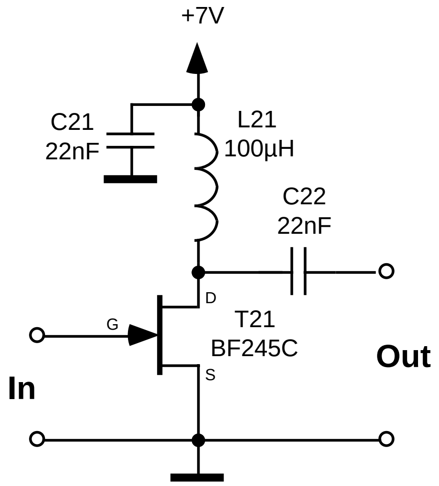
4.3.1. Using a network analyser, measure the frequency response and adjust the elements to obtain the desired result. Observe the Bode plots phase and amplitude from 1 MHz to 100 MHz.

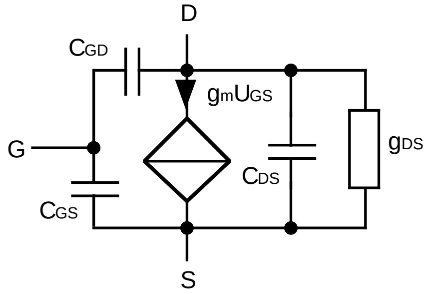
4.3.2. Make precise measurements around 14 MHz and adjust the elements to optimise the frequency response.

4.3.3. Measure the insertion losses in the band pass.

5. Input and Output Impedances of a FET.

5.1. Schematics.





The FET is connected as a common source amplifier. The drain is polarized at +7V through L21 which has zero ohm for DC current but high impedance at the working frequency.

5.2. Theoretical forecasts.

5.2.1 With the given HF small signal model, and assuming that Z_{L21} is very high, find the expression of the input impedance as function of the transconductance, the load impedance and the frequency.

5.2.2. With the given HF small signal model, and assuming that Z_{L21} is very high, find the expression of the output impedance as function of the transconductance, the source impedance and the frequency.

5.3. Measurements.

5.3.1. Use the netwok analyzer HP-4195A and its impedance measurement kit. At first, calibrate the test set, including the connexion coaxial cable from 13 to 15 MHz.

5.3.2. Report Z_{in} function of the frequency with a polarization of V_{GS} = 0 V and a low Z_{load} (50 Ω). Repeat this measure with a high Z_{load} (open).

5.3.3. Find an equivalent parallel circuit for both cases at 14.25 MHz.

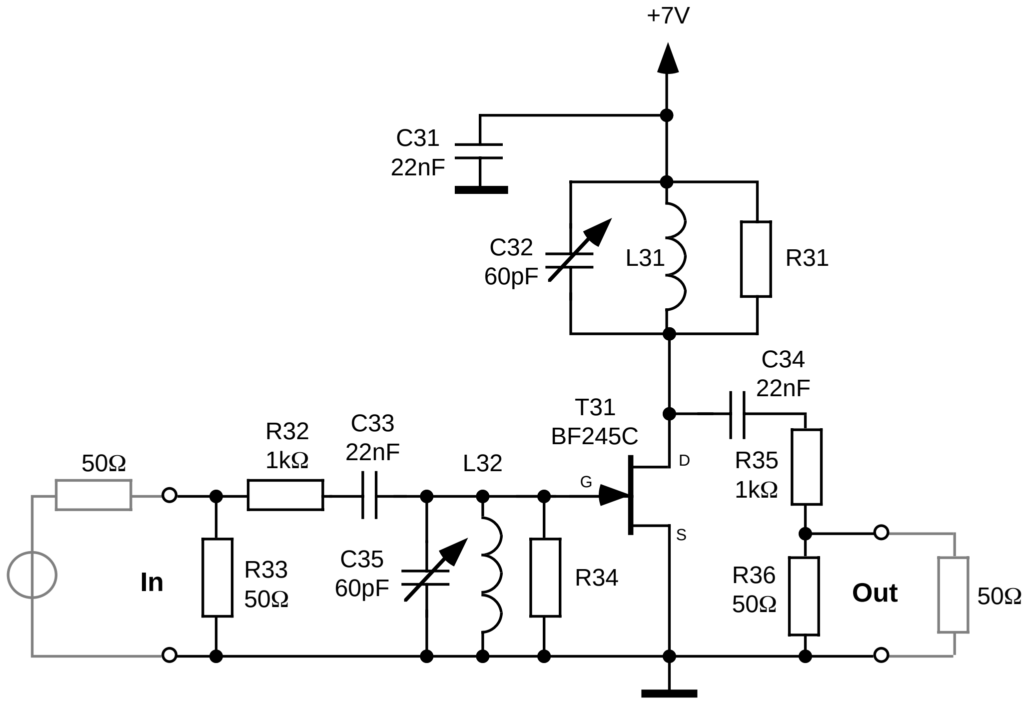
5.3.4. Make these same measurements with V_{GS} = -1 V.

5.3.5. Report Z_{out} function of the frequency with a polarization of V_{GS} = 0 V and a low Z_{source} (50 Ω). Repeat this measure with a high Z_{source} (10 kΩ).

5.3.6. Find an equivalent parallel circuit for both cases at 14.25 MHz.

6. The tuned amplifier.

6.1. Schematics.



This amplifier is made of a FET in common source configuration with two LC resonators one at the input in the gate connection and the second as the load in the drain. The resistors R32, R33, R35 and R36 are added for measuring purposes: R32 is simulating a source impedance, R33 is the termination for the signal generator,. R35+R36 are simulating a load and making impedance matching with the signal analyser. Such an impedance matching is made for measuring purposes only and is not usable in a practical design where maximum power transmitted to the load is desired.

6.2. Theroretical forecasts.

6.2.1. Which type of coupling is used between the two resonators ?

6.2.2. If both LC resonators have the same quality factor Q_i , what is the global quality factor Q_{global} of this selective amplifier?

6.2.3. This amplifier is also a filter, what is his order, what are the slope (dB/decade) of the bode diagram below, respectively above the resonant frequency.

6.2.4. We want a –3 dB band pass from 13 to 15 MHz. Calculate Q_{global}, Q_i, and then L31, R31, L32 and R34 (input and output impedances of the FET are neglected).

6.2.5. Calculate the voltage gain $A_V = U_D / U_G$ at centre frequency.

6.3. Measurements et tuning.

6.3.1. With a network analyser, observe the bode plot from 1 MHz to 100 MHz. Adjust C32 and C35 to obtain the desired curve.

6.3.2. Measure the frequency response between 13 MHz and 15 MHz after a fine tuning.

6.3.3. Measure the voltage gain U_{Out}/U_{In} at centre frequency and calculate $A_V = U_D/U_G$.

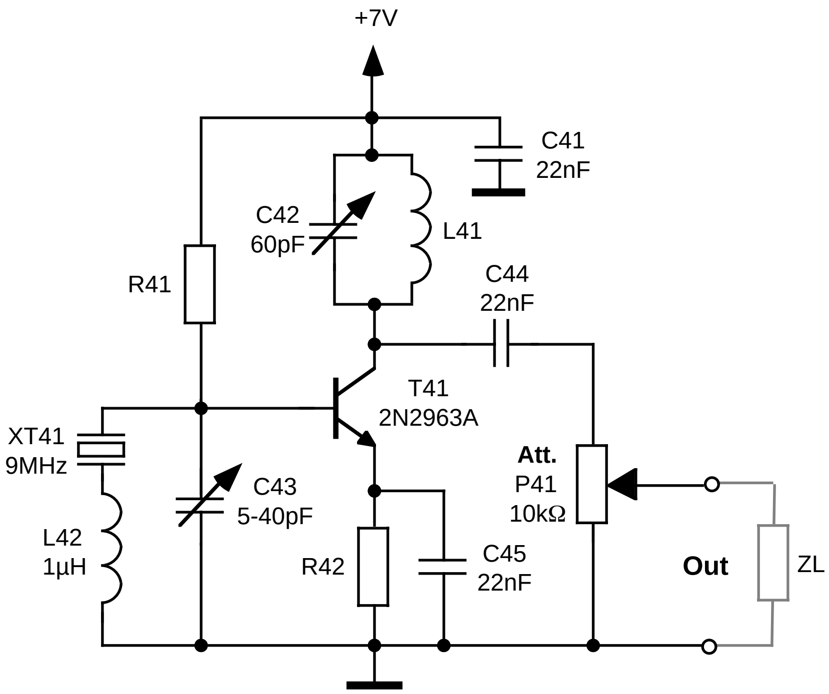
6.3.4 With a waveform generator, apply a 14 MHz sine signal at the input and observe the spectrum of the output signal.

6.3.5. Find the 1 dB compression point of this amplifier.

6.3.6. Apply a dual tone signal (by example 13,9 MHz & 14.1 MHz) at the input, measure the intermodulation distortion factor for different input levels. Estimate the third order intercept point.

7. A quartz oscillator.

7.1. Schematics.



The resistors R41 et R42 set the polarization current of the transistor. The inductor L42 and the capacitor C43 modify slightly the serie and parallel resonant frequencies of the quart. C43 allows then a fine tuning of the frequency of oscillation. Resonator L41-C42 allows to select one harmonics of the quartz if an overtone is used (not in this case)

7.2. Theoretical forecasts.

7.2.1. How is made the positive feedback in this circuit ? Which type of oscillator is it ?

7.2.2. Does the value of C42 influence the frequency of oscillation ?

7.2.3. Does the position of P41 (with a load connected) influence the frequency of oscillation ?

7.2.4. Calculate R41 and R42 to obtain quiescent current of 1 mA with 1 V at the emitter.

7.2.5. What is the maximum peak-to-peak output voltage ?

7.2.6. Calculate the value of L41 to allow oscillation at the fundamental frequency of the quartz (9 MHz).

7.3. Measurements and tuning.

7.3.1. Place the cursor of P41 near the ground side. Observe the output signal.

7.3.2. Adjust C43 at midrange and tune C42 to make the circuit oscillate.

7.3.3. Measure the spectrum of the output signal around 9 MHz and tune C42 and C43 to obtain a oscillation precisely at 9.000 MHz.

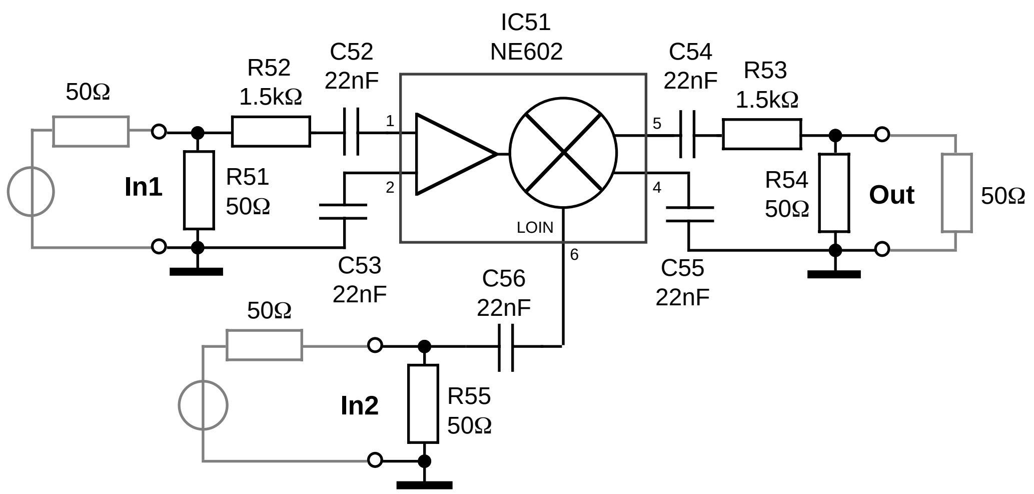
7.3.4. Observe the influence of the position of P41 on this frequency.

7.3.5. Check that the oscillator is self-starting when powering-up the board.

7.3.6. Observe the spectrum of the output signal, looking for harmonics.

8. The "Gilbert" cell balanced mixer.

8.1. Schematics.



This mixer is using an integrated four quadrants analog multiplier also known as the "Gilbert" cell. The resistors R51, R52, R53 and R54 are added for measuring purposes: R52 is matched with the input impedance of the mixer, R51 is the termination for the signal generator,. R53+R54 are simulating a load matched to the output impedance of the mixer and making impedance matching with the signal analyser. Such an impedance matching is made for measuring purposes only and is not usable in a practical design where maximum power transmitted to the load is desired.

In1 signal is at 9 MHz, In2 signal (LOIN) at 5 MHz and the desired output at 14 MHz.

8.2. Theoretical forecasts.

8.2.1. Based on the datasheets of the NE602, estimate the input and output resistances of the circuit given in the schematics.

8.2.2. Why is it specified to apply a signal of at least 200 mV peak-peak at the input LOIN ?

8.3. Measurements.

8.3.1. Apply 200 mVeff at 5 MHz at In2 and an input signal of 10 mVeff at 9 MHz at In1, observe the spectrum of the output from 1 MHz to 150 MHz. Identify each spectral component.

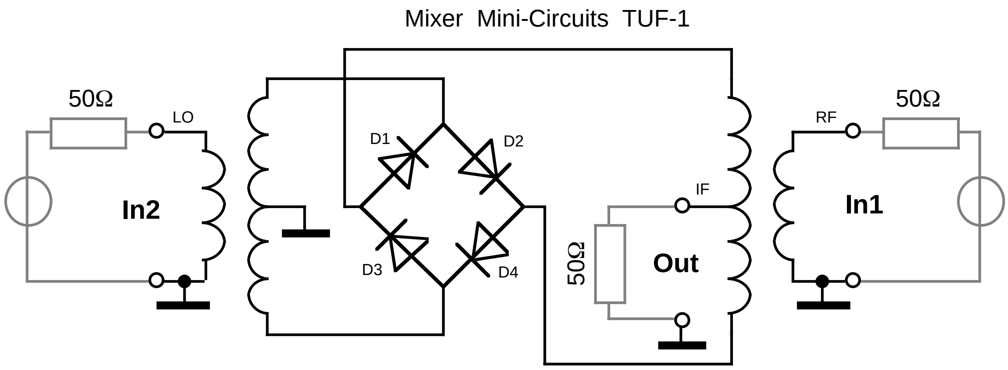
8.3.2. Estimate the conversion gain (pin 1 to pin 5).

8.3.3. Measure the input level at pin 1 to obtain 1 dB compression.

8.3.4. Apply a dual tone signal around 9 MHz at the input, measure the intermodulation distortion factor for different input levels. Estimate the third order intercept point.

9. Passive double balanced mixer.

9.1. Schematics.



The diodes in this mixer are used as switches. The signal at LO input should be strong enough so that D2 and D4 are conducting during the positive half period, and D1 and D3 are conducting during the negative half period. The small signal applied to RF input is transmitted to the IF output, in phase when D2 and D4 are conducting, and reversed when D1 and D3 are conducting. The IF signal is then the product of the RF signal and the sign of the LO signal.

Under some conditions the different access can be exchanged.

9.2. Theoretical forecasts.

9.2.1. By studying the internal schematics of this mixer, explain why it gives a good isolation between the different access.

9.3. Measurements .

9.3.1. Apply 500 mVeff at 5 MHz at In2 and an input signal of 100 mVeff at 9 MHz at In1, observe the spectrum of the output from 1 MHz to 150 MHz. Identify each spectral component.

9.3.2. Estimate the conversion gain from In1 to Out.

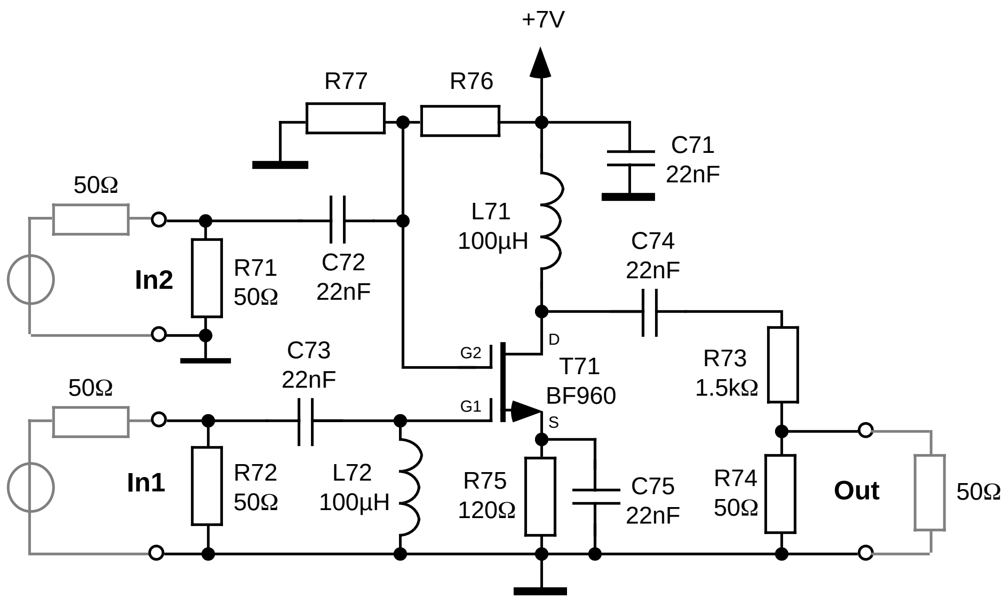
9.3.3. Measure the input level at In1 to obtain 1 dB compression.

9.3.4. Apply a dual tone signal around 9 MHz at In1, measure the intermodulation distortion factor for different input levels. Estimate the third order intercept point.

9.3.5. Measure the isolation from In2 (LO) to In1 (RF) with Out (IF) loaded with 50 Ω.

10. The "Dual Gate" MOSFET mixer.

10.1. Schematics.



In a "Dual Gate" MOS transistor the drain current is controlled by both gates. In this application, G1 Is at 0 V, the source is polarised slightly positively through R75, and G2 is polarised positively with R76-R77. The LO signal applied to In2 cause large changes of the drain current, thus of the transconductance and thus of the gain from In1 to Out, creating an amplitude modulation.

The resistors R73 and R74 are added for measuring purposes: simulating a load compatible with the output impedance of the mixer and making impedance matching with the signal analyser. Such an impedance matching is made for measuring purposes only and is not usable in a practical design where maximum power transmitted to the load is desired. R71 and R72 are terminations for the signal generators.

10.2. Theoretical forecasts.

10.2.1. Choose R76 and R77 to have 1 VDC between G2 and GND.

10.2.2. Which is the function of L72 ?

10.3. Measurements.

10.3.1. Apply 1 Veff at 5 MHz at In2 and an input signal of 10 mVeff at 9 MHz at In1, observe the spectrum of the output from 1 MHz to 150 MHz. Identify each spectral component.

10.3.2. Estimate the conversion gain from In1 to the drain of the MOS.

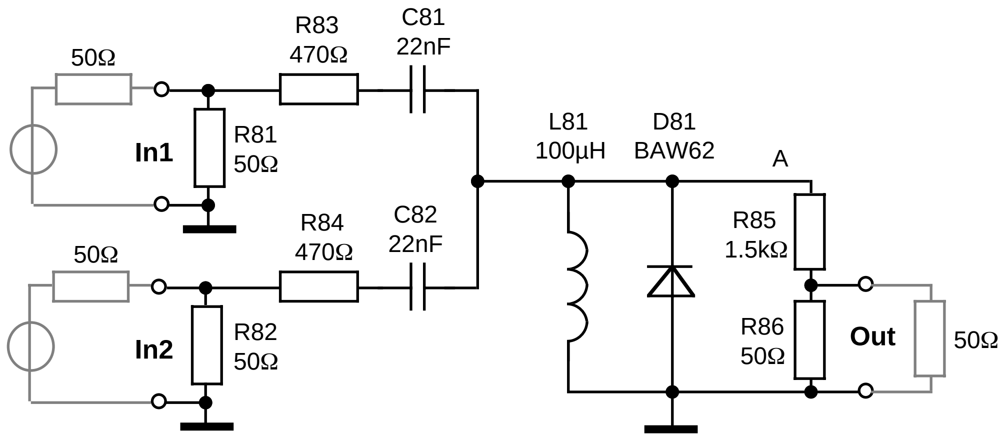
10.3.3. Measure the input level at In1 to obtain 1 dB compression.

10.3.4. Apply a dual tone signal around 9 MHz at In1, measure the intermodulation distortion factor for different input levels. Estimate the third order intercept point.

10.3.5. Measure the isolation from In2 to In1 with Out loaded with 50 Ω.

11. The single diode mixer.

11.1. Schematics.



The resistors R81 and R82 are terminations for the signal generators.

The resistors R85 and R864 are added for measuring purposes: simulating a load compatible with the output impedance of the mixer and making impedance matching with the signal analyser. Such an impedance matching is made for measuring purposes only and is not usable in a practical design where maximum power transmitted to the load is desired.

The signals at In1 and In2 are added and hard limited by the diode. The non-linearity creates harmonics and intermodulation products, thus mixing the input signals

This circuit can also be seen as chopping the small signal applied to In1, at the frequency of the signal applied to In2. If this signal on In2 is strong it turns the diode on during its negative half-wave thus short-circuiting to GND the signal from In1.

11.2. Theoretical forecasts.

11.2.1. Which is the function of L81 ?

11.2.2. Is it possible to specify input and output impedances?

12.2.3. Which is the peak current flowing into In1 and In2.

11.3. Measurements.

11.3.1. Apply 2 Veff at 5 MHz at In2 and an input signal of 10 mVeff at 9 MHz at In1, observe the spectrum of the output from 1 MHz to 150 MHz. Identify each spectral component.

11.3.2. Estimate the conversion gain from In1 to point A.

11.3.3. Measure the input level at In1 to obtain 1 dB compression.

11.3.4. Apply a dual tone signal around 9 MHz at In1, measure the intermodulation distortion factor for different input levels. Estimate the third order intercept point.

11.3.5. Measure the isolation from In2 to In1 with Out loaded with 50 Ω.

13. Conclusions on mixers.

13.1. Give a summary of pro and con of each mixer.

13.2. Give some examples of application of each mixer