MICROWAVE MIXERS

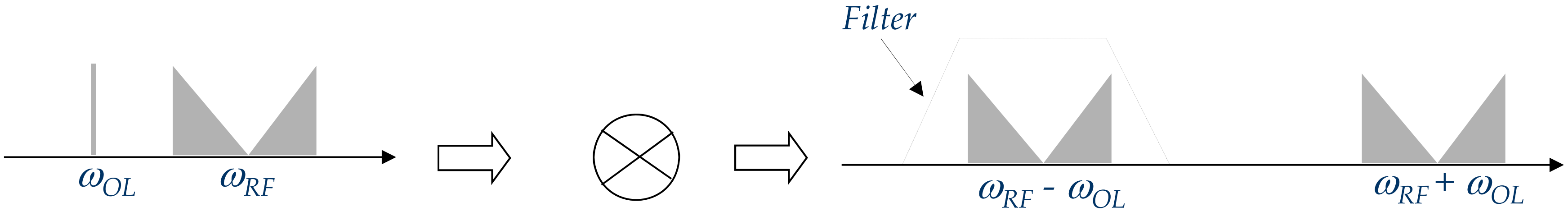
Mixer Goal

Translate the carrier frequency of a RF signal.
Conceptually this implies a multiplication:

$$V_{RF} = V_M(t)\cos(\omega_{RF}t + \Phi(t)) \qquad V_{OL} = V_o\cos(\omega_{OL}t)$$

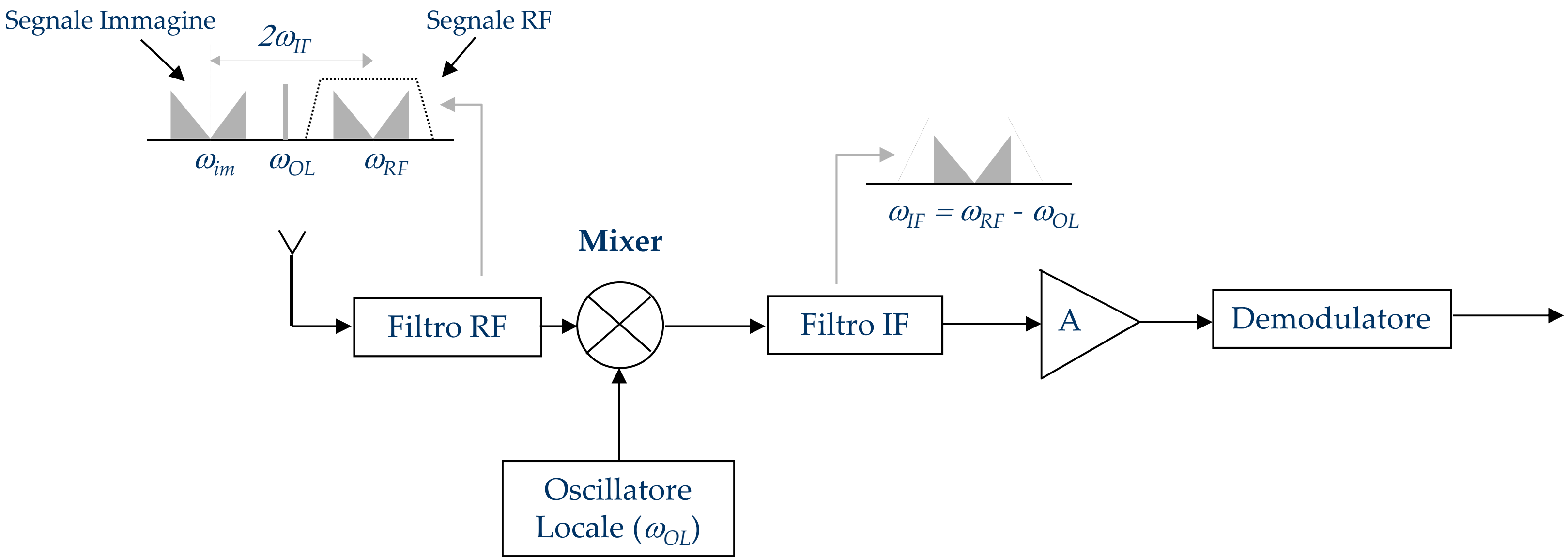
$$V_U = V_{RF}\cdot V_{OL} = V_M(t)V_0\cos(\omega_{RF}t + \phi(t))\cos(\omega_{OL}t) =$$

$$\frac{V_0}{2}\left[V_M(t)\cos((\omega_{RF} - \omega_{OL})t + \phi(t)) + V_M(t)\cos((\omega_{RF} + \omega_{OL})t + \phi(t))\right]$$



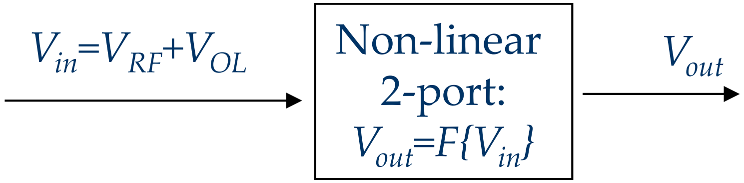
Mixer in communication systems

Frequency conversion receiver:



Practical implementation of a microwave mixer

At microwave frequency is more easy to realize the frequency conversion exploiting 2-port the non-linear devices:



F() non-linear characteristic:

$$V_{out} = a_1 V_{in} + a_2 V_{in}^2 + a_3 V_{in}^3 + \ldots$$

Substituting V_{RF} and V_{OL} and using the first 2 non-linear terms of the expansion:

$$V_{out} = \frac{a_2}{2}\left(V_0 + V_M\right) + a_1\left(V_0 \cos\left(\omega_0 t\right) + V_M \cos\left(\omega_{RF} t\right)\right) +$$

$$+\frac{a_2}{2}\left(V_0^2 \cos\left(2\omega_0 t\right) + V_M^2 \cos\left(2\omega_{RF} t\right)\right) + a_2\left(2V_0 V_M \cos\left(\omega_0 t\right)\cdot\cos\left(\omega_{RF} t\right)\right) + \ldots$$

Classes of microwave mixers

The most used non-linear device is a **Schotcky diode.**

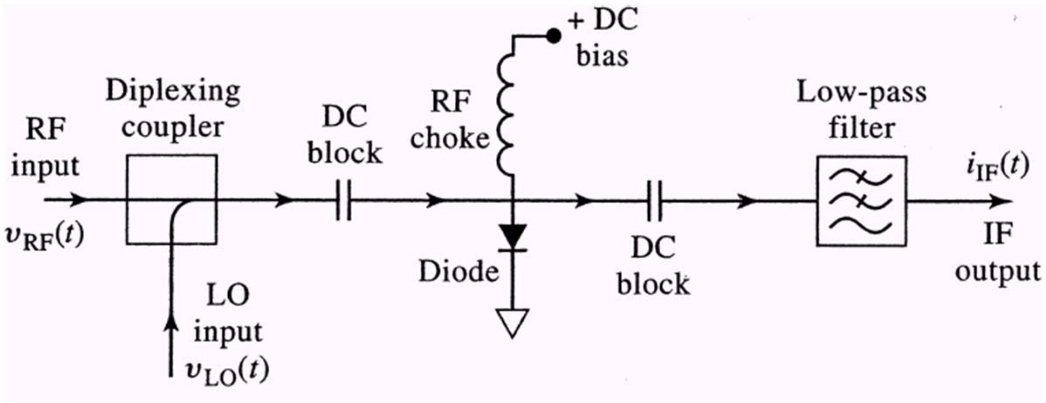
There are two main classes of microwave mixers:

- **Mixers with a single diode (single-ended)**
- **Balanced Mixers (with 2 o 4 diodes)**

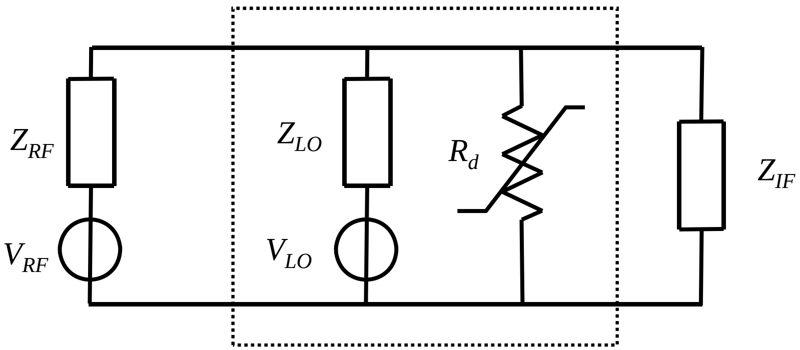
Parameters of a microwave mixer:

- Conversion Loss(dB) (5-15 dB)
- Linearity (referred to the translated RF signal)
- Noise
- Suppression of spurious products
- Input-output match
- Isolation (RF-OL, IF-OL)

Analysis of single-ended mixers



Equivalent circuit:



"Pumped" diode

The diode (R_d) is represented by the exponential curve:

$$I_D = I_S\left(e^{\frac{V_D}{V_T}} - 1\right)$$

It can be assumed memoryless (in a first as approximation)

Distortion in a mixer

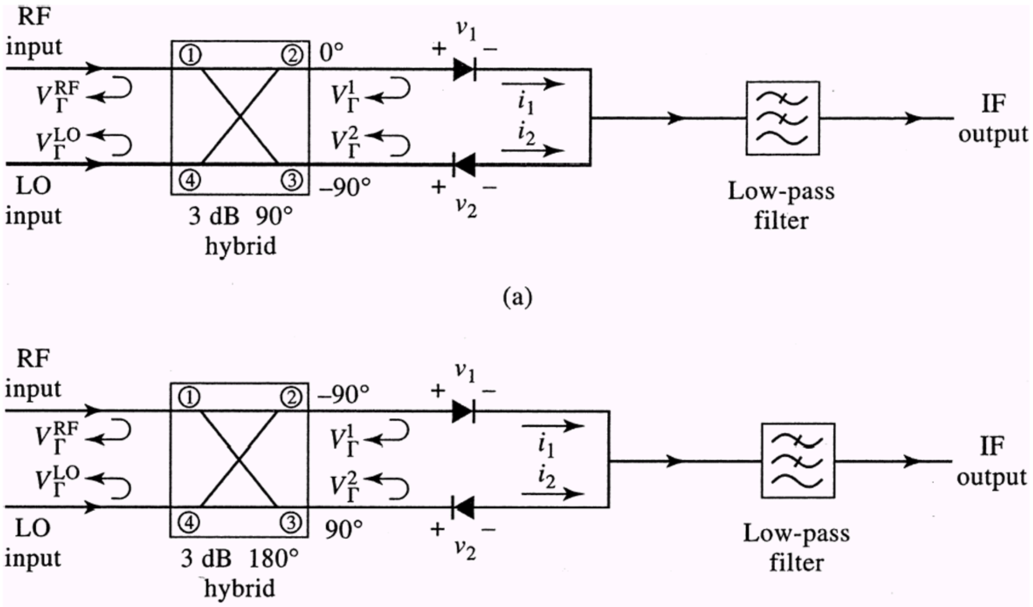
Effects of distortion:

- The spectrum of the frequency-translated signal around the new carrier frequency is different from the original one
- New replicas of the original RF signal, LO and combination of them are generated at different carrier frequencies

The local linearity is described by the same parameters used for amplifiers (P_{1dB}, IP); in the mixers case the input-output frequencies are different. Moreover the mentioned parameters depend also on the power level of the local oscillator

Single-balanced mixers

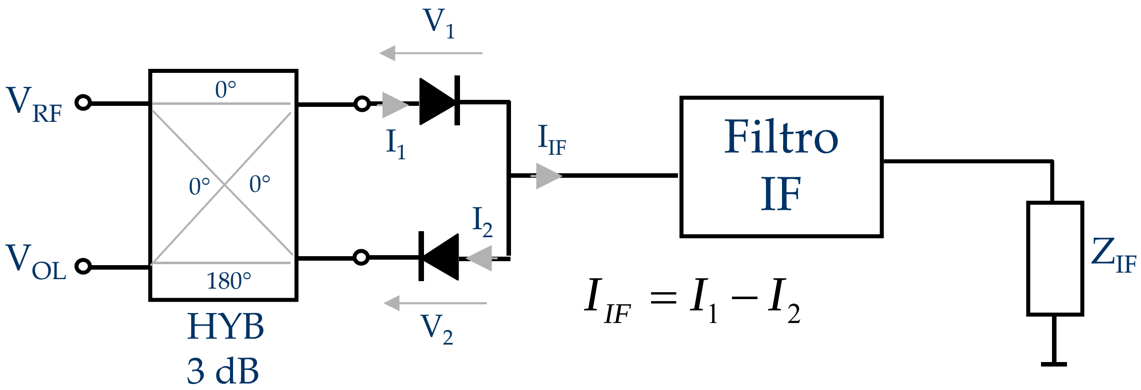
They allow an intrinsic suppression of some spurious products.
An higher power from the LO is requested. A better linearity is obtained, together with higher losses (compared to single-ended mixers)



Balance mixer with a 180°hybrid

$$V_{RF} = V_r \cos(\omega_{RF} t)$$
$$V_{OL} = V_P \cos(\omega_P t)$$

$$V_1 \doteq V_{RF} + V_{OL}$$
$$V_2 \doteq V_{RF} - V_{OL}$$



$$I_{IF} = I_1 - I_2$$

I/V characteristic of diodes: $I_D = a_1 V_D + a_2 V_D^2 + a_3 V_D^3 + \ldots$

Then: $I_1 = a_1 V_1 + a_2 V_1^2 + a_3 V_1^3 + \ldots \qquad I_2 = -a_1 V_2 + a_2 V_2^2 - a_3 V_2^3 + \ldots$

The overall current is given by:

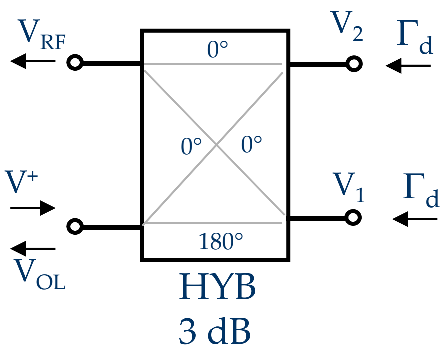
$$I_{IF} = a_1 (V_1 + V_2) + a_2 (V_1^2 - V_2^2) + a_3 (V_1^3 + V_2^3) + \ldots = 2a_1 V_{RF} + 4a_2 V_{RF} V_{OL} + 2a_3 (V_{RF}^3 + 3V_{RF} V_{OL}^3) + \ldots$$

$$= 2a_1 V_r \cos(\omega_{RF} t) + 2a_2 V_r V_P \left[\cos((\omega_{RF} - \omega_P) t) + \cos((\omega_{RF} + \omega_P) t) \right] +$$

$$+ 2a_3 \left[V_r \cos^3(\omega_{RF} t) + 3V_r V_P^2 \cos^2(\omega_P t) \cos(\omega_{RF} t) \right] + \ldots$$

Characteristics of 180° hybrid mixer

- All harmonics of LO are suppressed at IF
- Also the even harmonics of RF are suppressed
- AM Noise of LO is eliminated (NOT the phase noise)
- RF-LO ports are intrinsically isolated

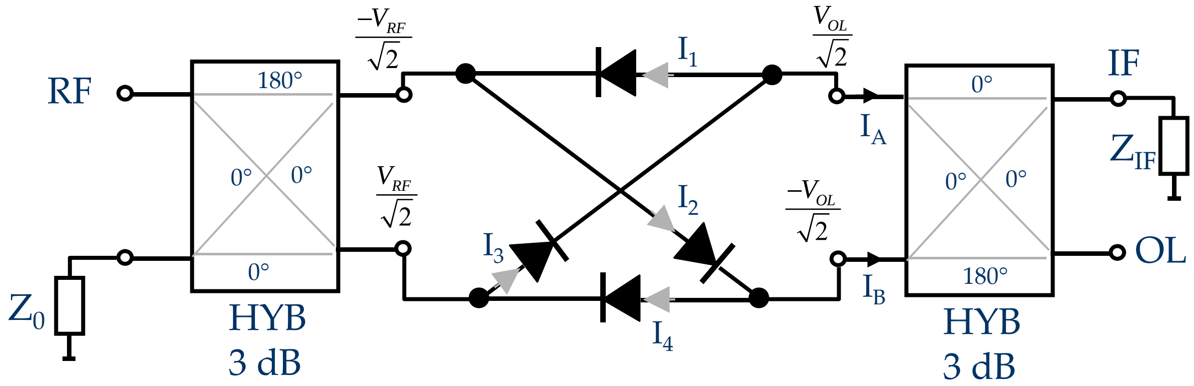


$$V_2 = \frac{V^+}{\sqrt{2}}, \quad V_1 = -\frac{V^+}{\sqrt{2}}$$

$$V_{OL} = -\frac{\Gamma_d V_1}{\sqrt{2}} + \frac{\Gamma_d V_2}{\sqrt{2}} = \frac{\Gamma_d V^+}{2} + \frac{\Gamma_d V^+}{2} = \Gamma_d V^+ \quad \Rightarrow \quad \Gamma_{OL} = \Gamma_d$$

$$V_{RF} = \frac{\Gamma_d V_1}{\sqrt{2}} + \frac{\Gamma_d V_2}{\sqrt{2}} = -\frac{\Gamma_d V^+}{2} + \frac{\Gamma_d V^+}{2} = 0 \quad \Rightarrow \quad S_{OL-RF} = 0$$

Double-balanced Mixer



$$I_D = a_1 V_D + a_2 V_D^2$$

$$V_2 = \frac{-V_{RF} + V_{OL}}{\sqrt{2}}, \quad V_1 = \frac{V_{RF} + V_{OL}}{\sqrt{2}}$$

$$V_3 = \frac{V_{RF} - V_{OL}}{\sqrt{2}}, \quad V_4 = \frac{-V_{RF} - V_{OL}}{\sqrt{2}}$$

$$V_A = kI_A = k\left(I_3 - I_1\right) = k\left(a_1 V_3 + a_2 V_3^2 - a_1 V_1 - a_2 V_1^2\right) = k\left[a_1\left(V_3 - V_1\right) + a_2\left(V_3^2 - V_1^2\right)\right] =$$

$$= \frac{k}{\sqrt{2}}\left[-2a_1 V_{OL} - 4a_2 V_{OL} V_{RF}\right]$$

$$V_B = kI_B = k\left(I_2 - I_4\right) = k\left(a_1 V_2 + a_2 V_2^2 - a_1 V_4 - a_2 V_4^2\right) = k\left[a_1\left(V_2 - V_4\right) + a_2\left(V_2^2 - V_4^2\right)\right] =$$

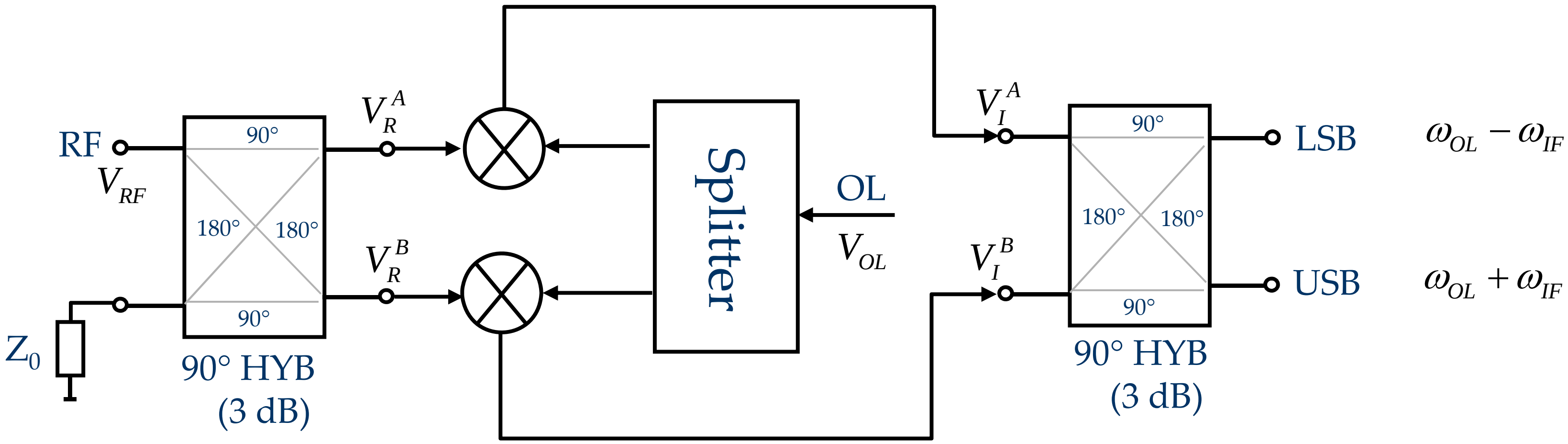
$$= \frac{k}{\sqrt{2}}\left[2a_1 V_{OL} - 4a_2 V_{OL} V_{RF}\right]$$

$$V_{IF} = \frac{V_A + V_B}{\sqrt{2}} = -\frac{k}{2}\left[8a_2 V_{OL} V_{RF}\right]$$

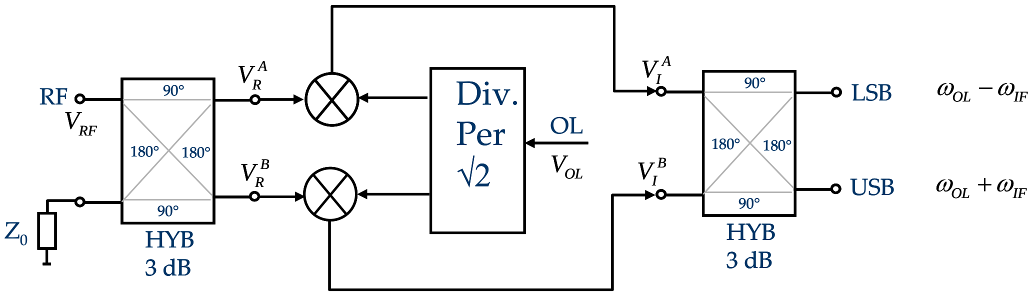
Characteristics of double-balanced mixers

- ALL harmonics of LO and RF are suppressed
- ALL even intermodulation products are suppressed
- Perfect isolation LO-RF
- High LO power required
- Worsens conversion loss
- Linearity improvement

Image-suppression mixers



This configuration separates the translated and image signals. The image filter is then no more necessary (or its requirements are strongly reduced)



$$V_{OL} = V_0 \cos(\omega_0 t), \quad V_{RF} = V_U \cos((\omega_0 + \omega_{IF})t) + V_L \cos((\omega_0 - \omega_{IF})t)$$

$$V_R^A = \frac{V_U}{\sqrt{2}} \sin((\omega_0 + \omega_{IF})t) + \frac{V_L}{\sqrt{2}} \sin((\omega_0 - \omega_{IF})t), \quad V_R^B = -\frac{V_U}{\sqrt{2}} \cos((\omega_0 + \omega_{IF})t) - \frac{V_L}{\sqrt{2}} \cos((\omega_0 - \omega_{IF})t)$$

$$V_I^A = k\frac{V_U V_0}{2}\left[\sin((\omega_0 + \omega_{IF})t)\cos(\omega_0 t)\right] + k\frac{V_L V_0}{2}\left[\sin((\omega_0 - \omega_{IF})t)\cos(\omega_0 t)\right] =$$

$$= k\frac{V_U V_0}{4}\left[\sin((2\omega_0 + \omega_{IF})t) + \sin(\omega_{IF} t)\right] + k\frac{V_L V_0}{4}\left[\sin((2\omega_0 - \omega_{IF})t) - \sin(\omega_{IF} t)\right]$$

$$V_I^B = k\frac{V_U V_0}{2}\left[-\cos((\omega_0 + \omega_{IF})t)\cos(\omega_0 t)\right] + k\frac{V_L V_0}{2}\left[-\cos((\omega_0 - \omega_{IF})t)\cos(\omega_0 t)\right] =$$

$$= k\frac{V_U V_0}{4}\left[-\cos((2\omega_0 + \omega_{IF})t) - \cos(\omega_{IF} t)\right] - k\frac{V_L V_0}{4}\left[\cos((2\omega_0 - \omega_{IF})t) + \cos(\omega_{IF} t)\right]$$

$$V_{USB} = j\left(\frac{V_I^B}{\sqrt{2}}\right) - \frac{V_I^A}{\sqrt{2}} = -k\frac{V_U V_0}{2\sqrt{2}}\left[\sin((2\omega_0 + \omega_{IF})t) + \sin(\omega_{IF} t)\right] - k\frac{V_L V_0}{2\sqrt{2}}\left[\sin((2\omega_0 - \omega_{IF})t)\right]$$

$$V_{LSB} = j\left(\frac{V_I^A}{\sqrt{2}}\right) - \frac{V_I^B}{\sqrt{2}} = k\frac{V_L V_0}{2\sqrt{2}}\left[\cos(\omega_{IF} t)\right]$$