8. 混频器. Mischer.

(0) 通信中的调制的核心是混频器, 原理是三角函数的积化和差公式.

$$\cos(w_1 t)\cos(w_2 t) = \frac{1}{2}\left[\cos(w_1+w_2)t + \cos(w_1-w_2)t\right]$$

用于乘法器的非线性. 例如伏安特性 $i=f(u)$. 在VL4中我们讨论了二阶的非线性.

这里在西安电子科技大学的高频电子线路中有更为普遍的结论, 西电牛逼!!

通常我们调制, 用大信号控制开关, 小信号则被搬移到大信号, 小信号为低频, 大信号则为高频. 反过来也没问题

(1) 先考虑一种简单情形(当然是n为...的情形)

$$i=\sum_{n=0}^{\infty} a_n u_i^n = \sum_{n=0}^{\infty} a_n U_1^n \cos^n w_1 t, \quad \cos^n x = \begin{cases} \frac{1}{2^n}C_n^{\frac{n}{2}} + \sum_{k=0}^{\frac{n}{2}-1} C_n^k \cos(n-2k)x, & n为偶 \\ \frac{1}{2^{n-1}}\sum_{k=0}^{\frac{1}{2}(n-1)} C_n^k \cos(n-2k)x, & n为奇 \end{cases}$$

用这个公式可以得到 $i=\sum_{n=0}^{\infty} b_n U_1^n \cos n w_1 t$, 也就是傅里叶变换后的结果.

那么当两个信号相乘后, 例如 $U_1\cos w_1 t \cdot U_2 \cos w_2 t$, 则会有 w_2+nw_1 或 w_2-nw_1.

(2) 更普遍的情形, 实际上的开关都是采用MOS或者二极管来实现, 可以 $u_i=U_0+u_1+u_2$

如上面所分析, 会产生的频率为 $w_{p,q}=|\pm p w_1 \pm q w_2|$, p, q 都为自然数.

- p+q 称为阶数. 通常我们只取 p=1, q=1. $w=|\pm w_1 \pm w_2|$.
- 凡是 p+q 为偶数的组合分量, 均为幂指数为偶数且大于p+q的各项产生
- 凡是 p+q 为奇数的组合分量, 均为幂指数为奇数且大于等于p+q的各项.

8.1 开始谈下大的调解

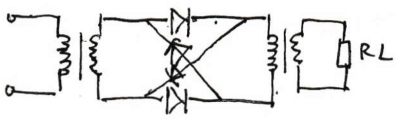
调制. 载波 $f_1=f_{LO}$, 信号 $f_2=f_{IF}$, $f_{HF}=f_{LO}\pm f_{IF}$.

我们想要的是 $f_{HF}\pm f_{LF}$, 解调 $f_1=f_{LO}$. 信号 $f_2=f_{HF}$ → $f_{IF}=|f_{LO}-f_{HF}|$

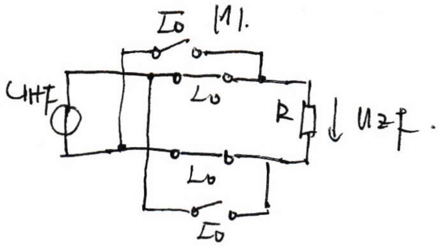
8.2. Passive Mischer, ~~Widerstandsmischer~~. Double-balance-Strunker. 双平衡电路

实际上如前所说, 可以采用二极管环形电路, 如右图(1)

从理论上来说, 简单点, 二极管可以看成开关, 对于数字电路, 非线性则是方波, 如图(2)



(1).



(2)

$U_{HF}(t)=\hat{U}_{HF}\cos(w_{HF}t)$.

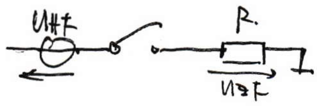
开关信号(注意, 这里可以看成解调)

$S_{LO}(t)$ 是方波, 傅里叶展开.

$$S_{LO}(t)=\frac{1}{2}+\frac{2}{\pi}\left\{\cos(w_{LO})-\frac{1}{3}\cos(3w_{LO}t)+\frac{1}{5}\cos(5w_{LO}t)\ldots\right\}$$

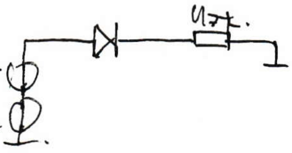
$$\begin{aligned} U_{IF}(t) &= U_{HF}(t)\cdot S_{LO}(t)+[-U_{HF}(t)]\cdot[1-S_{LO}(t)] \\ &= 2S_{LO}(t)\cdot U_{HF}(t)-U_{HF}(t) \\ &= U_{HF}(t)\cdot\frac{4}{\pi}\left\{\cos(w_{LO})-\frac{1}{3}\cos(3w_{LO}t)+\frac{1}{5}\cos(5w_{LO}t)\cdots\right\} \\ &= \frac{2\hat{U}_{HF}}{\pi}\Big\{[\cos(w_{LO}-w_{HF})t+\cos(w_{LO}+w_{HF})t]-\frac{1}{3}[\cos(3w_{LO}t-w_{HF})t+\cos(3w_{LO}t+w_{HF})t] \\ &\quad +\frac{1}{5}[\cos(5w_{LO}-w_{HF})t+\cos(5w_{LO}+w_{HF})t]\Big\} \end{aligned}$$

Widerstandsmischer. , U_{HF0} 在实际电路中可以认为用来做偏置, 补偿开启电压.



图(1)

$$\begin{aligned} U_{IF}(t) &= U_{HF}(t)\cdot S_{LO}(t) \\ &= [U_{HF0}+\hat{U}_{HF}\cos(w_{HF}t)]\cdot S_{LO}(t) \\ &= \frac{U_{HF0}}{2}+\frac{2U_{HF0}}{\pi}\left\{\cos w_{LO}(t)-\frac{1}{3}(3w_{LO}t)+\frac{1}{5}\cos(5w_{LO}t)+\cdots\right\} \\ &\quad +\frac{\hat{U}_{HF}}{2}\cos w_{HF}t+\frac{\hat{U}_{HF}}{\pi}\cdot\left\{\cos(w_{LO}-w_{HF})t+\cdots\right\} \end{aligned}$$

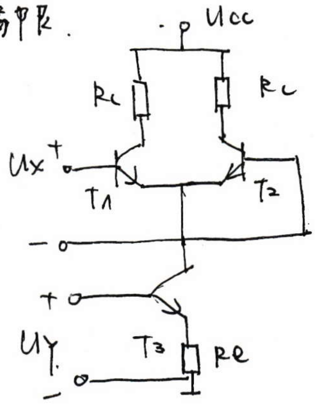


图(2).

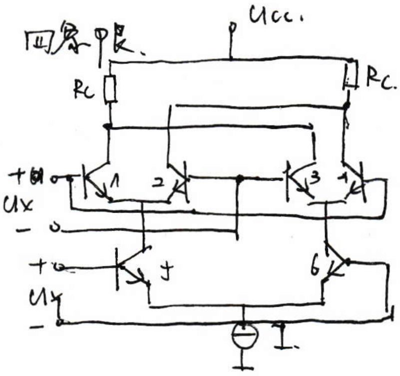
8.3. Aktiven Mischen.

原理上可以采用模拟乘法器

两象限.



四象限.



$$U_0 = (i_{C1} - i_{C2}) R_C = I \cdot \tanh\frac{U_x}{2U_T} \cdot R_C$$

泰勒近似.

当 $U_x \ll 2U_T$ 时.

$$U_0 = I \cdot \cancel{\tanh} \cdot \frac{U_x}{2U_T} R_C$$

$$= \frac{U_Y - U_{BE3}}{R_3} \cdot \frac{U_x}{2U_T} \cdot R_C \approx \frac{R_C}{2U_T R_e} \cdot U_x U_Y$$

U_x 可正可负. U_Y 大于0 或大于 U_{BE}.

$$U_0 = R_C \cdot [(i_{C1} + i_{C3}) - (i_{C2} + i_{C4})]$$

$$= R_C [(i_{C1} - i_{C2}) + (i_{C4} - i_{C3})]$$

$$= R_C \cdot I_{01} \cdot \frac{U_x}{2U_T} + I_{02} \cdot \frac{(-U_x)}{2U_T}$$

$$= R_C \cdot \frac{U_x}{2U_T} \cdot (I_{01} - I_{02})$$

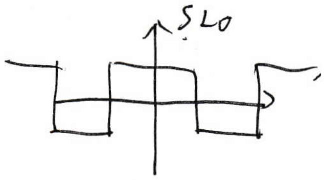
$$= R_C \cdot \frac{U_x U_Y}{4U_T^2} I = \frac{I \cdot R_C}{4U_T^2} U_x U_Y$$

U_x, U_Y 正负都可.

令 $U_x = U_{LO}$, $U_Y = U_{HF}$.

$$U_{HF}(t) = \hat{U}_{HF} \cos(\omega_{HF} t)$$

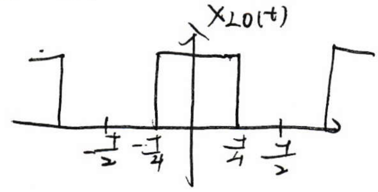
$$S_{LO}(t) = \frac{4}{\pi}\left[\cos(\omega_{LO} t) - \frac{1}{3}\cos(3\omega_0 t) + \frac{1}{5}\cos(5\omega_0 t)\right]$$



⇒ 代入乘法器就好.

MI-01.

(1)



~~$X(e^{jw})$~~

$$x_{LO}(t) = \sum_{-\infty}^{\infty} c_k e^{-j\cdot k\cdot 2\pi\cdot f_{LO} t}, \quad w_k = 2\pi f_{LO}$$

$$c_k = f_{LO}\int_{-\frac{T_{LO}}{4}}^{\frac{T_{LO}}{4}} e^{-jw_k t}\, dt = f_{LO}\cdot -\frac{1}{jw_k}\left(e^{-j\frac{\pi}{2}k} - e^{j\frac{\pi}{2}k}\right)$$

$$\Rightarrow x_{LO}(t) = \frac{1}{2} + 2\sum_{k=1}^{\infty}\cdot\frac{-1}{j2\pi k}\cdot\left[-j\sin\left(\frac{\pi}{2}k\right)\right]\cdot e^{-jw\cdot k t}$$

$$= \frac{1}{2} + \sum_{k=1}^{\infty}\frac{2\sin(\frac{\pi}{2}k)}{\pi k}\cdot\left[e^{-jw\cdot kt}\right]_{Re}$$

$$\Rightarrow x_{LO}(t) = \frac{1}{2} + \frac{2}{\pi}\cos(2\pi f_{LO} t) - \frac{2}{3\pi}\cos(2\pi\cdot 3 f_{LO} t)\ldots$$

(2)
$$u_{ZF}(t) = u_{HF}(t)\cdot u_{LO}(t)$$

$$= \left[U_{HF0} + \hat{U}_{HF}\cos(w_{HF} t)\right]\cdot\left[\frac{1}{2} + \frac{2}{\pi}\cos(2\pi f_{LO} t) - \frac{2}{3\pi}\cos(2\pi\cdot 3 f_{LO} t)\right]$$

$$= \frac{1}{2}U_{HF0} + \frac{2U_{HF0}}{\pi}\cos(2\pi f_{LO} t) - \frac{2U_{HF0}}{3\pi}\cos(2\pi\cdot 3 f_{LO} t) +$$

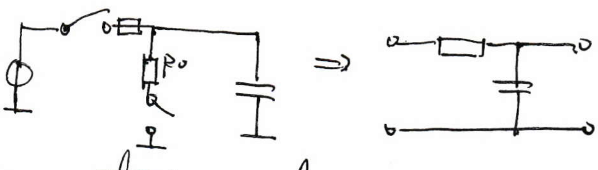
$$\frac{1}{2}\hat{U}_{HF}\cos(w_{HF} t) + \frac{\hat{U}_{HF}}{\pi}\{\cos[(w_{HF}+w_{LO})t] + \cos[(w_{HF}-w_{LO})t]\}$$

$$- \frac{\hat{U}_{HF}}{3\pi}\{\cos[(w_{HF}+3w_{LO})t] + \cos[(w_{HF}-3w_{LO})t]\}$$

代入 $f_{HF} = 100MHz$, $\hat{U}_{HF} = 50mV$, $U_{HF0} = 1V$, $f_{LO} = 102MHz$.

f ~~Name~~	Name	$\hat{U}_{ZF}$	$\hat{U}'_{ZF}$
0	Gleichanteil	$\frac{U_{HF0}}{2} = 0.5V$	
$f_{HF} - f_{LO} = 2MHz$	ZF-Signal (Abwärtsmischprodukt)	$\frac{\hat{U}_{HF}}{\pi} = 15.9mV$	15.8 mV
$f_{HF} = 100MHz$	HF-Durchgriff	$\frac{\hat{U}_{HF}}{2} = 25mV$ ~~63.7mV~~	3.53 mV
$f_{LO} = 102MHz$	LO-Durchgriff	$\frac{2U_{HF0}}{\pi} = 637mV$	98.2mV
$f_{LO}+f_{HF} = 202MHz$	Aufwärtsmischprodukt	$\frac{\hat{U}_{HF}}{\pi} = 15.9mV$	1.25mV
$3f_{LO} = 306MHz$	LO-Verdreifachung	$\frac{2U_{HF0}}{3\pi} = 212mV$	11 mV

3)

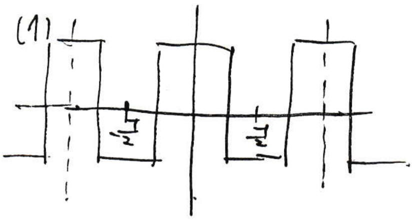


$$\frac{\underline{U}'_{ZF}}{\underline{U}_{ZF}} = \frac{1}{1+jwCR_{ON}} \qquad \hat{U}'_{ZF} = \frac{\hat{U}_{ZF}}{\sqrt{1+(wCR_{ON})^2}}$$

$$f_{3dB} = \frac{1}{RC} = \frac{1}{5k\cdot 2\times10^{-12}} = 10^8 = 100MHz.$$

MI-03.

(1)



设上一问为 $S_{LO}(t)$

$$S_L(t) = 2S_{LO}(t) - 1 = \frac{4}{\pi}\left[\cos(2\pi f_{LO} t) - \frac{1}{3}\cos(2\pi \cdot 3 f_{LO} t) + \frac{1}{5}\cos(5\omega_{LO} t)\right]$$

2) $I_T(t) = I_A + g_T u_{HF}(t) = I_A + g_T \hat{u}_{HF} \cos(\omega_{HF} t)$

$u_{ZF}(t) = R_C \cdot I_T(t) \cdot \frac{S_{LO}(t)}{U_T}$?，代入.

gemischt. Zahlen

$f_{LO} - f_{HF} = 10.7\,MHz$.

$\hat{u}_{ZF}(10.7\,MHz) = \frac{4R_Z \cdot g_T}{2\pi} \cdot \hat{u}_{HF} = 286.5\,mV$

$V_n = \frac{\hat{u}_{ZF}}{\hat{u}_{HF}} = 9.35$

$V_{n,dB} = 19.6\,dB$.

MI-02.

代入 Vorlesung 的公式.

$f_{LO} - f_{HF} = f_{ZF} = 10.7\,MHz$, $\hat{u}_{ZF} = \frac{2\hat{u}_{HF}}{\pi} = 6.37\,mV$

$f_{LO} + f_{HF} = 211.7\,MHz$ $\hat{u}_{ZF} = \frac{2\hat{u}_{HF}}{\pi} = 6.37\,mV$

$3f_{LO} - f_{HF} = 233.1\,MHz$
$3f_{LO} + f_{HF} = 434.1\,MHz$ $\Big\}$ $\hat{u}_{ZF} = \frac{2\hat{u}_{HF}}{3\pi} = 2.12\,mV$.

MI-04.

四象限乘法器见 Vorlesung. 答案见 Übung-unlock.