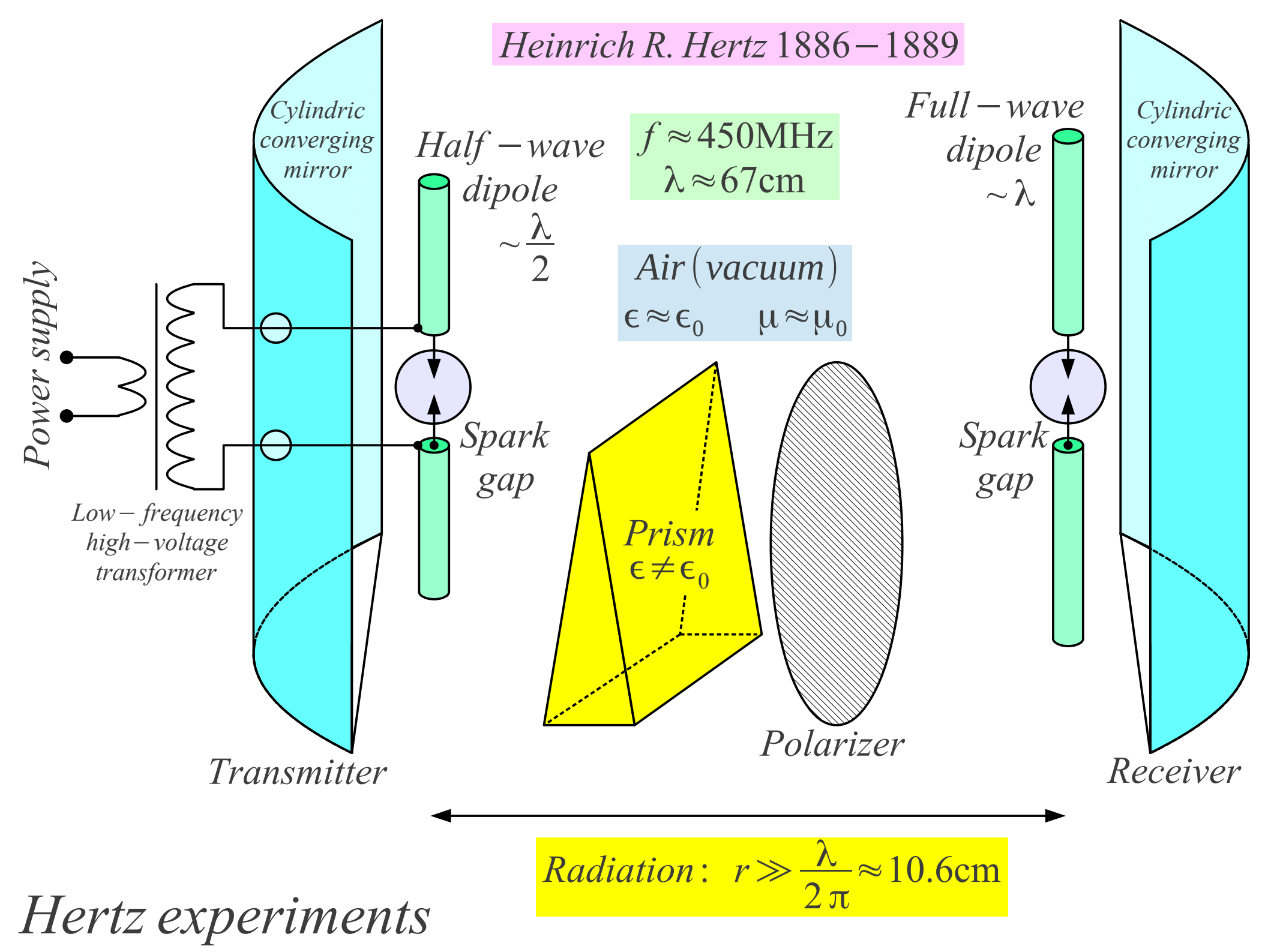
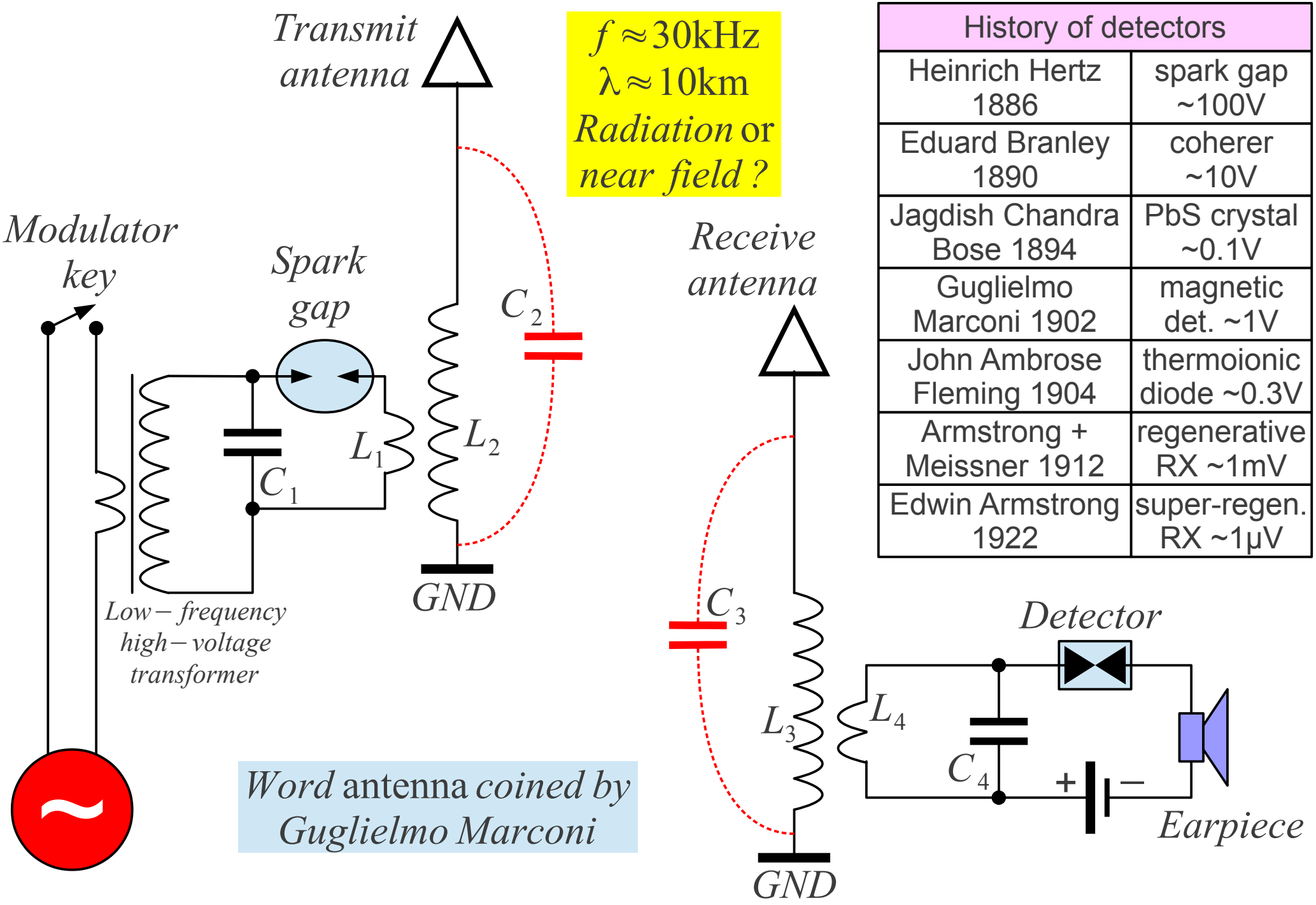
Communication Electronics

Lecture 10:

Transmitters and receivers

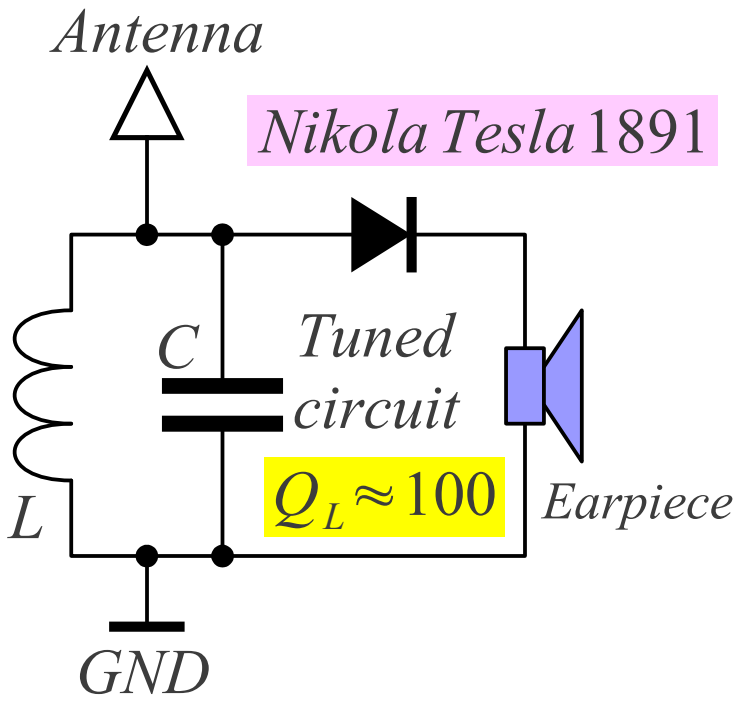


Hertz experiments

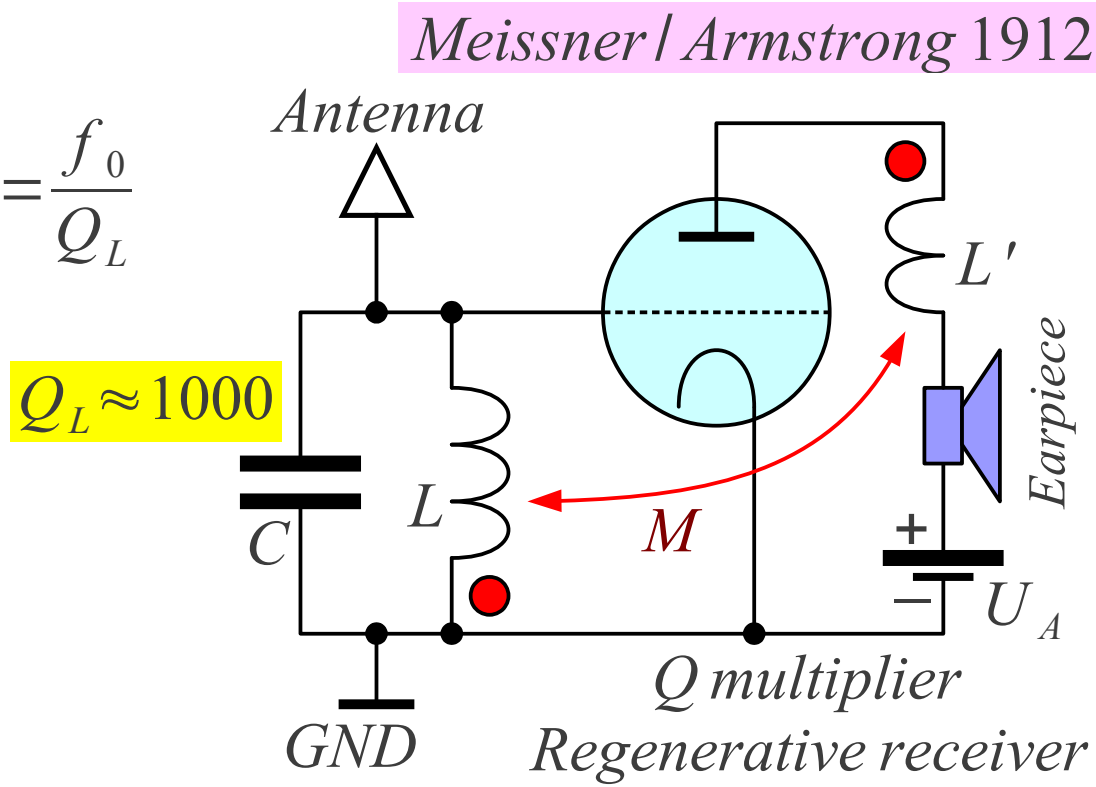


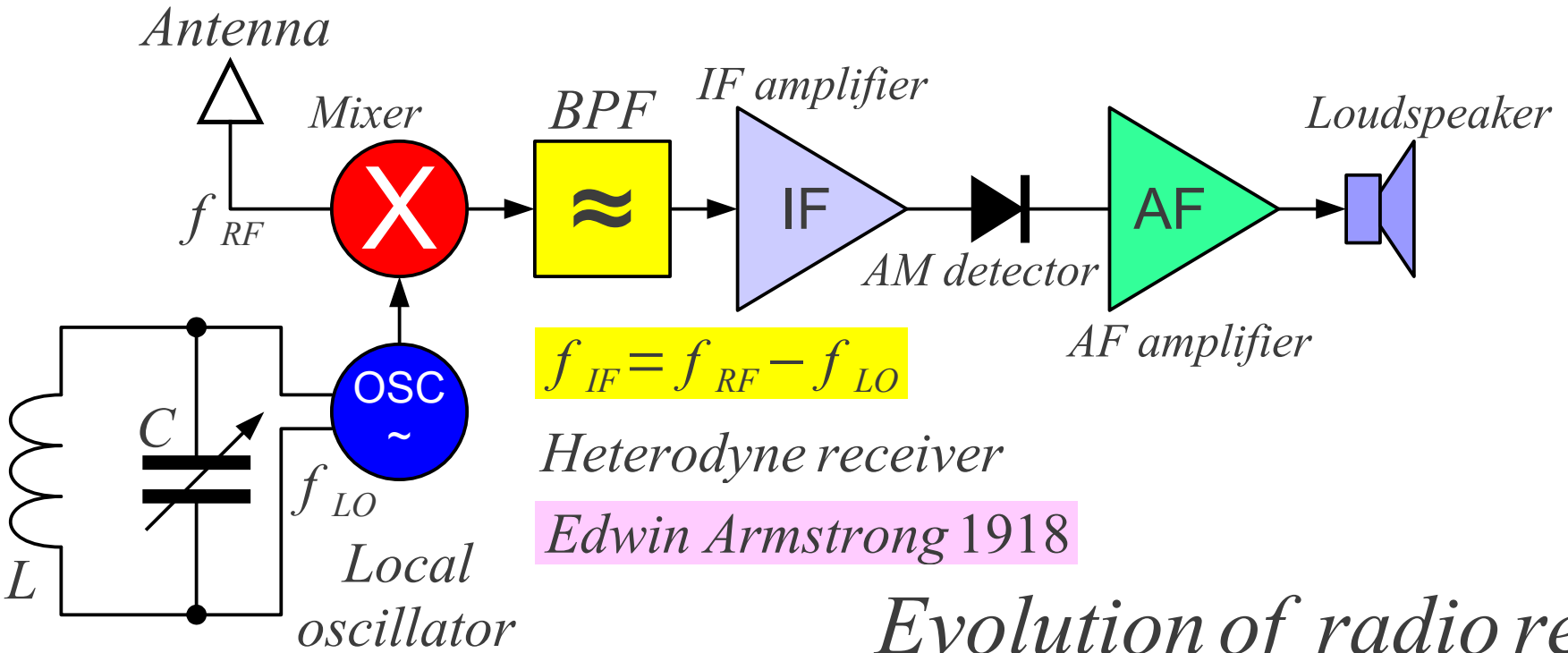
History of detectors	
Heinrich Hertz 1886	spark gap ~100V
Eduard Branley 1890	coherer ~10V
Jagdish Chandra Bose 1894	PbS crystal ~0.1V
Guglielmo Marconi 1902	magnetic det. ~1V
John Ambrose Fleming 1904	thermoionic diode ~0.3V
Armstrong + Meissner 1912	regenerative RX ~1mV
Edwin Armstrong 1922	super-regen. RX ~1μV

Four tuned circuits (Nikola Tesla)

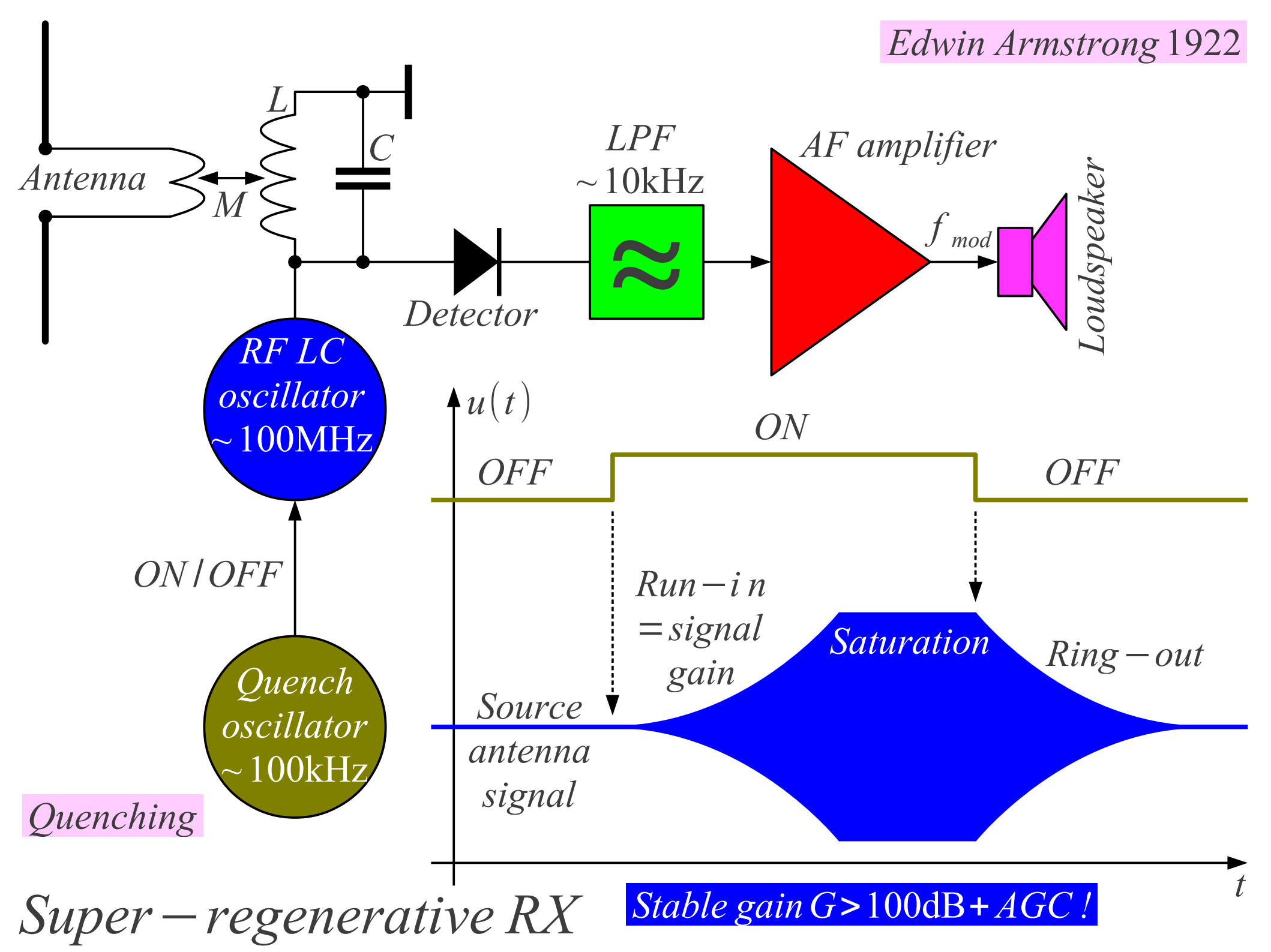


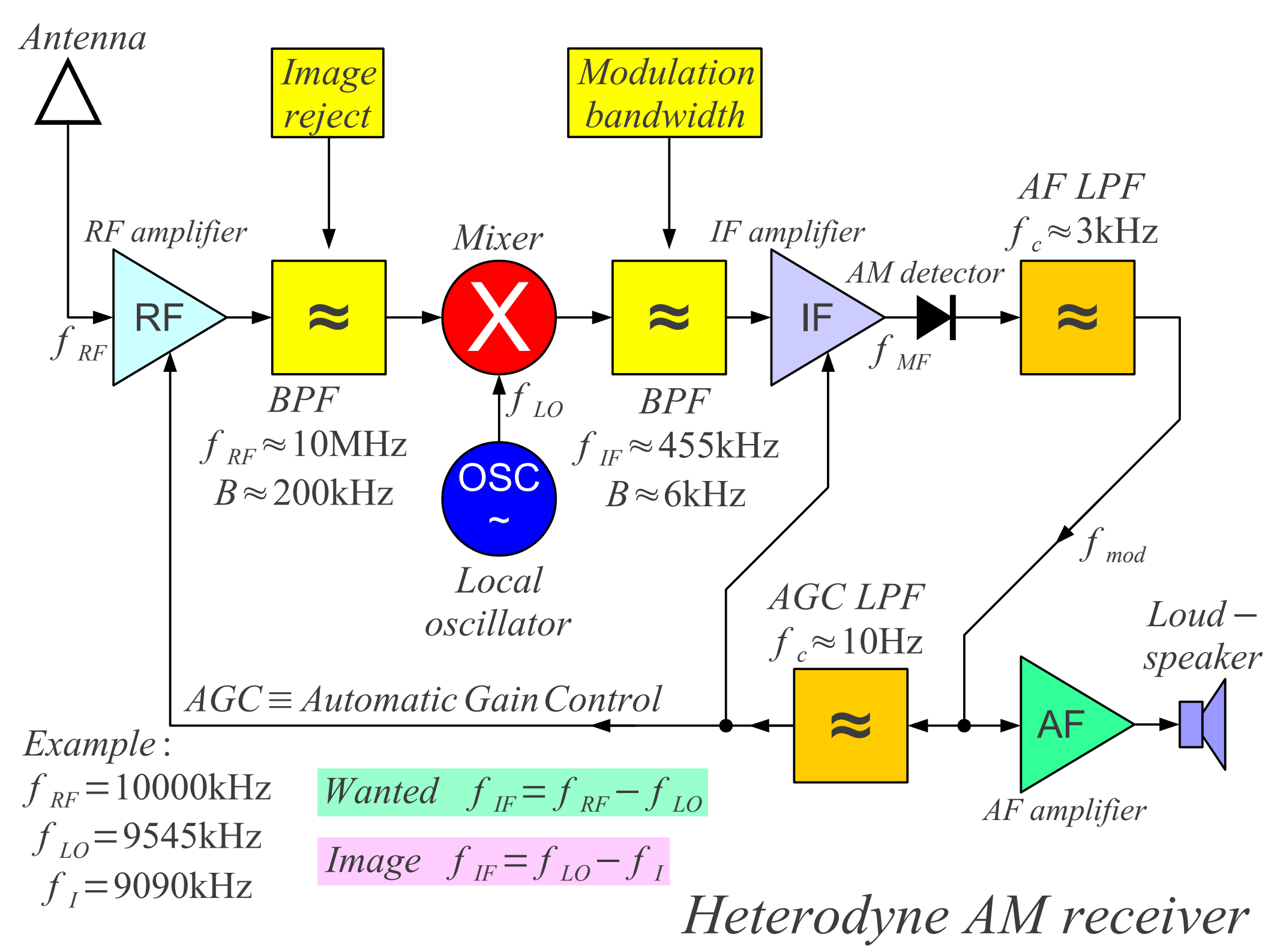
$$B = \frac{f_0}{Q_L}$$

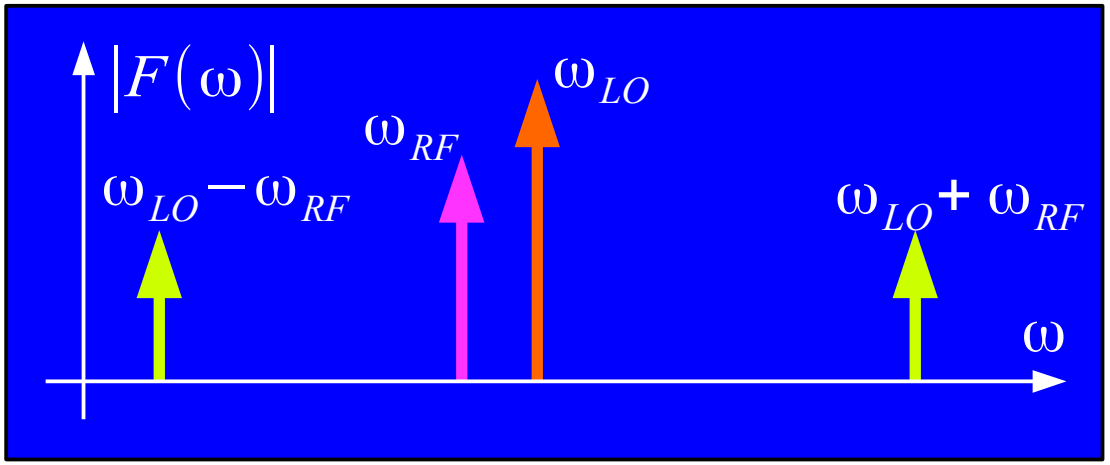




Evolution of radio receivers


Edwin Armstrong 1922
L
C
Antenna
M
LPF
~10kHz
AF amplifier
f mod
Loudspeaker
Detector
RF LC
oscillator
~100MHz
u(t)
ON
OFF
OFF
ON/OFF
Run−in
=signal
gain
Saturation
Ring−out
Source
antenna
signal
Quench
oscillator
~100kHz
t
Quenching
Super−regenerative RX
Stable gain G>100dB+AGC !


Antenna
Image reject
Modulation bandwidth
RF amplifier
Mixer
IF amplifier
AM detector
AF LPF
$f_c \approx 3\text{kHz}$
RF
f_{RF}
BPF
$f_{RF} \approx 10\text{MHz}$
$B \approx 200\text{kHz}$
f_{LO}
OSC
Local oscillator
BPF
$f_{IF} \approx 455\text{kHz}$
$B \approx 6\text{kHz}$
IF
f_{MF}
f_{mod}
AGC LPF
$f_c \approx 10\text{Hz}$
Loud – speaker
AGC ≡ Automatic Gain Control
AF
AF amplifier
Example :
$f_{RF} = 10000\text{kHz}$
$f_{LO} = 9545\text{kHz}$
$f_I = 9090\text{kHz}$
Wanted $f_{IF} = f_{RF} - f_{LO}$
Image $f_{IF} = f_{LO} - f_I$
Heterodyne AM receiver



$u_{RF}=A_{RF}\cdot\cos\omega_{RF}t$

$u_{LO}=A_{LO}\cdot\cos\omega_{LO}t$

RF

LO

IF

Analog multiplier as frequency mixer

$u_{IF}=K_m\cdot u_{RF}\cdot u_{LO}$

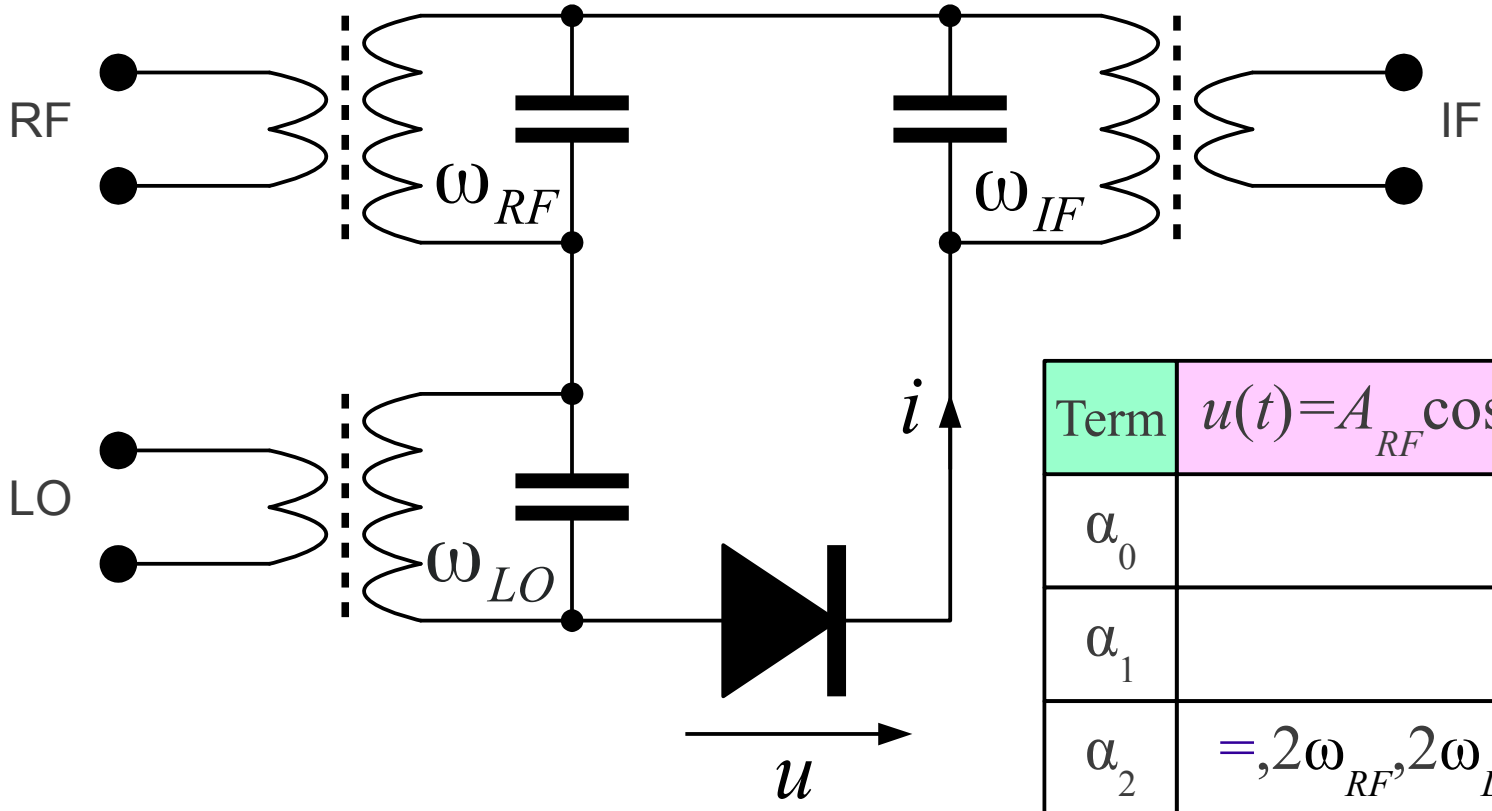
$K_m\left[\mathrm{V}^{-1}\right]\equiv multiplier\ factor$

$$u_{IF}=K_m A_{RF} A_{LO}\cos\omega_{RF}t\cos\omega_{LO}t$$

$$\cos x\cos y=\frac{1}{2}\cdot\left[\cos(y+x)+\cos(y-x)\right]$$

$$u_{IF}=\frac{K_m A_{RF} A_{LO}}{2}\cdot\left[\cos(\omega_{LO}+\omega_{RF})t+\cos(\omega_{LO}-\omega_{RF})t\right]$$

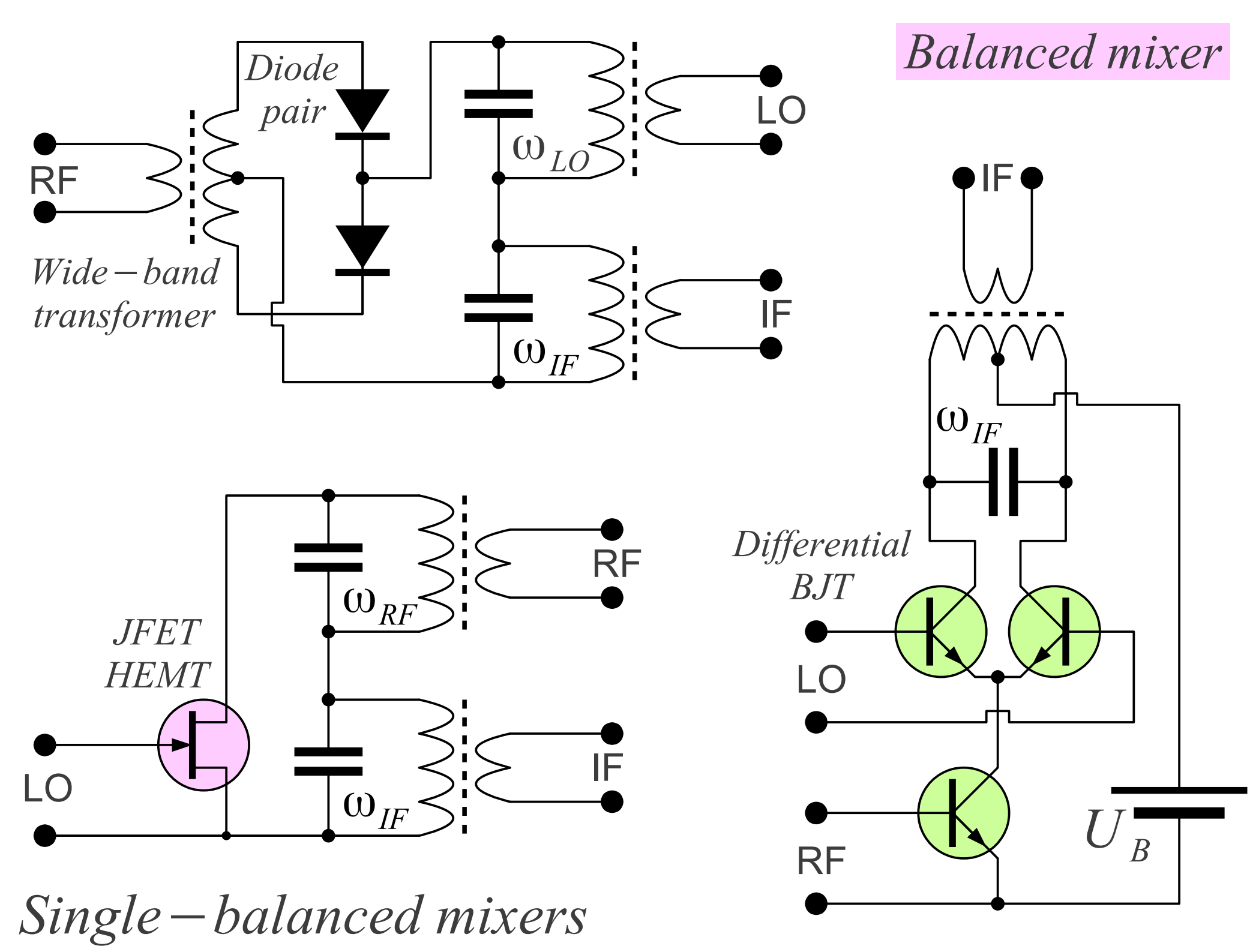
Multiplier as frequency mixer (modulator)

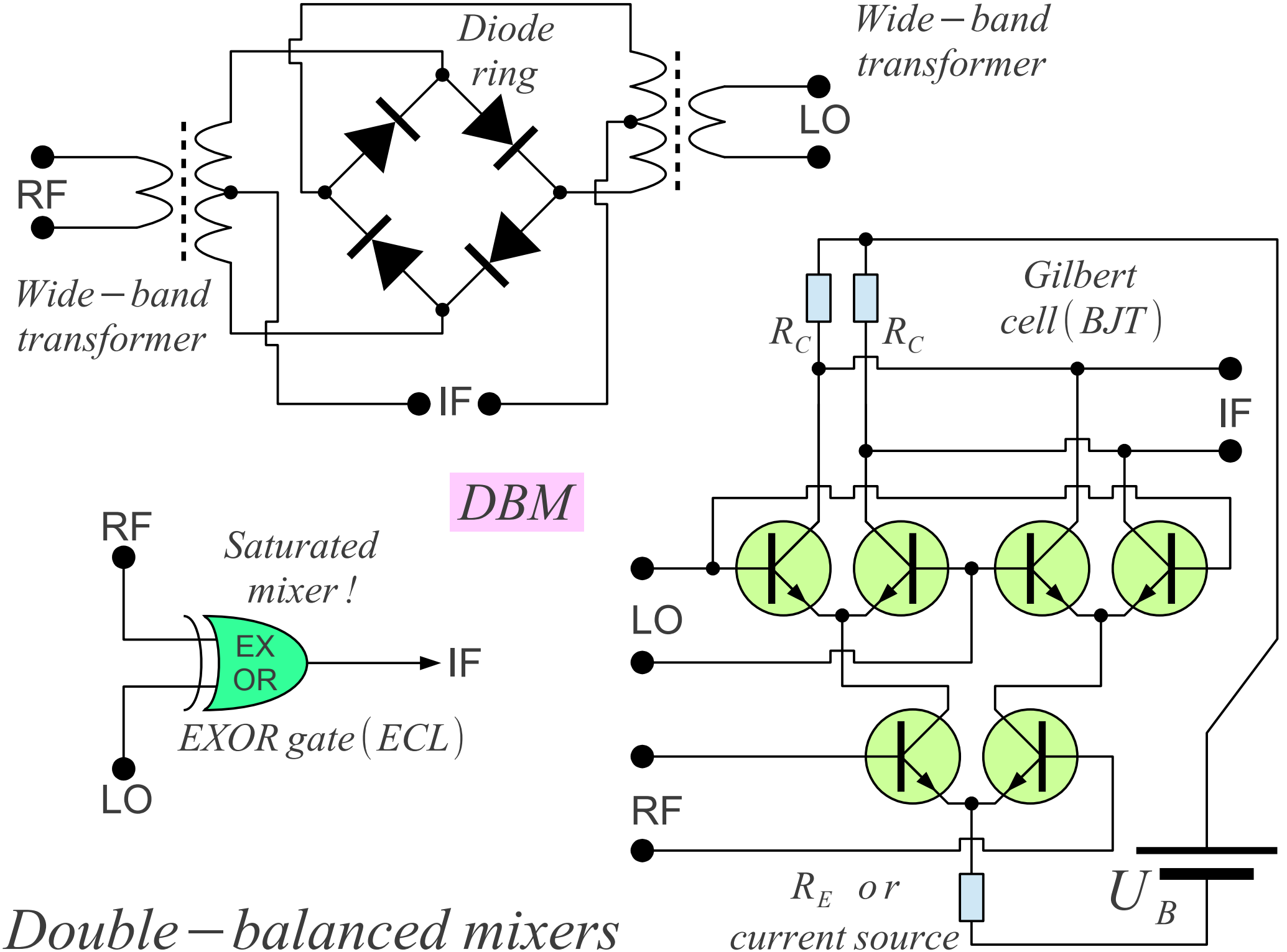


$$i = I_S\left(e^{\frac{u|Q_e|}{n k_B T}} - 1\right) =$$
$$= \alpha_0 + \alpha_1 \cdot u + \alpha_2 \cdot u^2 +$$
$$+ \alpha_3 \cdot u^3 + \alpha_4 \cdot u^4 + \alpha_5 \cdot u^5 +$$
$$+ \alpha_6 \cdot u^6 + \alpha_7 \cdot u^7 + \ldots$$

Term	$u(t)=A_{RF}\cos(\omega_{RF}t)+A_{LO}\cos(\omega_{LO}t)$
α_0	$=$
α_1	ω_{RF},ω_{LO}
α_2	$=,2\omega_{RF},2\omega_{LO},\omega_{RF}+\omega_{LO},\omega_{LO}-\omega_{RF}$
α_3	$\omega_{RF},\omega_{LO},3\omega_{RF},3\omega_{LO},2\omega_{RF}+\omega_{LO},$ $2\omega_{RF}-\omega_{LO},\omega_{RF}+2\omega_{LO},2\omega_{LO}-\omega_{RF}$
α_4	$=,2\omega_{RF},2\omega_{LO},\omega_{RF}+\omega_{LO},\omega_{LO}-\omega_{RF},$ $4\omega_{RF},4\omega_{LO},3\omega_{RF}+\omega_{LO},$ $2\omega_{RF}+2\omega_{LO},\omega_{RF}+3\omega_{LO},3\omega_{RF}-\omega_{LO},$ $2\omega_{LO}-2\omega_{RF},3\omega_{LO}-\omega_{RF}$
α_5	$\ldots 5\omega_{RF},5\omega_{LO}\ldots$

Single – diode mixer


Balanced mixer
Diode pair
RF
LO
IF
ω_{LO}
ω_{IF}
Wide – band transformer
JFET HEMT
ω_{RF}
Differential BJT
U_B
Single – balanced mixers



Double – balanced mixers

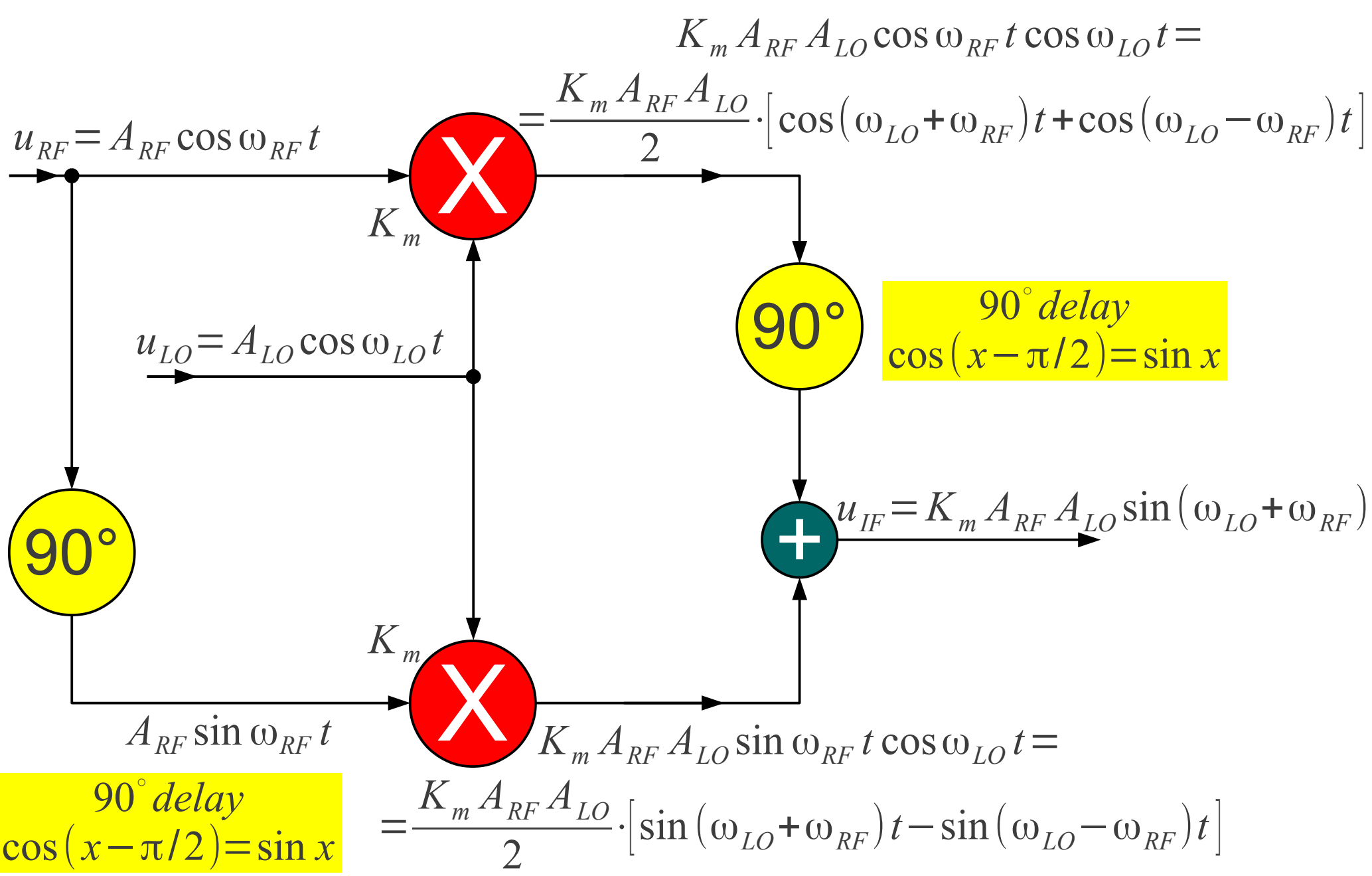


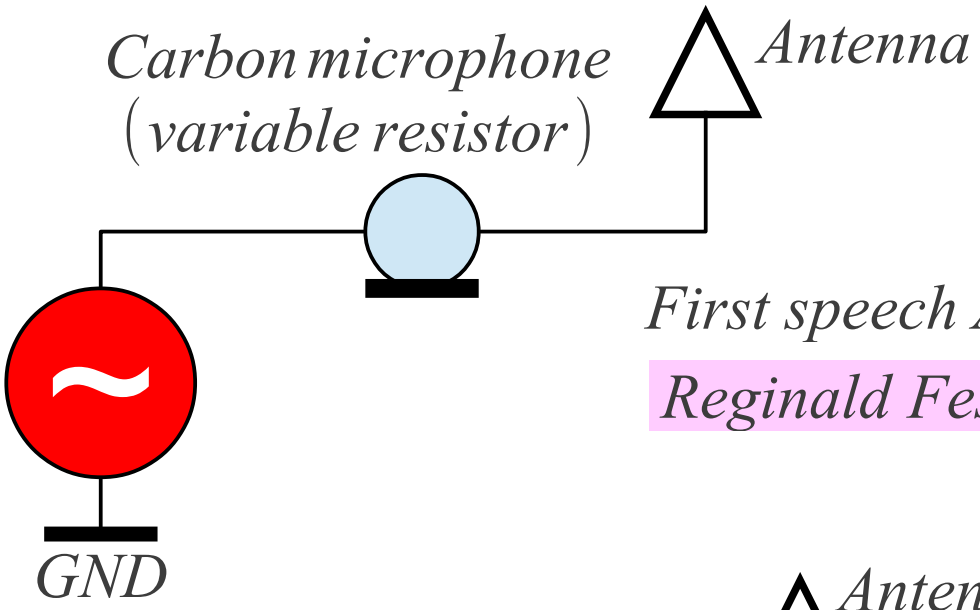
Image – reject mixer

Ernst Alexanderson 1904

Electro – mechanical generator $f \approx 50\text{kHz}$

Nikola Tesla 1891
$f \approx 15\text{kHz}$

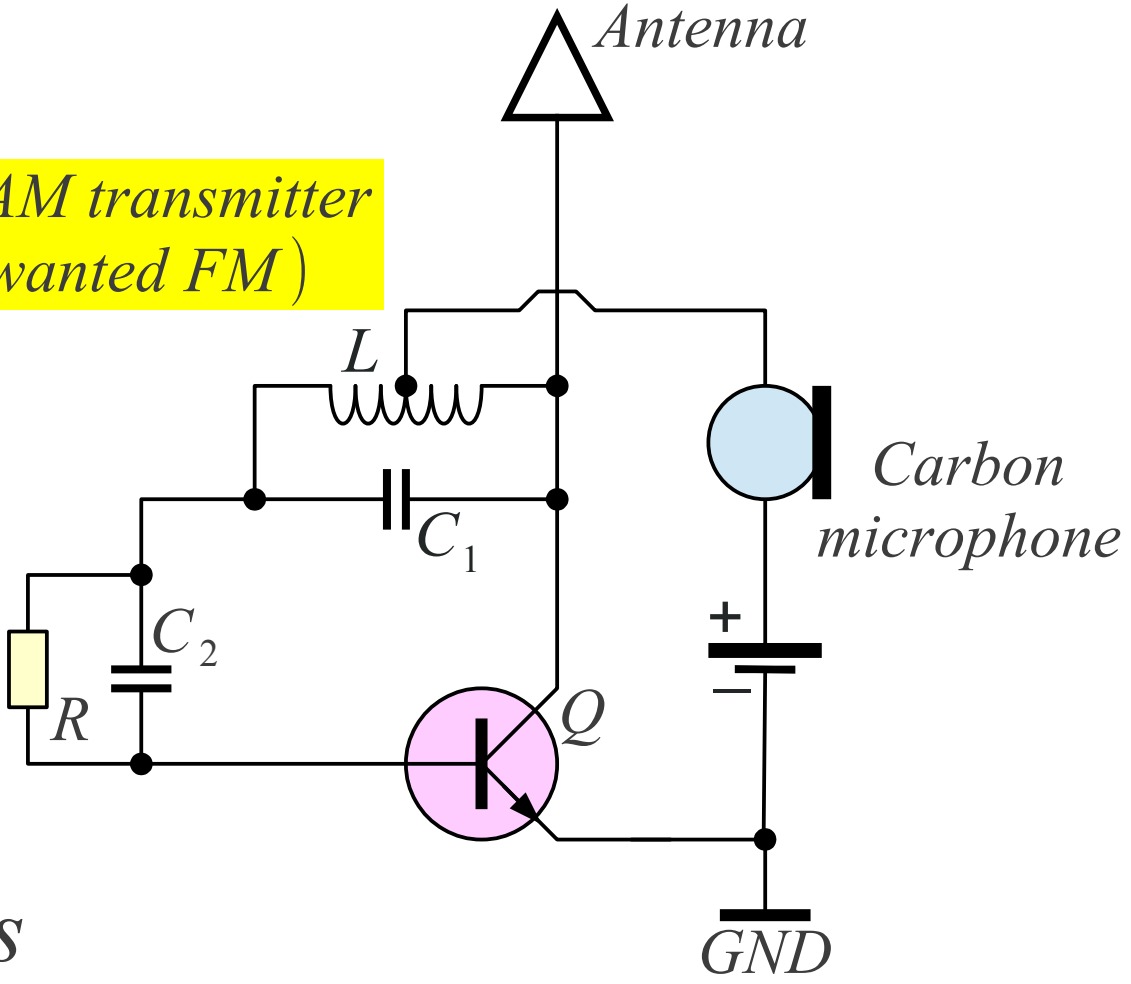
Electro – mechanical RF generator design survives today as stepper motors !



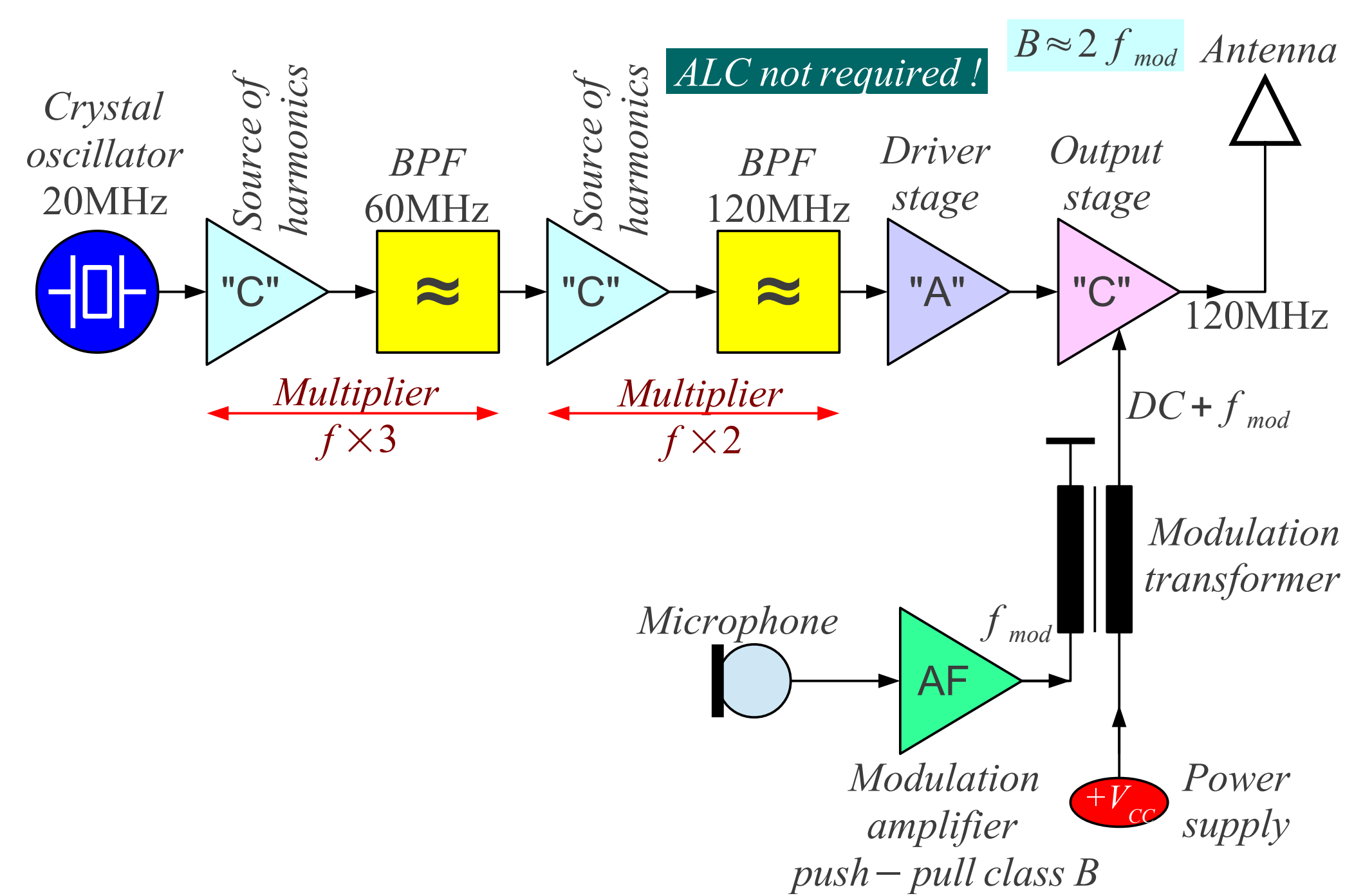
First speech AM transmitter

Reginald Fessenden 1906

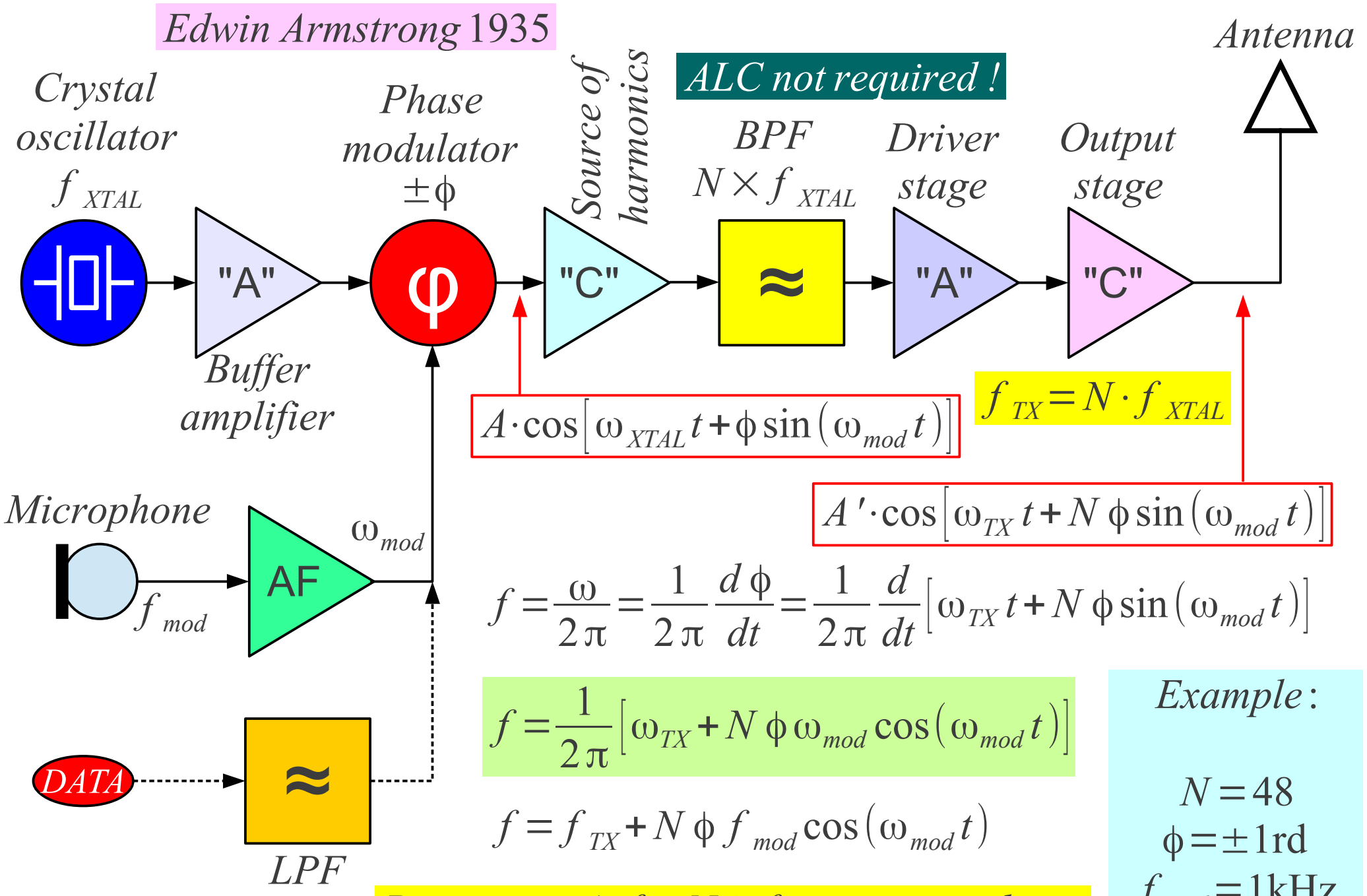
Simple AM transmitter (+unwanted FM)

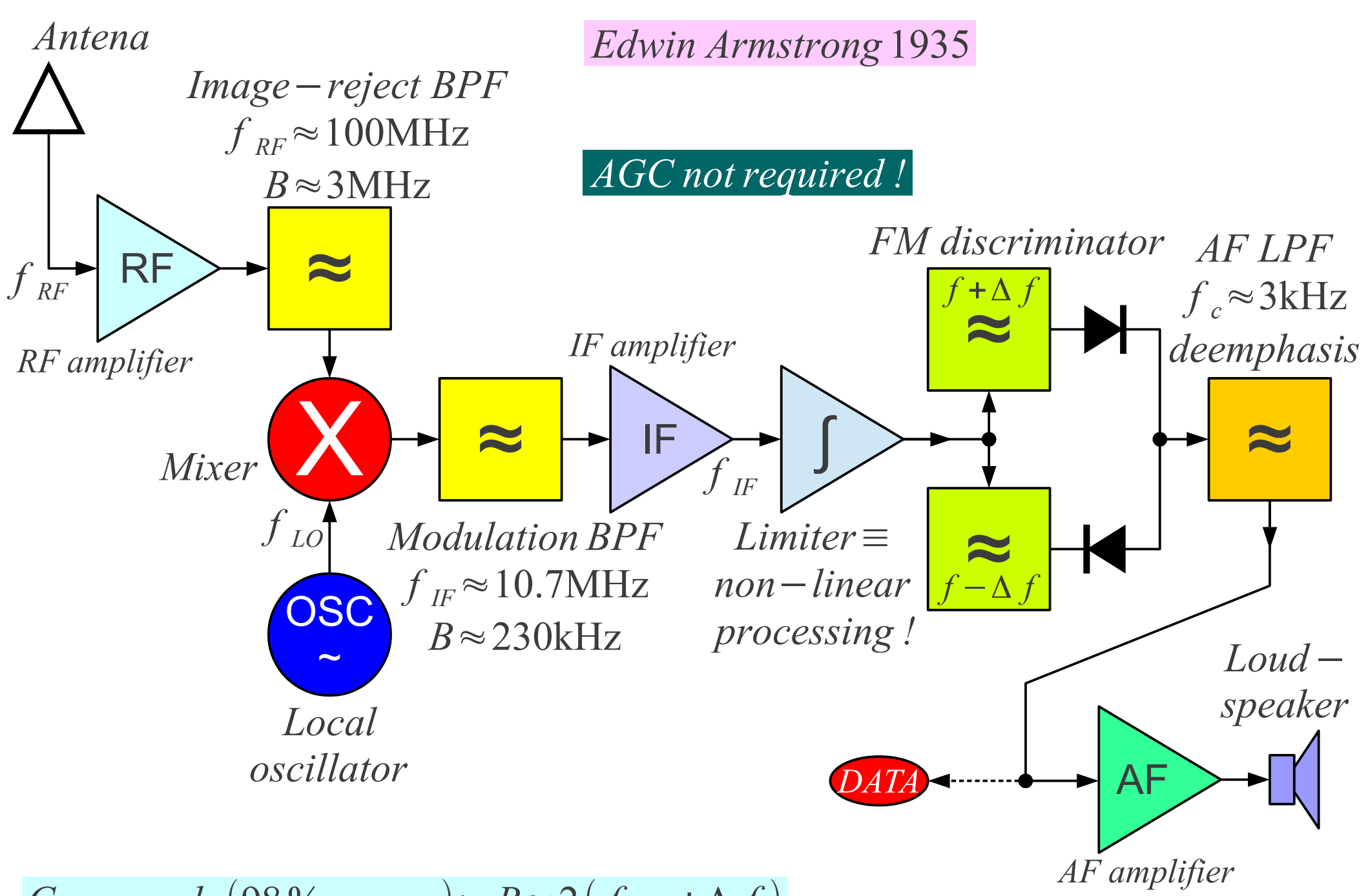


AM (speech) transmitters



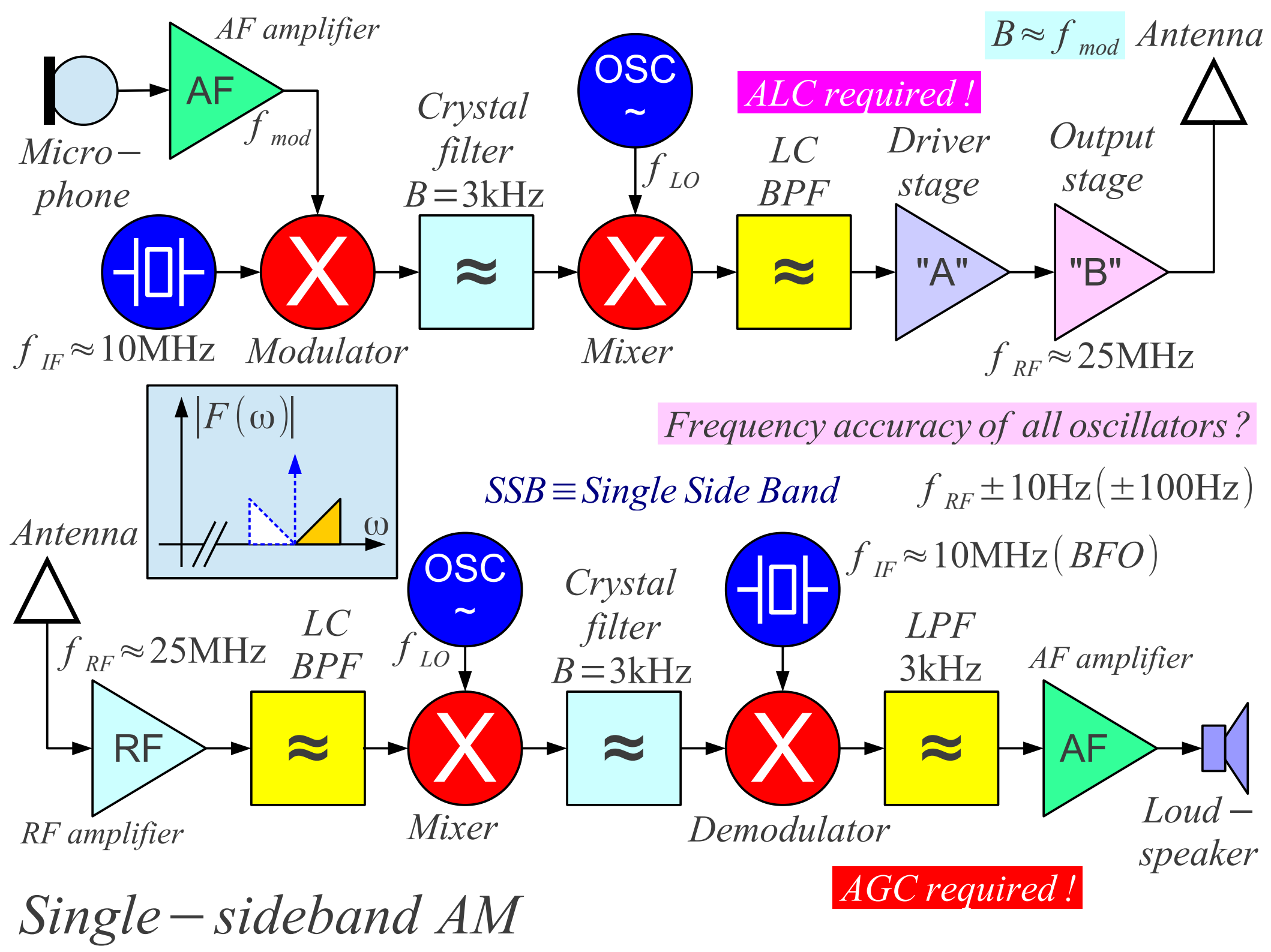
AM transmitter with output modulation

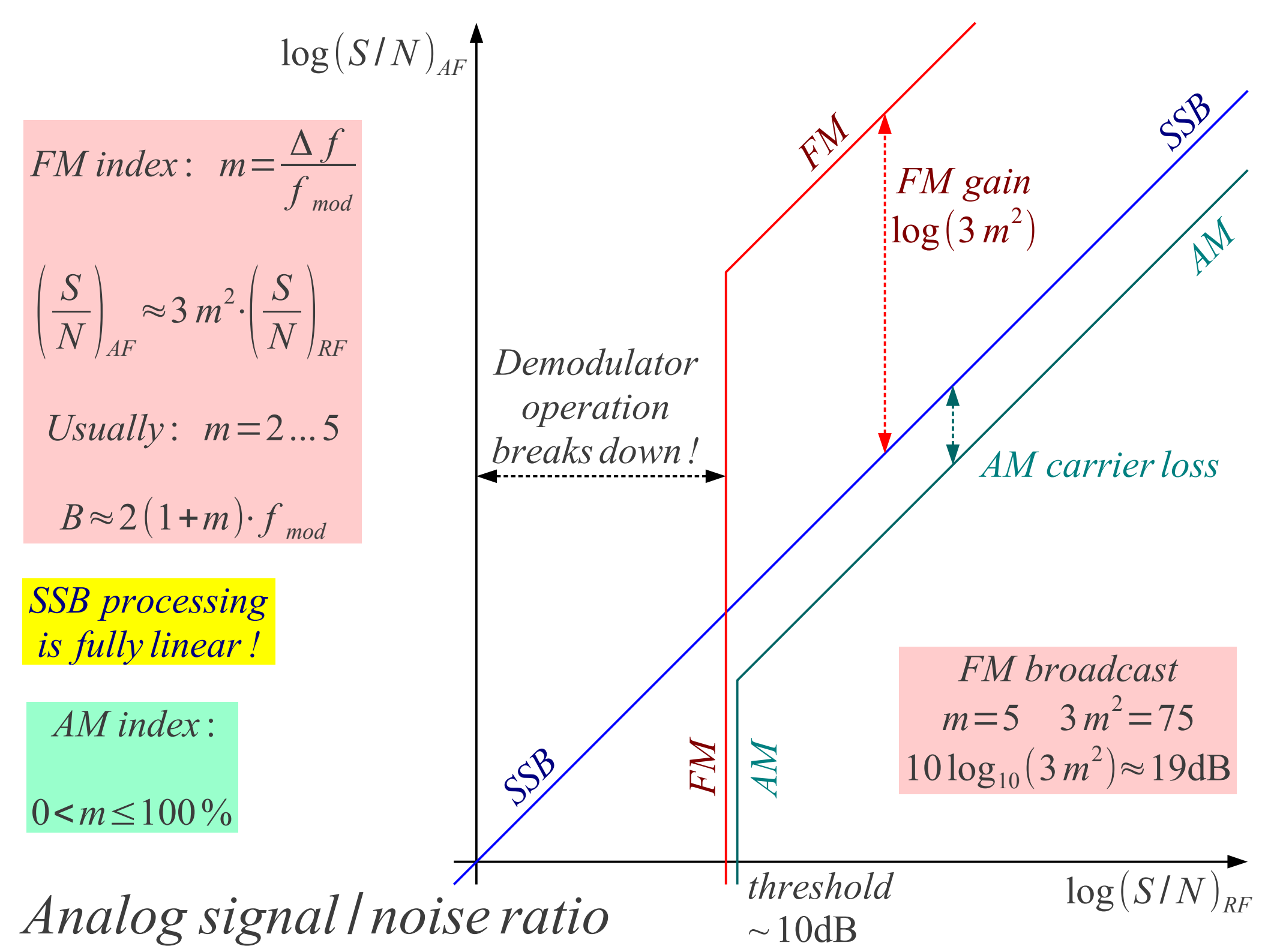

Edwin Armstrong 1935
Antenna
Crystal oscillator
f_{XTAL}
Phase modulator
$\pm\phi$
Source of harmonics
ALC not required !
BPF
$N \times f_{XTAL}$
Driver stage
Output stage
"A"
"C"
Buffer amplifier
$A \cdot \cos\left[\omega_{XTAL} t + \phi \sin(\omega_{mod} t)\right]$
$f_{TX} = N \cdot f_{XTAL}$
$A' \cdot \cos\left[\omega_{TX} t + N\,\phi \sin(\omega_{mod} t)\right]$
Microphone
f_{mod}
AF
ω_{mod}
$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\frac{d\phi}{dt} = \frac{1}{2\pi}\frac{d}{dt}\left[\omega_{TX} t + N\,\phi \sin(\omega_{mod} t)\right]$
DATA
LPF
$f = \frac{1}{2\pi}\left[\omega_{TX} + N\,\phi\,\omega_{mod} \cos(\omega_{mod} t)\right]$
$f = f_{TX} + N\,\phi\, f_{mod} \cos(\omega_{mod} t)$
Example:
$N = 48$
$\phi = \pm 1\text{rd}$
$f_{mod} = 1\text{kHz}$
$\Delta f = \pm 48\text{kHz}$
$\text{Deviation} \equiv \Delta f = N\,\phi\, f_{mod} \equiv \text{preemphasis}$
Frequency (phase) – modulated transmitter



$Carson\,rule\,(98\,\%\,power):\quad B \approx 2\left(f_{mod} + \Delta f\right)$

Heterodyne FM receiver


AF amplifier
AF
f_{mod}
Micro–
phone
$B \approx f_{mod}$
Antenna
ALC required !
OSC
~
Crystal
filter
$B = 3\text{kHz}$
f_{LO}
LC
BPF
Driver
stage
Output
stage
"A"
"B"
$f_{IF} \approx 10\text{MHz}$
Modulator
Mixer
$f_{RF} \approx 25\text{MHz}$
$|F(\omega)|$
ω
Frequency accuracy of all oscillators ?
SSB ≡ Single Side Band
$f_{RF} \pm 10\text{Hz} (\pm 100\text{Hz})$
Antenna
OSC
~
$f_{IF} \approx 10\text{MHz}$ (BFO)
$f_{RF} \approx 25\text{MHz}$
LC
BPF
f_{LO}
Crystal
filter
$B = 3\text{kHz}$
LPF
3kHz
AF amplifier
RF
AF
RF amplifier
Mixer
Demodulator
Loud –
speaker
AGC required !
Single – sideband AM



$$FM\ index: \quad m = \frac{\Delta f}{f_{mod}}$$

$$\left(\frac{S}{N}\right)_{AF} \approx 3\,m^2 \cdot \left(\frac{S}{N}\right)_{RF}$$

$$Usually: \quad m = 2 \ldots 5$$

$$B \approx 2(1+m) \cdot f_{mod}$$

SSB processing is fully linear !

AM index:

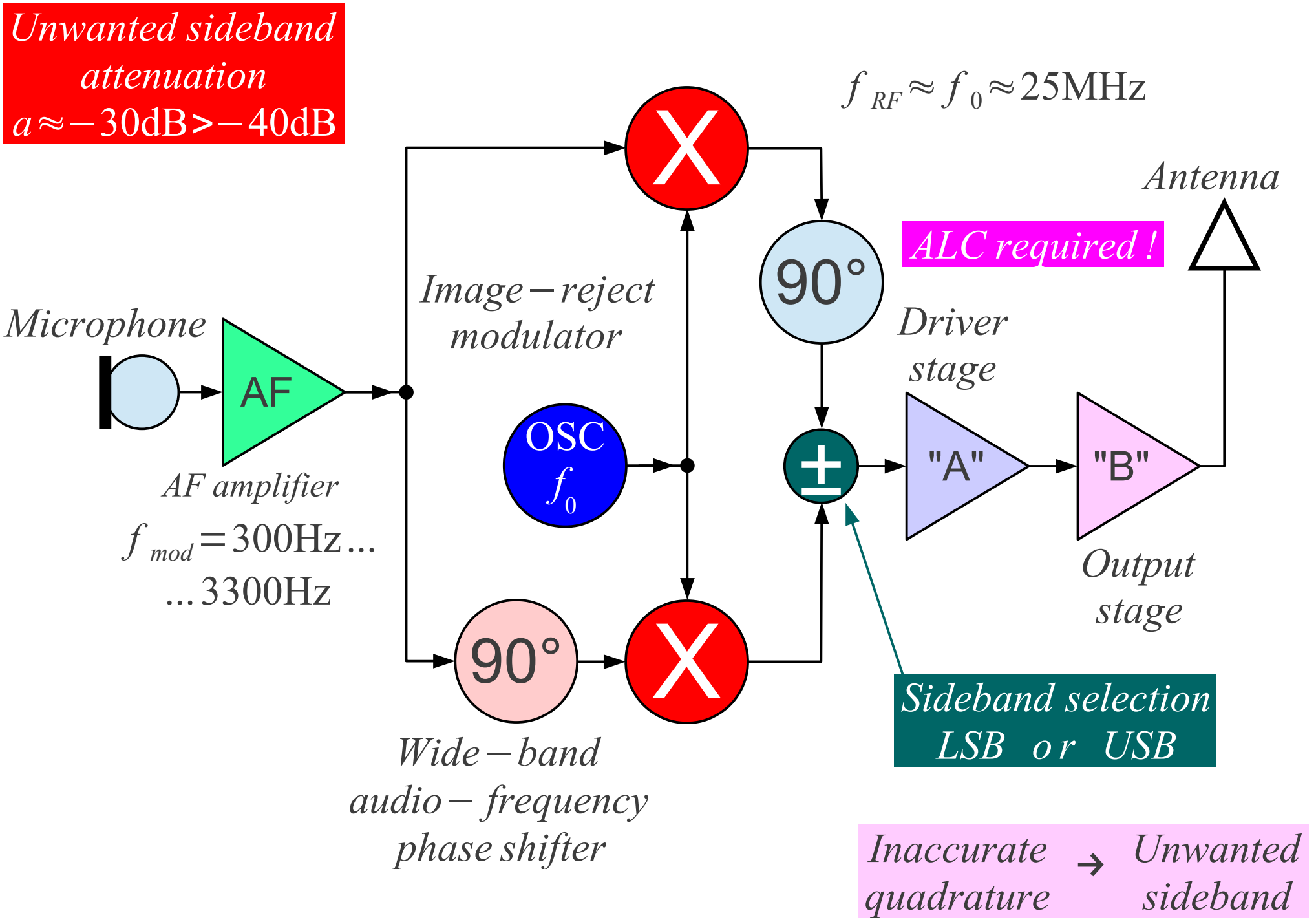
$$0 < m \leq 100\,\%$$

FM broadcast

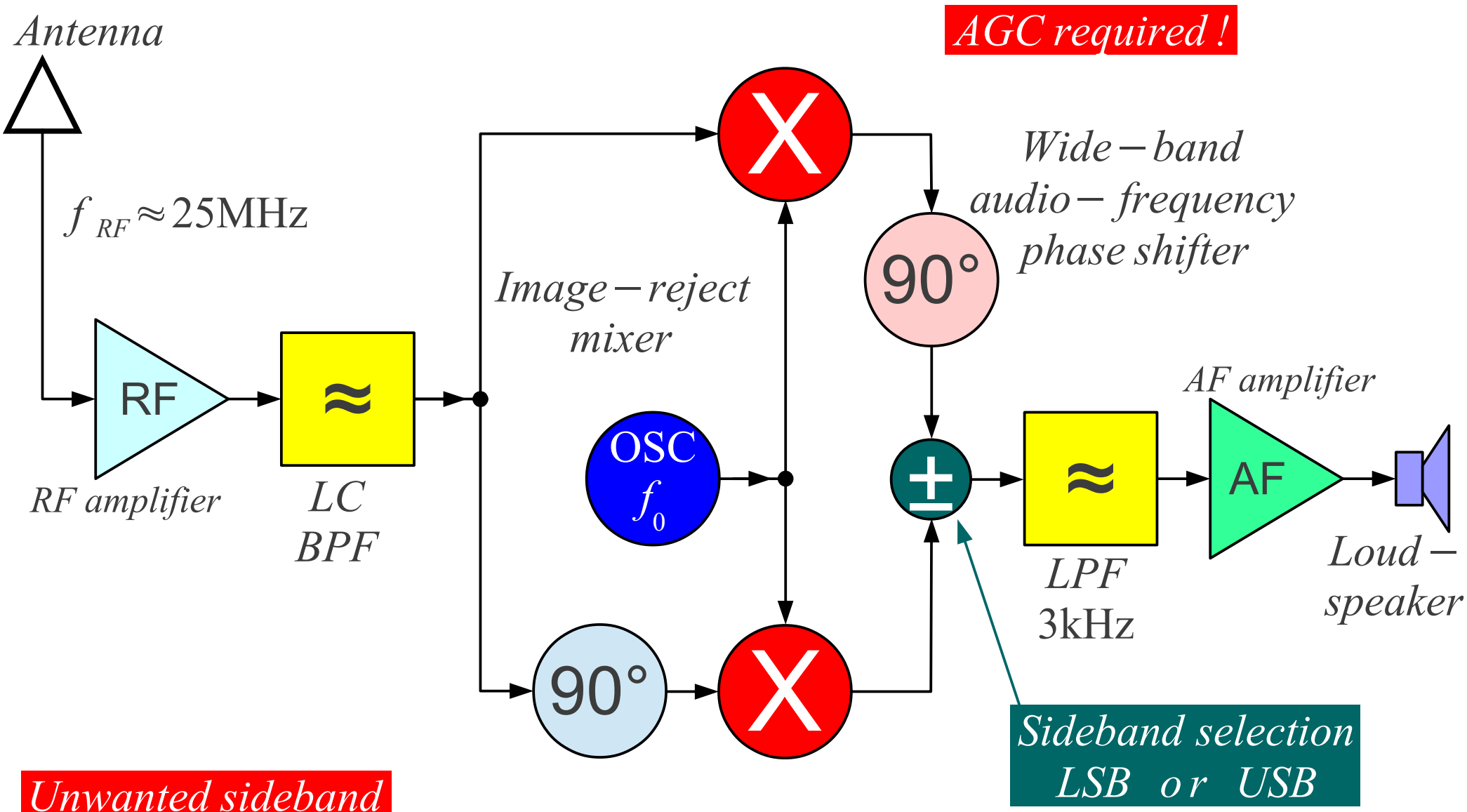
$$m = 5 \quad 3\,m^2 = 75$$

$$10 \log_{10}(3\,m^2) \approx 19\text{dB}$$

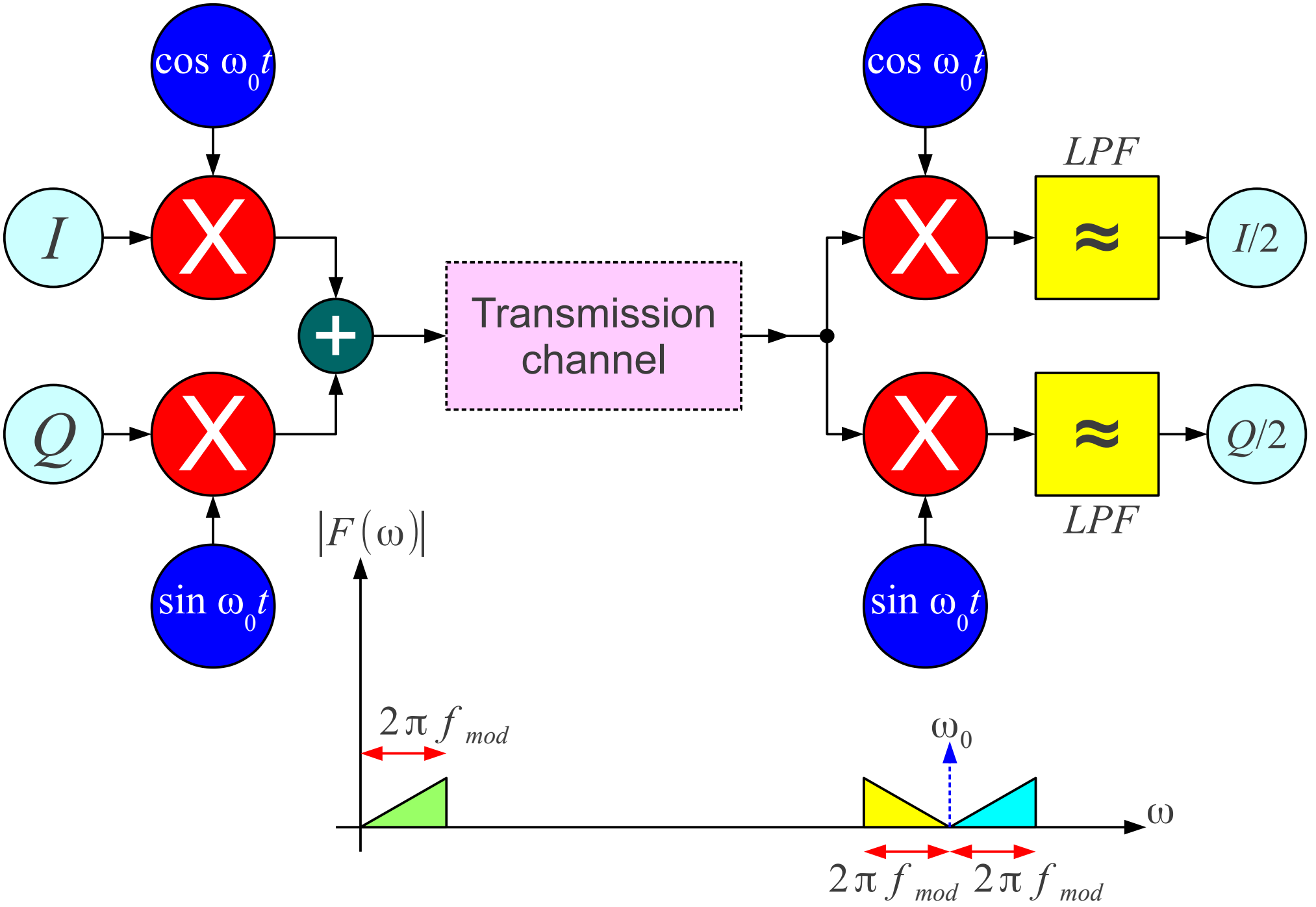
Analog signal / noise ratio



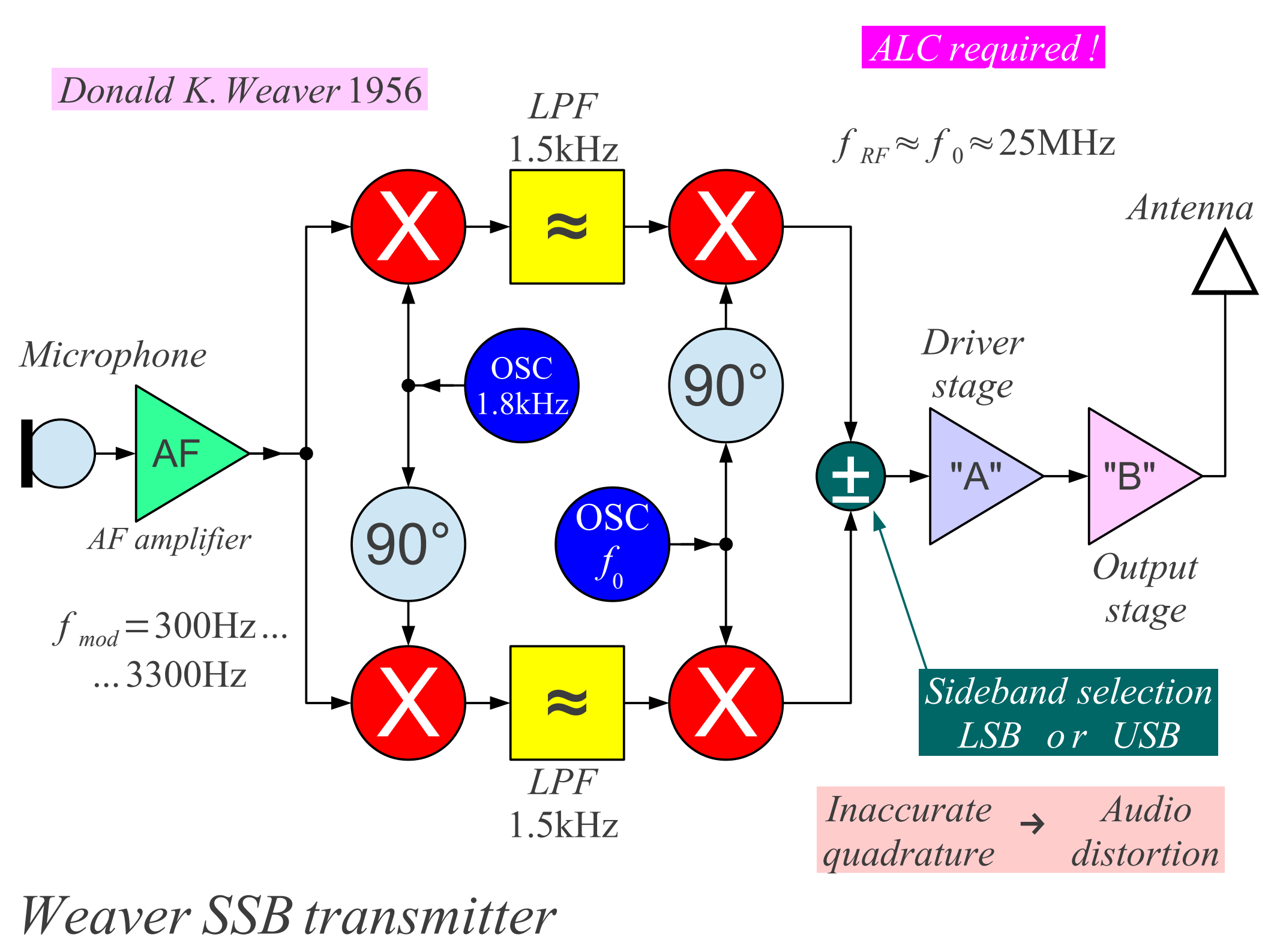
SSB transmitter with image rejection



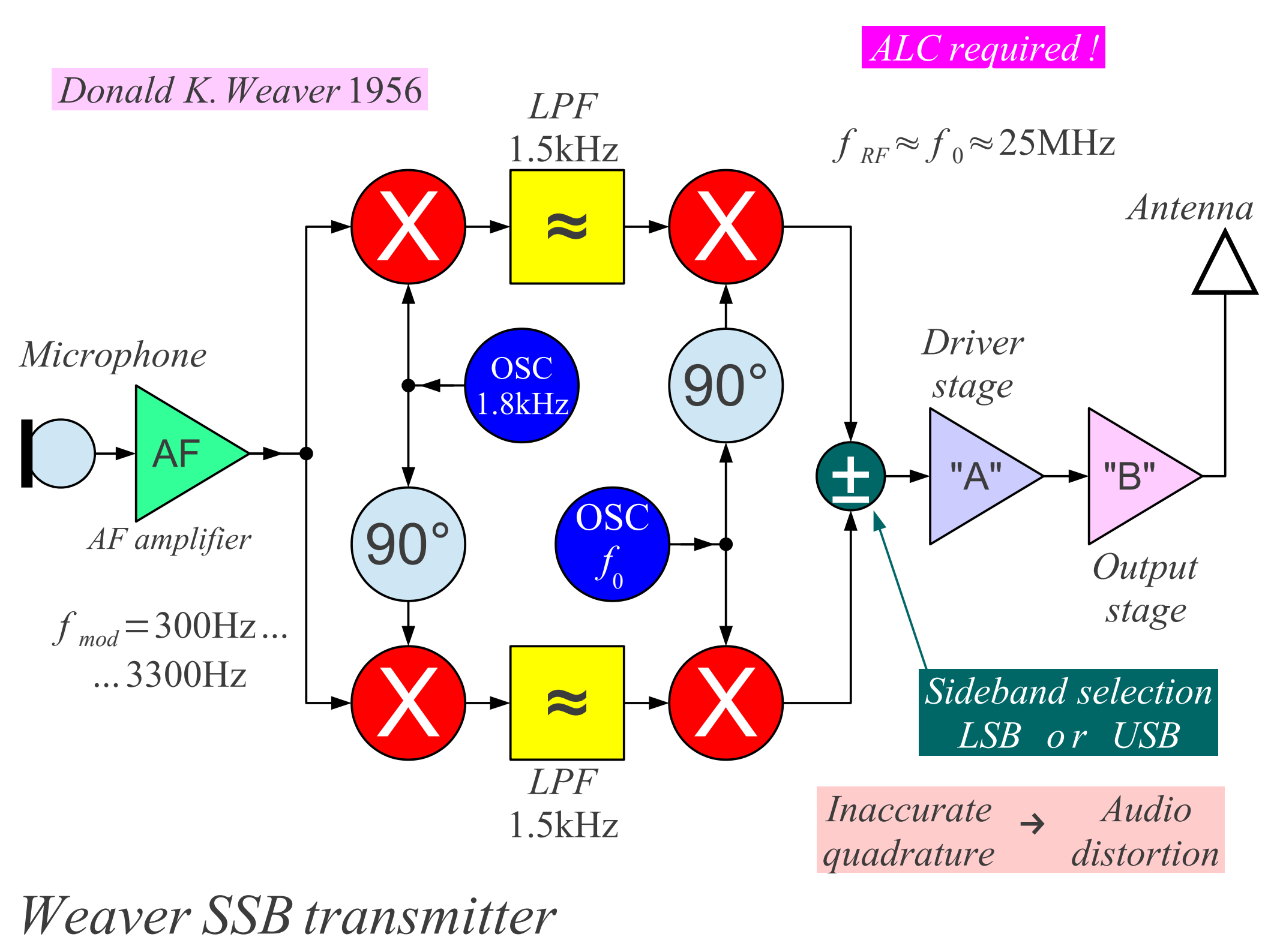
SSB receiver with image rejection



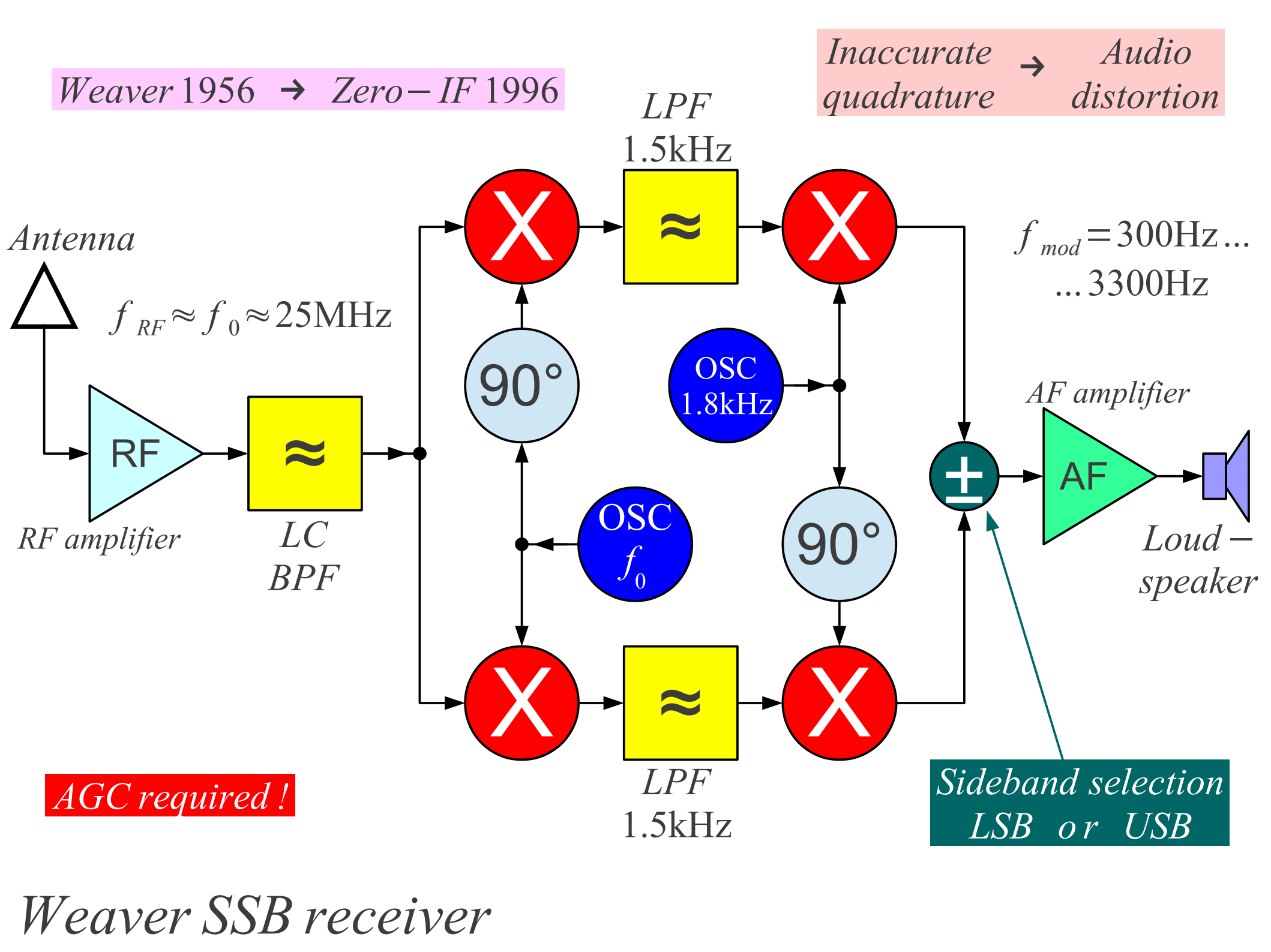
Quadrature amplitude modulation (QAM)



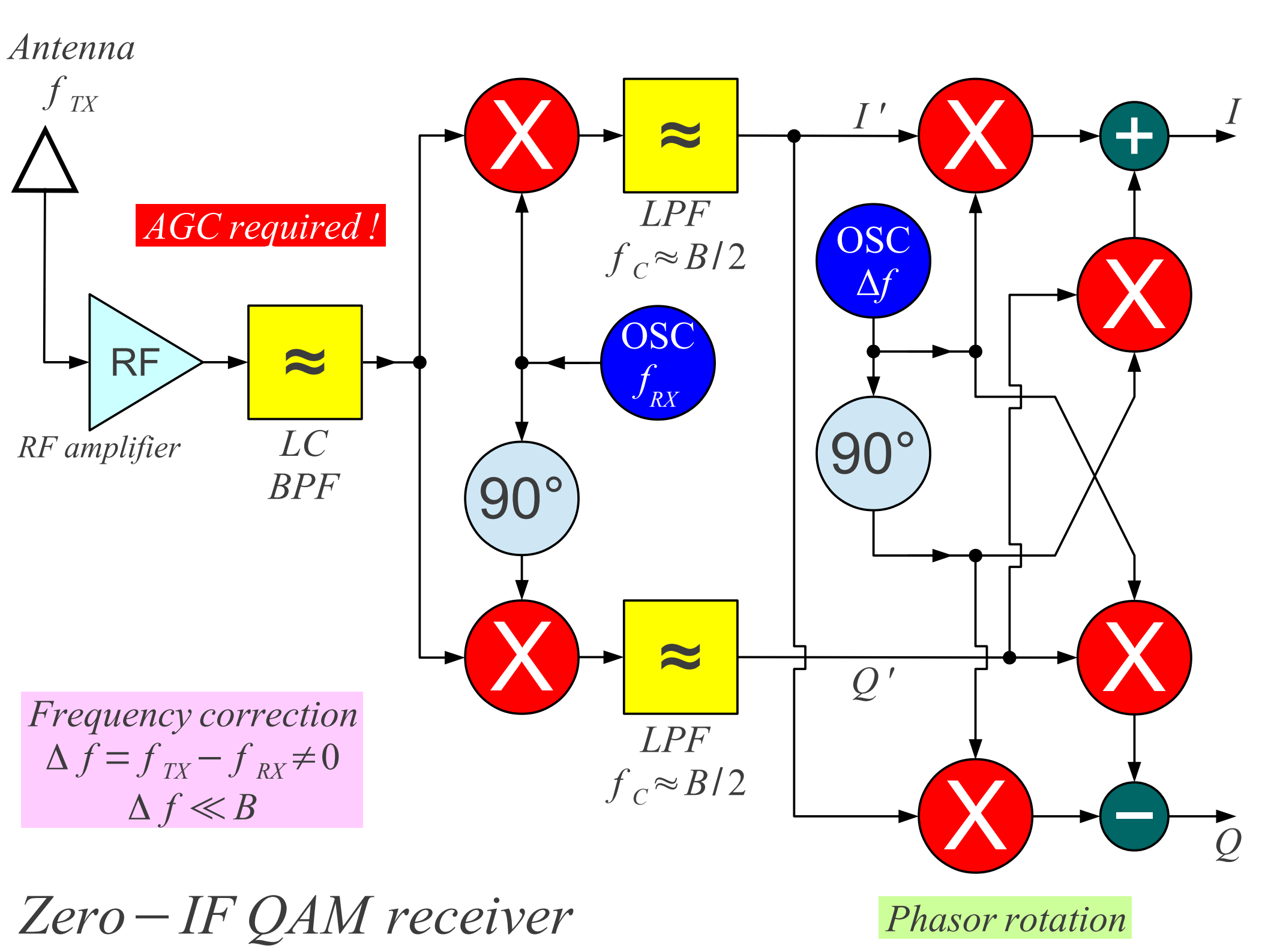
Weaver SSB transmitter

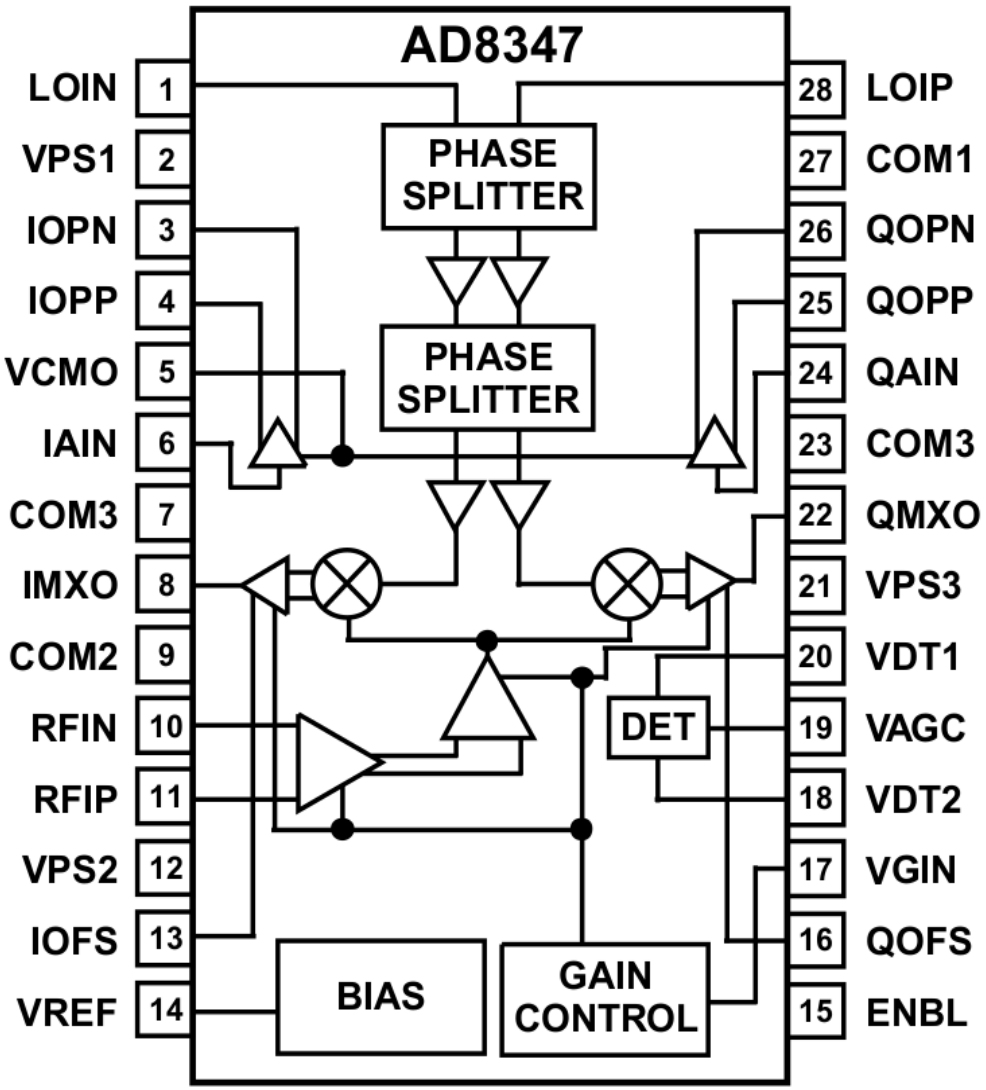


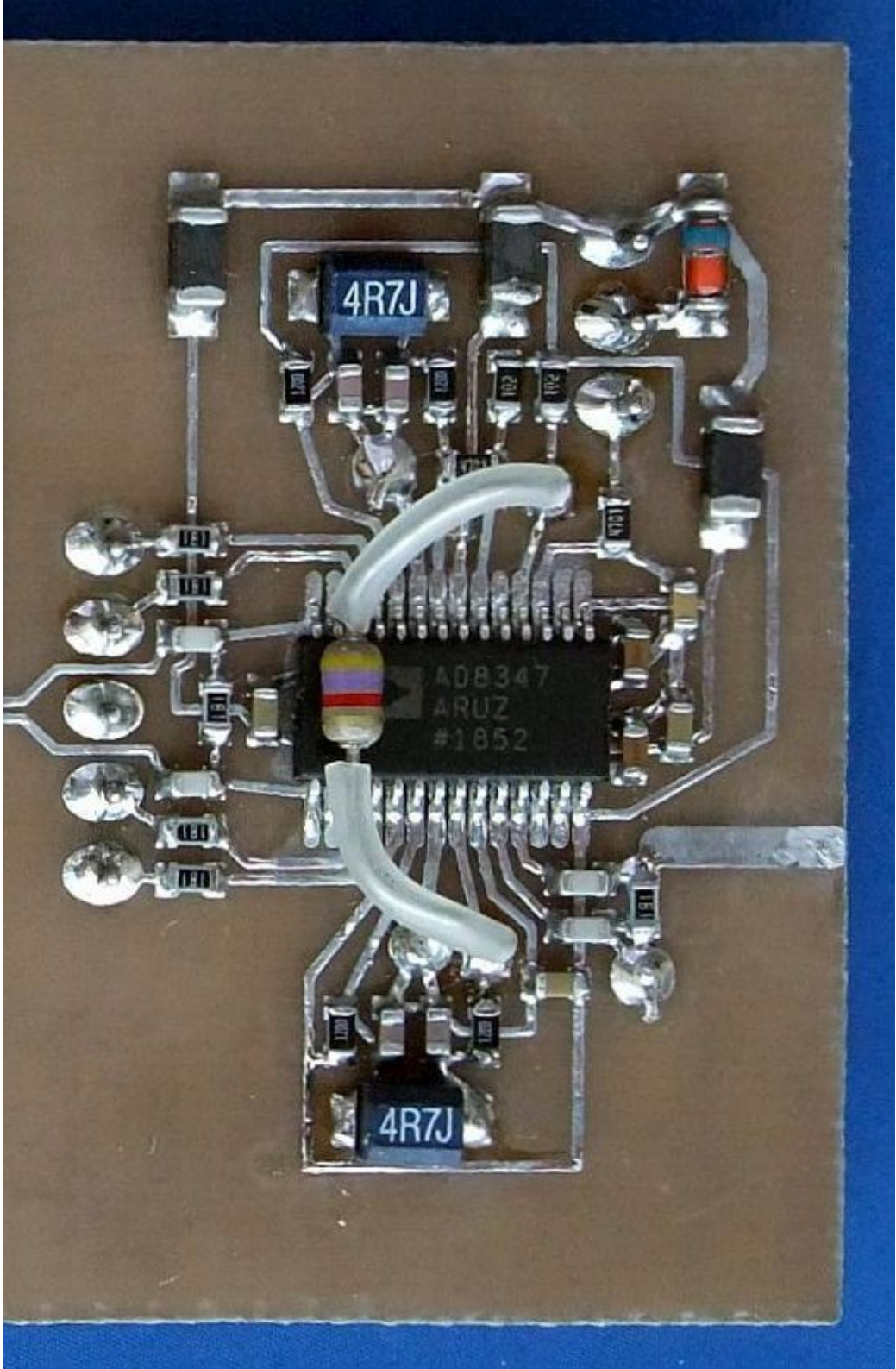
Weaver SSB transmitter



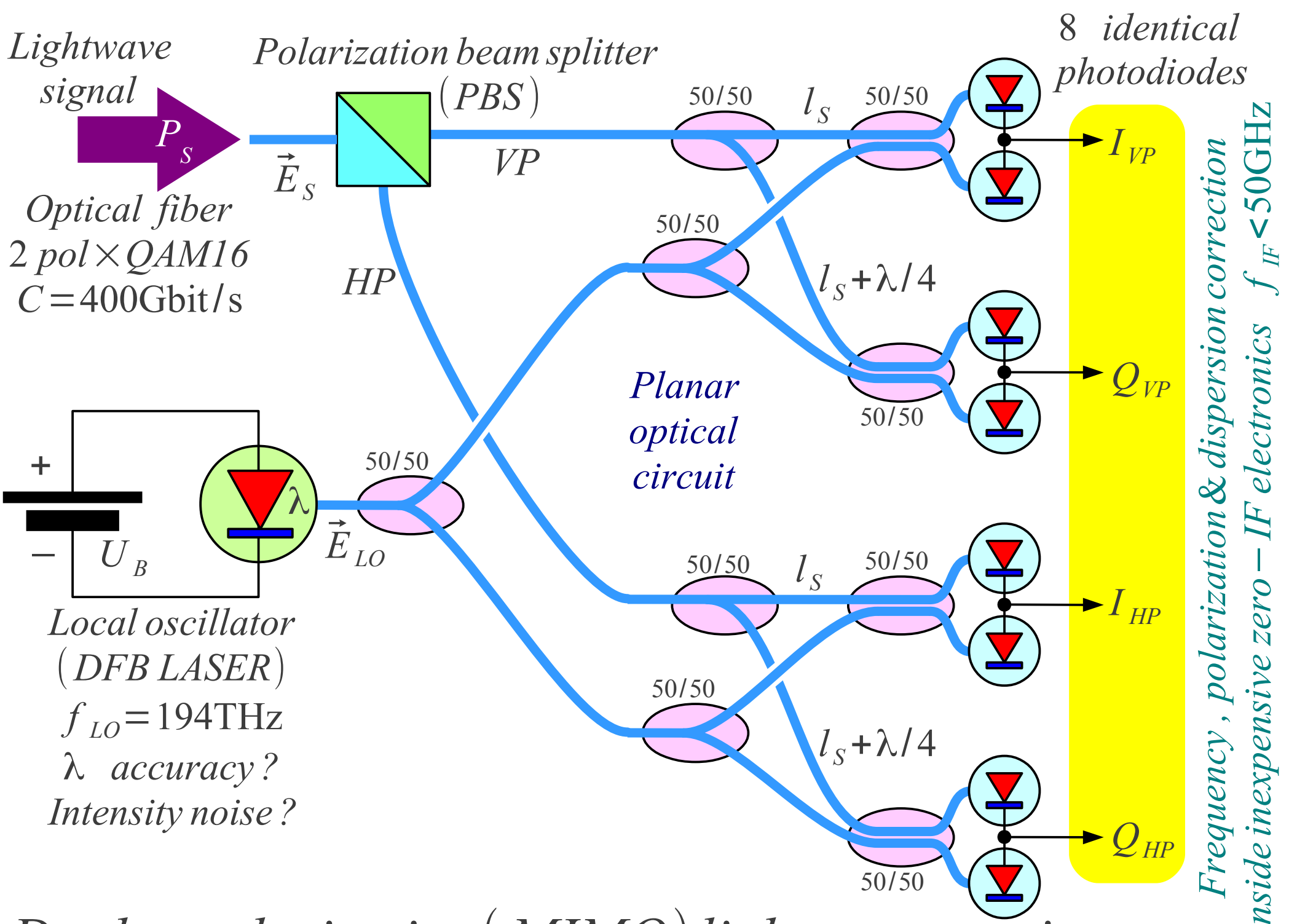
Weaver SSB receiver


Antenna
f_{TX}
AGC required !
RF
RF amplifier
LC
BPF
OSC
f_{RX}
90°
LPF
$f_C \approx B/2$
I'
OSC
Δf
90°
I
Q'
LPF
$f_C \approx B/2$
Q
Frequency correction
$\Delta f = f_{TX} - f_{RX} \neq 0$
$\Delta f \ll B$
Zero – IF QAM receiver
Phasor rotation





Zero – IF receiver AD8347


Lightwave signal
P_S
Optical fiber
2 pol × QAM16
C = 400Gbit/s
Polarization beam splitter (PBS)
$\vec{E}_S$
VP
HP
50/50
l_S
$l_S + \lambda/4$
Planar optical circuit
8 identical photodiodes
I_{VP}
Q_{VP}
I_{HP}
Q_{HP}
+
−
U_B
λ
$\vec{E}_{LO}$
Local oscillator (DFB LASER)
f_{LO} = 194THz
λ accuracy ?
Intensity noise ?
Frequency, polarization & dispersion correction inside inexpensive zero − IF electronics f_{IF} < 50GHz
Dual − polarization (MIMO) lightwave receiver