RF Amplifier Engineering Terms
射频放大器工程技术术语

## Gain 增益

Normaly expressed in decibels, dB

Power Gain (dB) = 10 Log $_{10}$ (RF Output Power / RF Input Power)

Gain is defined as the ratio of the output power to the input power in dB. Assume that the input power is 10 mW (+10 dBm) and the output power is 1 W (1000 mW, +30 dBm). The ratio will be 1000/10 = 100, and the gain will be 10 * log 100 = 20 dB.

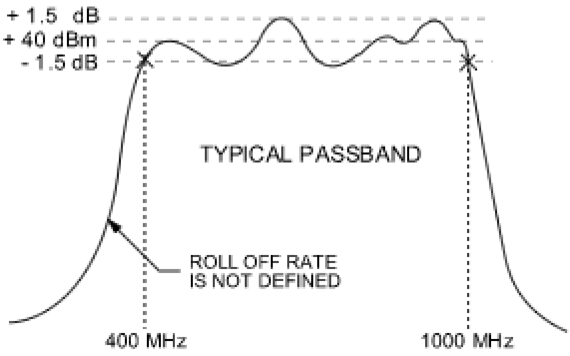
It is much easier to calculate gain by converting the power to dBm first, so the gain of the above amplifier will be 30-10 = 20 dB. A simple reduction will reveal the gain. In tradition, all power is read in dBm and the gain is in dB.

| **Frequently Used Decibel Conversions** | |
|---|---|
| **dB** | **Power Ratio** |
| O | 1 |
| 1 (-1) | 1.26 (0.8) |
| 3 (-3) | 2 (1/2) |
| 6 (-6) | 4 (1/4) |
| 10 (-10) | 10 (0.1) |
| 13 | 20 |
| 17 | 50 |
| 20 | 100 |
| 30 | 1000 |

## Passband Frequency Range Gain Flatness 带内增益平坦度

Normally defined as the ± 1.5 dB passband range. Refer to the appropriate technical data sheet for the specified value.

Small signal gain is measured 10 dB below the 1 dB compression point on Class A amplifiers and traditionally at the rated output power on Class AB and Class C amplifiers.




## RF Power and 1dB Compression Point 射频功率和 1dB 压缩点

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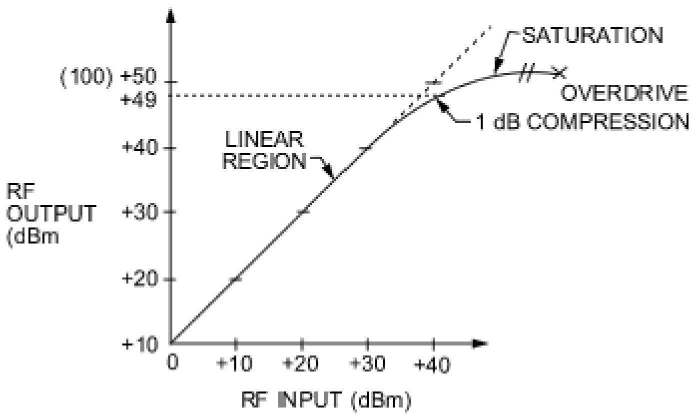
Normally expressed in watts or dBm (decibels over/below 1 milliwatt)




| Frequently Used Powerlevel Conversions | | | |
|---|---|---|---|
| **Level (watts)** | **Level (conventional)** | **Level (dBm)** | **Level (dBw)** |
| 1 x | | | |
| $10^{-12}$ | | | |
| 1 x | 1 picowatt | -90 | -120 |
| $10^{-9}$ | 1 nanowatt | -60 | -90 |
| 1 x | 1 microwatt | -30 | -60 |
| $10^{-6}$ | 1 milliwatt | 0 | -30 |
| 1 x | 0.1 watts | +20 | -10 |
| $10^{-3}$ | 1 watt | +30 | 0 |
| 0.1 | 10 watts | +40 | +10 |
| 1 | 100 watts | +50 | +20 |
| 10 | 1 kilowatt | +60 | +30 |
| 100 | | | |
| 1000 | | | |

## Peak Envelope Power 峰包功率

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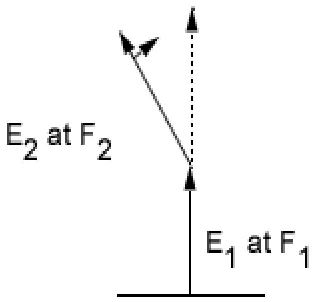



Phasor Representation

Voltage Maximum

**Example:**

$F_1$ = 10 MHz

$F_2$ = 10.1 MHz

$E_1 = E_2$ = IV

RL = 1 Ohm

**S I N G L E  C A R R I E R  C A S E  ( $F_1$ o n l y )**

$P = E^2 / R = (1)^2 / 1 = 1$ Watt CW or PEP

**T W O  C A R R I E R  C A S E  ( $F_1$ & $F_2$ )**

The voltage phasors, $E_1$ & $E_2$ are at a maximum every 10 microseconds since:

Coincidence Rate = $1 / (F_2 - F_1) = 1 / ((10.1 - 10) *10^6) = 10$ Microseconds

At coincidence $E_1$ & $E_2$ add directly, therefore:

$P = E_2 / R = (1+1)_2 / 1 = 4$ Watts PEP

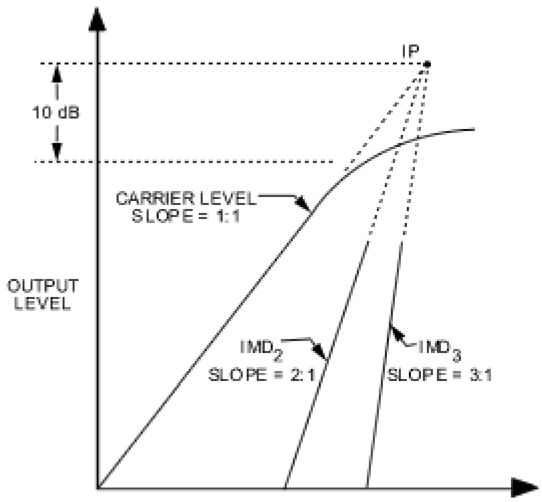
**N  C A R R I E R  C A S E  ($F_1 + F_2 \ldots +F_n$)**

$P = E_2 / R = N_2 / 1 = N_2$ Watts PEP

| NUMBERS OF CARRIERS | POWER IN EACH CARRIER FOR 7 W PEP OUTPUT | PEP OUTPUT POWER FOR N 1 W CARRIERS |
|---|---|---|
| **N** | **$P = 1 / N^2$ Watts** | **$P = N^2$ Watts** |
| 1 | 1 W | 1 W |
| 2 | 250 mW | 4 W |
| 3 | 111 mW | 9 W |
| 4 | 63 mW | 16 W |
| 10 | 10 mW | 100 W |

## Intercept Point 截点

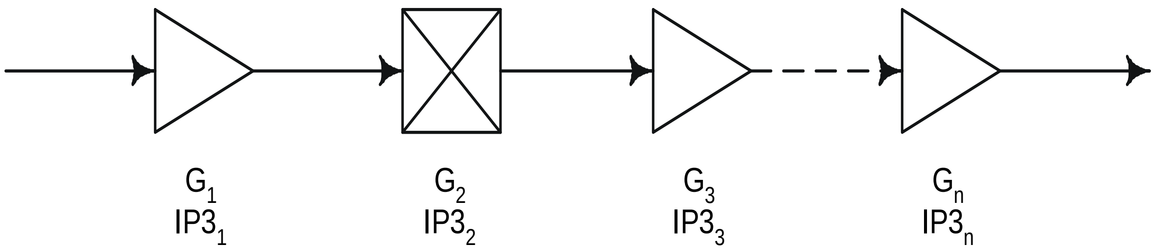
The intercept point (IP) is an imaginary point where the slopes of the fundamental, 2nd order IMD and 3rd order IMD meet.




**Rules of thumb:**

1. IP is 10 dB above 1 dB compression point.
2. IP is defined for Class A amplifiers only.

## Cascaded 3rd-order Intercept Point 级联三阶截点计算




Input intercept point for a number of cascaded stages is given by:

$$\mathrm{IP3_{tot}} = \frac{1}{\frac{1}{\mathrm{IP3_1}} + \frac{G_1}{\mathrm{IP3_2}} + \frac{G_1 G_2}{\mathrm{IP3_3}} + \cdots + \frac{G_1 G_2 \cdots G_n}{\mathrm{IP3_n}}}$$

$$G_n = 10^{G_{n.dB}/10}$$

$$\mathrm{IP3_n} = 10^{IP3_{n.dB}/10}$$

## Intermodulation Distortion 交调失真

**Second Order (IMD2) Frequencies (2 tones)**

$F_{IMD2} = F_1 + F_2$ & $F_2 - F_1$

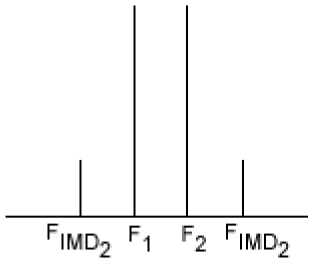
**Example:**

$F_1$ = 5 MHz

$F_2$ = 8 MHz

$F_{IMD2} = F_1 + F_2$ = 8 + 5 = 13 MHz and

$F_2 - F_1$ = 8 - 5 = 3 MHz




Second order IMD is out of band for HPA's with a bandwidth less than one octave.

**Third Order (IMD3) Frequencies (2 tones)**

$F_{IMD3} = 2F_1 - F_2$ & $2F_2 - F_1$

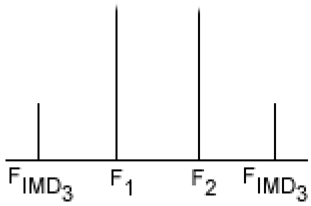
**Example:**

$F_1$ = 7 MHz

$F_2$ = 8 MHz

$F_{IMD3} = 2F_1 - F_2$ = 2(7) - 8 = 14 - 8 = 6 MHz and

$2F_2 - F_1$ = 2(8) - 7 = 16 - 7 = 9 MHz




## ACPR 邻道泄漏功率比

ACPR is used in many mobile radio/cellular standards. E.g. W-CDMA。

Take care, as some standards use different bandwidths for the wanted power and IM power measurements!

## Noise Figure & Level 噪声系数和电平

**Noise figure** is defined as:

NF =(So/No) /(Si/Ni)

## Background

N = Noise Power = kTB

Where K = Boltzman's Constant = 1.38 $*10^{-23}$ Joules/Kelvin

T = Absolute Temperature, K(0°C = 273K)

B = 3 dB Noise Bandwidth, Hz

**Example:** What is the noise level, in dBm, of a resistor (black body) at 17°C (room temperature) over a 1 MHz bandwidth?

N = kTB = $(1.38 * 10^{-23}) * (273 + 17) * (1 * 10^{6}) = 1.37 * 10^{-17} * 290 = 4.0 * 10^{-15}$ Joules/Second

Or = $4 * 10^{-15}$ Joules/Second = $4 * 10^{-15}$ Watts

**In dBm** $1 * 10^{-15}$ Watts = $1 * 10^{-12}$ mW = -120 dBm

Power Ratio of 4 = +6 dB

Noise level = -120 dBm + 6 dB = -114 dBm (Plot A on nomograph)

**Note:** NF of transistors are 2 dB to 30 dB due to bias currents, materials, etc.

**Noise Level** in dBm at the input of an amplifier assuming NF = 10 dB is - 104 dBm (Plot B):

**Noise Level** at the output, assuming the gain of the amplifier is 50 dB is:

No = KTB + NF + Gain = -114 dBm + 10 dB + 50 dB = -54 dBm

**Example:** If you add the gain of the amplifier to its NF (e.g., 50 dB + 10 dB = 60 dB), plot C indicates -54 dBm output noise level.

## VSWR & Return Loss (Impedance) 电压驻波比和回波损耗

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**Impedance** = Z = Ei/Ii

50 Ohm or 75 Ohm is normally used as the amplifier interface to other equipment where: Ei and Ii are the incident voltage and current.

**VSWR** = E max / E min = (1 + |P|) / (1 - |P|)

where P = reflection coefficient = $(Z - Z_0) / (Z + Z_0)$

**Return Loss** in dB = 20 log |P|

| COMMON TRANSFORMATIONS | | | | |
|---|---|---|---|---|
| **VSWR** | **RETURN LOSS** | **POWER REFLECTED** | **POWER TRANSMITTED** | **REFLECTION COEFFICIENT** |
| 1.0 | - | 0 % | 100 % | 0.00 |
| 1.1 | 26.4 dB | 0.2 % | 99.8 % | 0.05 |
| 1.25 | 19.1 dB | 1.2 % | 98.8 % | 0.11 |
| 1.5 | 14.0 dB | 4.0 % | 96.0 % | 0.20 |
| 1.75 | 11.3 dB | 7.4 % | 92.6 % | 0.27 |
| 2.0 | 9.5 dB | 11.1 % | 88.9 % | 0.33 |
| 3.0 | 6.0 dB | 25.0 % | 75.0 % | 0.50 |

| | | | | |
|---|---|---|---|---|
| 6.0 | 2.9 dB | 51.0 % | 49.0 % | 0.71 |
| - | 0 dB | 100 % | 0 % | 1.00 |

**Notes:** VSWR = $Z_L$ / $Z_O$ or $Z_O$ / $Z_L$ for resistive loads only.

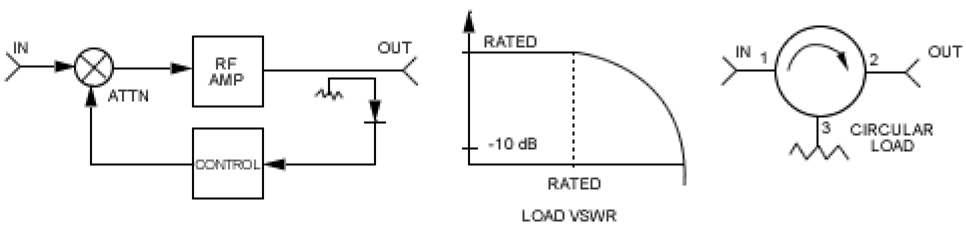
## Load VSWR & Protection 负载驻波比和保护

The total instantaneous RF voltage or current seen at the output of an amplifier under infinite load VSWR conditions can be twice the rated voltage or current. Refer to the Tech Data Sheet to determine the rated power, saturated power, operating load VSWR and the protected load VSWR. Three types of load VSWR protection (some optional) are included in general amplifiers.

**Brute Force** - The output transistors are sufficiently rugged and/or biased to withstand any load VSWR.

**Isolator** - Via a terminated circulator which is a magnetically biased ferrite device that interacts with the electromagnetic RF signal in such a way as to permit RF energy to travel in one direction only. The signal from the amplifier travels from port 1 to 2. If port 2 is properly terminated (50 Ohm) all the energy is dissipated in the output load. If not terminated, the RF energy proceeds from port 2 to 3 where it is dissipated in the circulator load internal to the HPA.

**Electronic** - The reflected signal from the load is sampled, detected and fed to a control circuit which in turn biases the input current controlled attenuator. This feedback process is analog and follows the curve below.




## Graceful Degradation 故障弱化

Solid state power amplifiers contain many isolated transistors in parallel at the output. There is a significant advantage in "graceful degradation" compared to tube amplifiers. A failure of the tube results in the total loss of output power while the failure of a parallel transistor still yields significant output power. Another significant advantage is that transistors do not change output power as a function of time whereas tubes continue to drift.

For N combined devices, the RF power output as a function of device failures is obtained by the following formula:

$$P_o = P_t \left( ( N - N_f ) / N \right)^2$$

where: $P_o$ = Output Power

$P_t$ = Total $P_o$ without transistor failures

N = Total number of devices

$N_f$ = Total number of failed devices

| N | REDUCTION IN OUTPUT POWER WITH A SINGLE DEVICE FAILURE | |
|---|---|---|
| | dB | % |
| 2 | -6.02 | 75 |
| 4 | -2.50 | 44 |
| 8 | -1.16 | 23 |
| 16 | -0.56 | 12 |
| 32 | -0.28 | 6 |
| 64 | -0.14 | 3 |

## Protection Circuits 保护电路

Unlike tubes, overstressed transistors will fail almost immediately. Empower RF recognizes that the amplifier may be overstressed in the field due to incorrect interface with the system, a system component failure, or an environmental extreme.

The following features are incorporated into most amplifiers to protect them from abnormal operation:

- Reverse voltage protection
- Input overdrive protection
- Load VSWR protection via current limit circuits or output circulator
- Thermal overload protection
- Overvoltage, undervoltage and overcurrent when AC power supply is used
- Out of band drive protection

Refer to the technical data sheets of interest to determine the standard and optional protection circuits available.

## Efficiency 效率

The primary consideration is to produce an amplifier that does the job well. An important secondary condition is to do the job efficiently, which keeps the temperature down, and therefore, increases reliability.

**Class AB & C CW Amplifiers**

Efficiency = (RF Forward Power Output (W) / DC Power Input (W)) *100%

DC input power is at the maximum level when rated RF drive is applied and at an idle level when RF drive is removed.

**Class AB & C Pulse Amplifiers**

Efficiency = ((Peak RF Power Output (W) * Duty Factor (%)) / Average DC Power Input (W)) *100%

DC input power is proportional to duty factor plus idle power.

**Class A Amplifiers**

Efficiency = (RF Forward Power Output (W) / DC Power Input (W)) *100%

Power added efficiency is usually specified at the 1 dB compression point. DC input power is continuous at all input levels (except saturation).

## Class of Amplifiers 放大器工作类别

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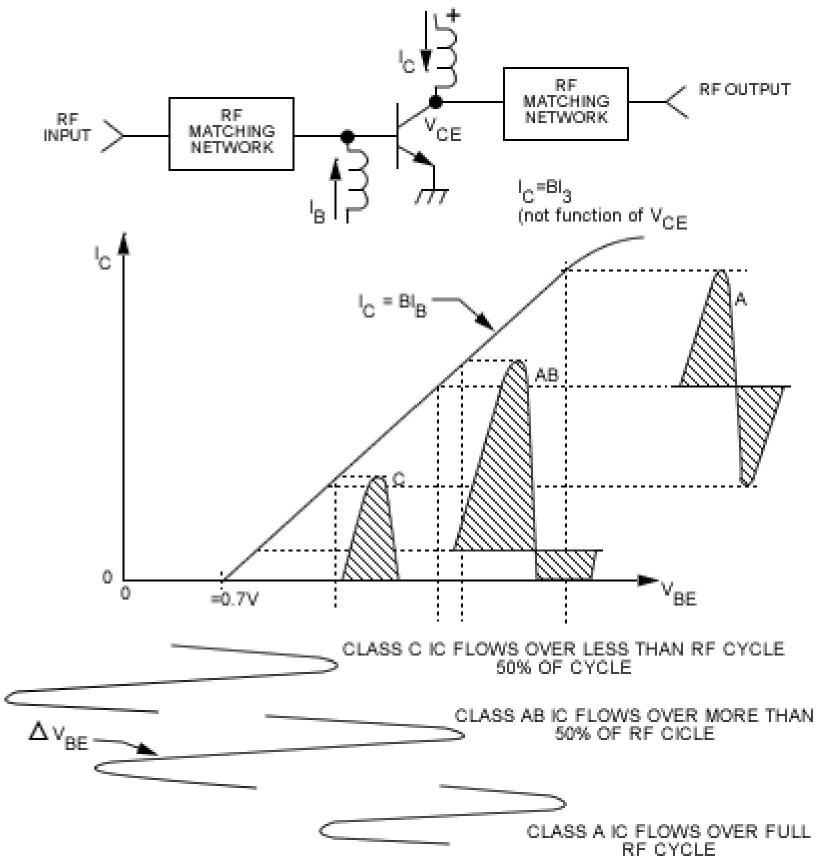
**B I A S & O P E R A T I N G P O I N T S A, A B, C**




## Class A Operation A 类工作

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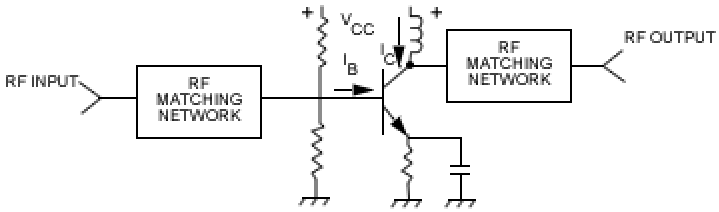
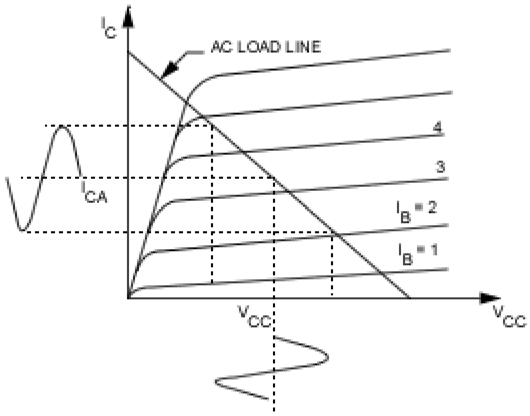
**Class A amplifiers** have a fixed forward bias.




Base current, $I_B$, and collector current, $I_C$, flow over the full RF cycle. In addition, when operated below compression, the RF signal swing is uniformly above and below the quiescent DC bias set point and well within the linear region of the transistor.




**Summary of Characteristics Class A**

**Class A Advantages:**

Excellent Linearity
Low Distortion
Faithful Pulse Response Below the 1 dB Compression Point
Broad Bandwidth
Good Noise Figure
Low Bandpass Ripple at All Output Levels
Medium Output Power Capability
Phase & Gain Stable at All Output Levels

**Class A Disadvantages:**

Poor Efficiency

More Heat Dissipated
Larger Size

**Applications:**

TWT Replacements
Sweeper/Synthesizer/Signal Generator Boosters
TV Amplifiers
Short Pulse Amplifiers
Multicarrier Amplification
Multicouplers
Baseband Amplifiers
IF and Low Noise Amplifiers
Multi Decade Amplifiers
AM Amplifiers
Laboratory Drivers
EW/ECM Jammers
RFI Testing

## Class AB Operation　AB 类工作

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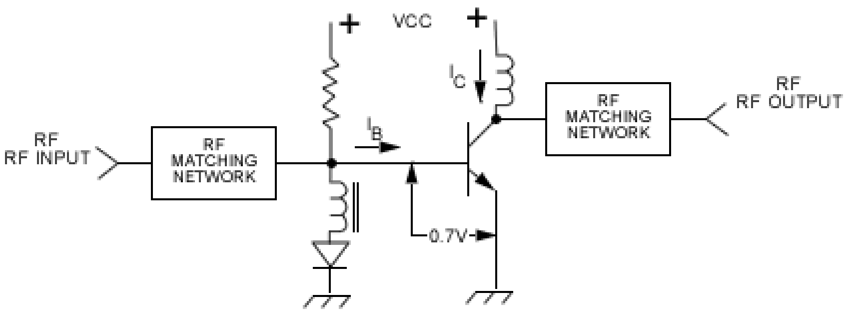
**Class AB Amplifiers** have a small forward DC bias, $I_B$. The collector current, $I_C$, (without RF drive) may be 1 % to 10% of the maximum design value.
As the RF drive is increased, the base bias ($I_B$) and the collector current ($I_C$) are increased proportionally.




**Summary of Characteristics Class AB**

**Class AB Advantages:**

Multikilowatt Output Power
Good Efficiency
Compact Size

Good Linearity
Low Distortion
Broad Bandwidth
Relatively Cool Operation
CW, AM, FM, TV, Phase and Pulse Amplification

**Class AB Disadvantages:**

Limited Dynamic Range (15 to 30 dB)
Restricted IMD Characteristic
Higher Bandpass Ripple at Low RF Input Levels

**Applications:**

ECM/EW Jammers
Booster Amplifiers
Transmitters
RFI/EMI Testing
High Power TWT Replacements
Visual Television Amplifiers
High Power Calibration Testing

## Class C operation　C 类工作

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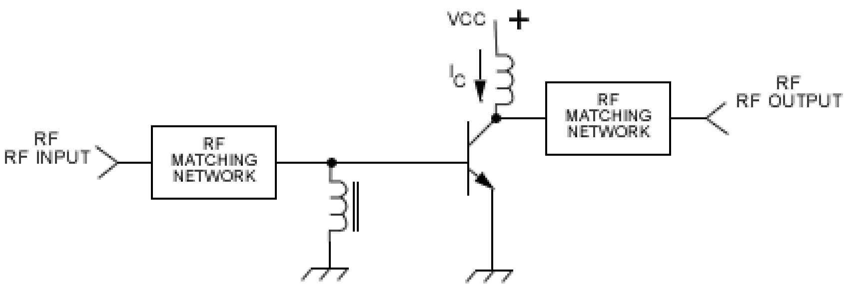
**Class C Amplifiers** are not DC forward biased. Collector current, I**C**, flows over significantly less than 50% of the RF input cycle.
Class C amplifiers have a very limited dynamic range (0 to 6 dB) and have a tendency to snap off if the RF input signal is reduced below the rated level.




**Class C Advantages:**

Excellent Efficiency

Compact Size

Multikilowatt Pulse Output Power

Cool Operation

CW, FM, Phase and Pulse Amplification

**Class C Disadvantages:**

Poor Dynamic Range

Cannot Support AM Signals

**Applications:**

Troposcatter Amplifiers

FM Amplifiers

EW/ECM

Booster Amplifiers

Communications Systems

TWT Replacements

TACAN Systems

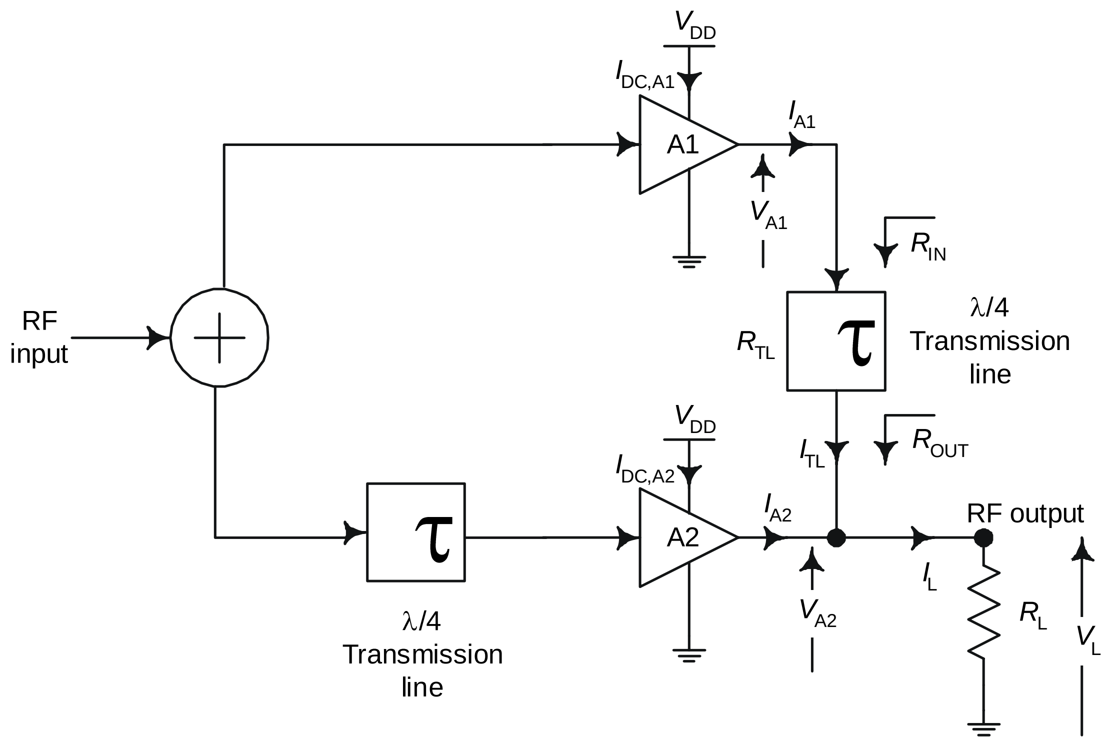
Radar Systems

## Memory Effects 记忆效应

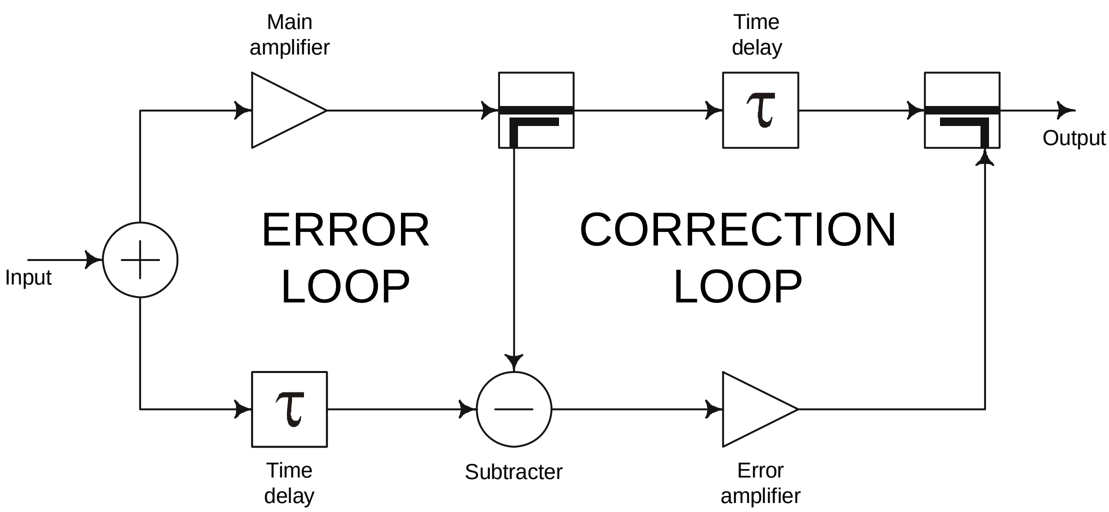
There are two main types of memory effect: thermal and electrical. Both result (by definition) in the PA output being determined by the recent history of PA inputs and not just the current PA input. Memory Effects will degrade the effect of linearity in PD (pre-distortion).

## Doherty Doherty 放大

Doherty is a PA configuration combining two or more Pas. It's used in Efficiency Boosting.

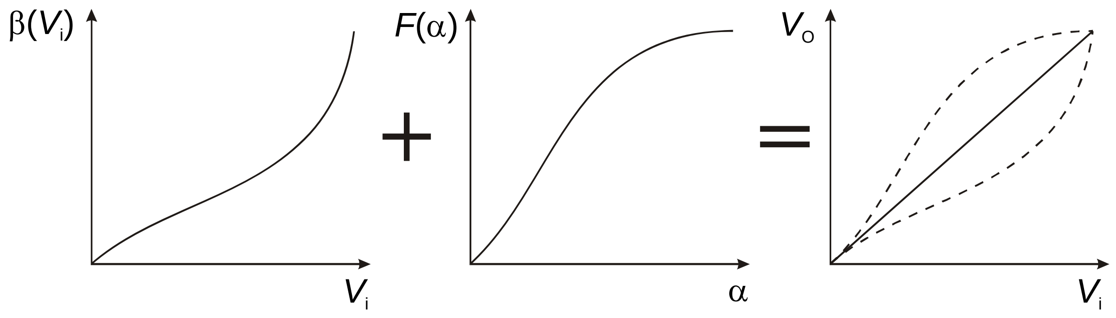



**Feed-forward PA 前馈功放**




**Pre-distortion PA 预失真功放**


$$F\{\beta(V_i)\} = A$$



β(Vi)
Vi
F(α)
α
Vo
Vi