RF/Microwave Circuit and System

Link Budget Calculation

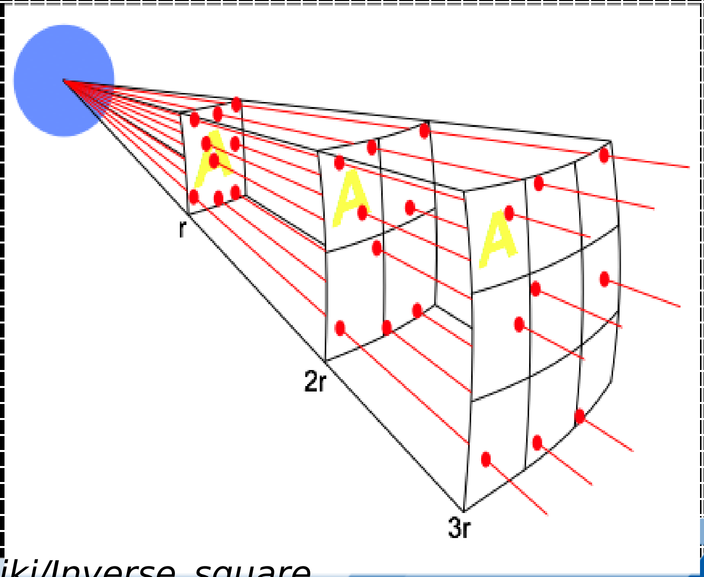
浙江大学 信息与电子工程学院
College of Information Science & Electronic Engineering, Zhejiang University

Goals

- To be able to calculate how far we can go with the equipment we have
- To understand why we need high masts for long links

Free space loss

- Signal power is diminished by geometric spreading of the wavefront, commonly known as ***Free Space Loss***
  - Geometric spreading happens because the wavefront radiated signal energy expands as a function of the distance from the transmitter



from http://en.wikipedia.org/wiki/Inverse_square

Free Space Loss (long distance)

- Using decibels to express the loss and using 2.45 GHz as the signal frequency, the equation for the Free Space Loss is:

$$L_{fsl} = 100 + 20*\text{Log}(D)$$

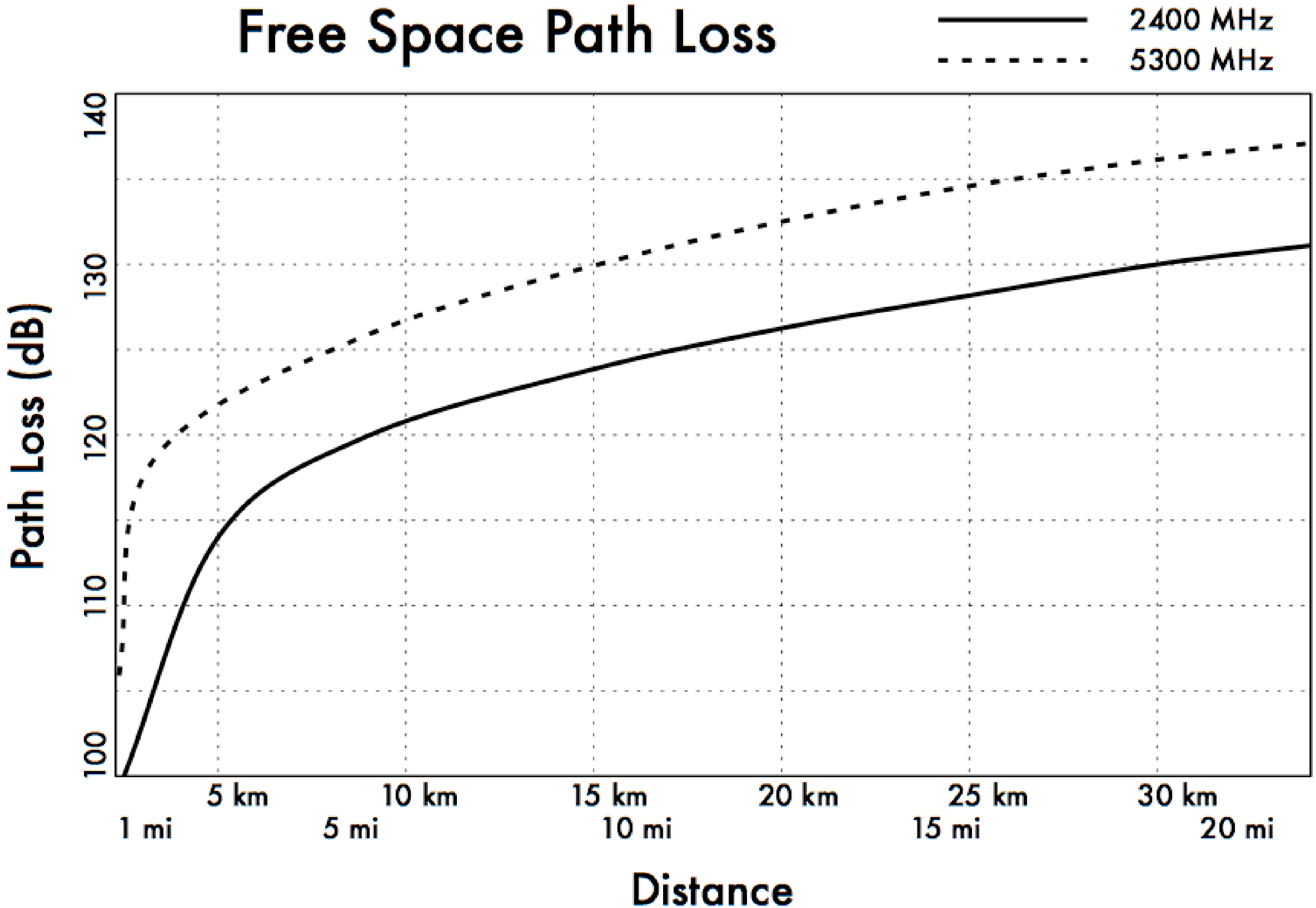
- where L_{fsl} is expressed in dB and D is in kilometers

Free Space Loss (short distance)

- Using decibels to express the loss and using 2.4 GHz as the signal frequency, the equation for the Free Space Loss is:

$$L_{fsl} = 40 + 20*\log(d)$$

- where L_{fsl} is expressed in dB and d is in meters.



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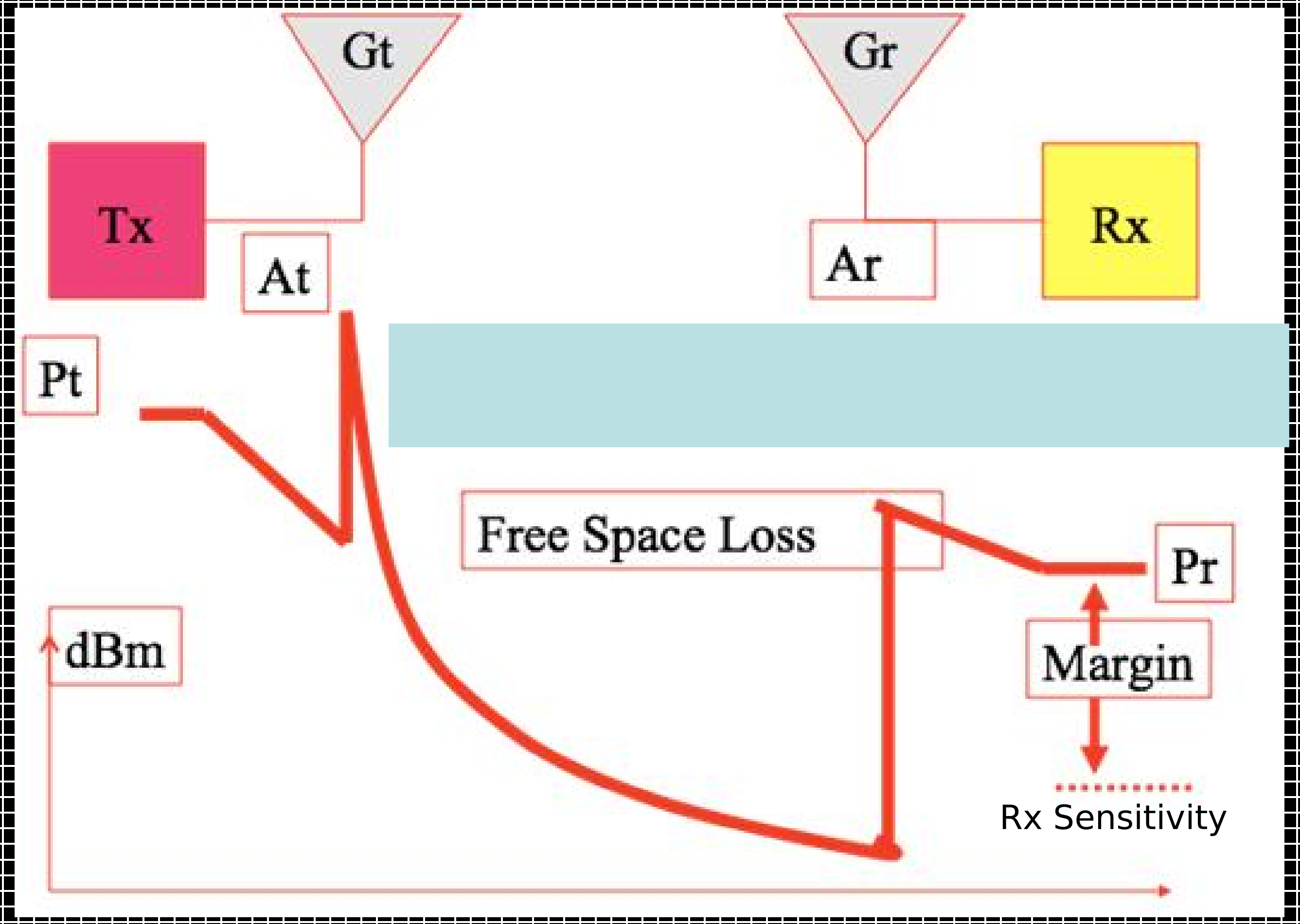
Power in a wireless system

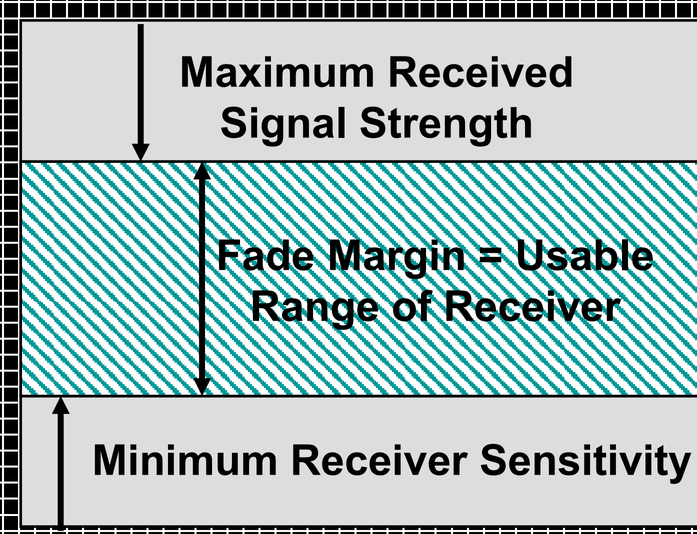


Link budget

- The performance of any communication link depends on the quality of the equipment being used.
- ***Link budget*** is a way of quantifying the link performance.
- The received power in an 802.11 link is determined by three factors: *transmit power*, ***transmitting antenna gain***, and ***receiving antenna gain***.
- If that power, minus the ***free space loss*** of the link path, is greater than the ***minimum received signal level*** of the receiving radio, then a link is possible.
- The difference between the minimum received signal level and the actual received power is called the ***link margin***.
- The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

RF Basics - Fade Margin

- Receiver Sensitivity is the minimum signal level in dB needed by the receiver to output received data
- Fade Margin in dB is the amount of received signal above the receiver's minimum required usable Receiver Sensitivity.
- Fade Margin is controlled by
  - Transmitter Power
  - Transmitter feedline attenuation
  - Transmitting antenna gain
  - Receiving antenna gain
  - Receiver feedline attenuation
  - Receiver Sensitivity



Example link budget calculation

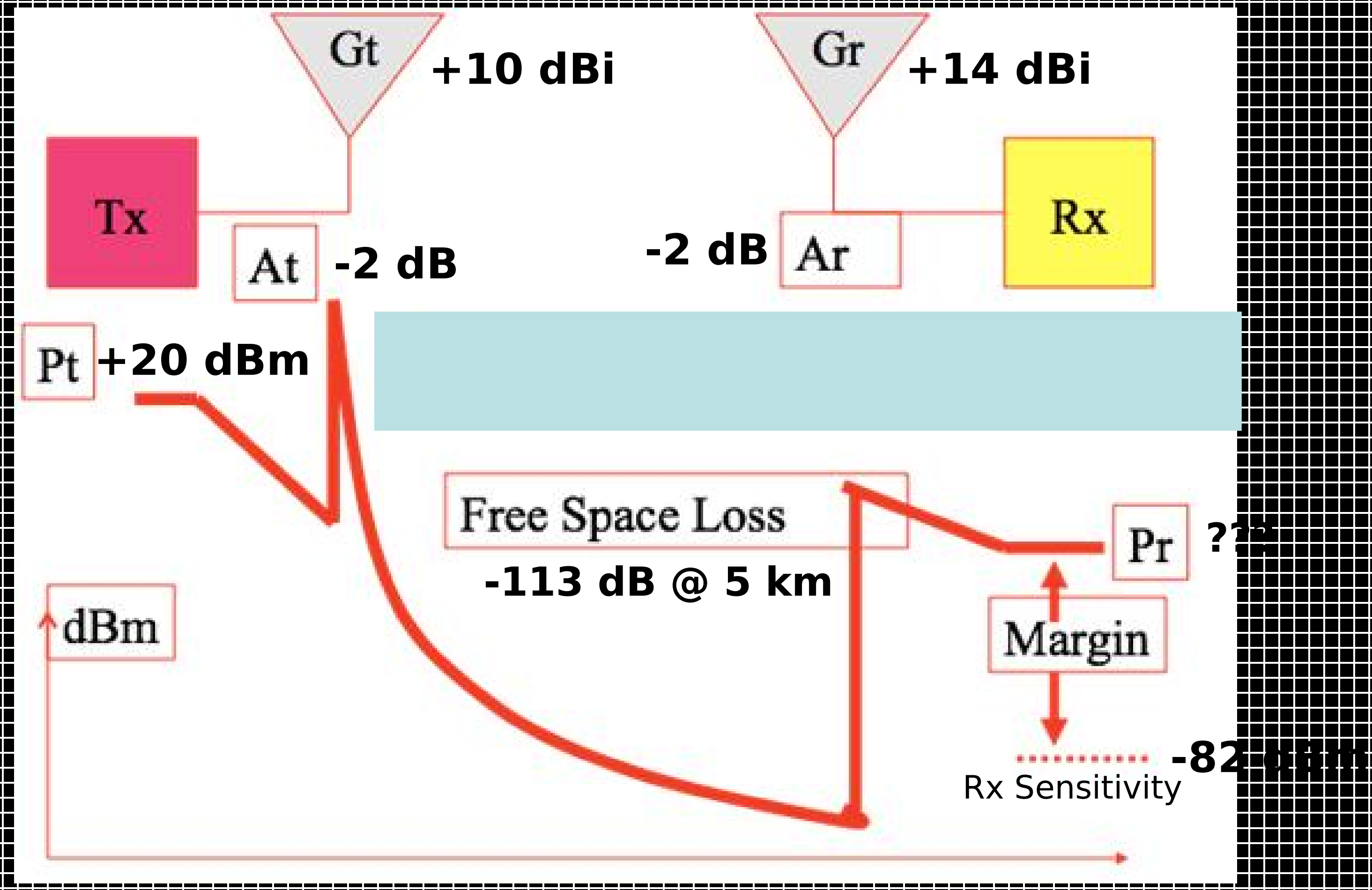
Let's estimate the feasibility of a 5 km link, with one access point and one client radio.

The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** and a receive sensitivity of **-89 dBm**.

The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.

The cables in both systems are short, with a loss of **2dB** at each side at the 2.4 GHz frequency of operation.

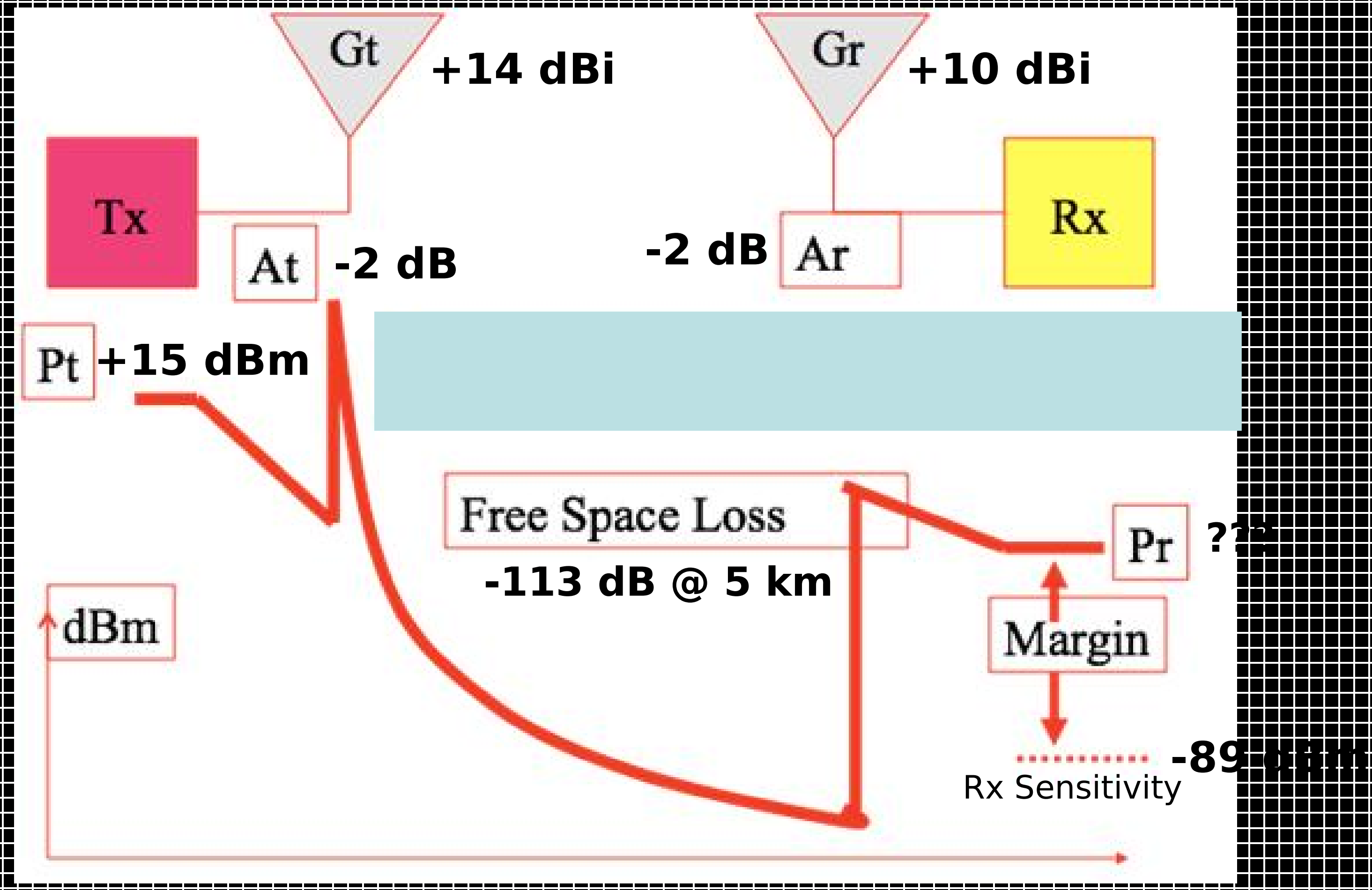
AP to Client link



Link budget: AP to Client link

```
   20 dBm  (TX Power AP)
+  10 dBi  (Antenna Gain AP)
-   2 dB   (Cable Losses AP)
+  14 dBi  (Antenna Gain Client)
-   2 dB   (Cable Losses Client)
----------------
   40 dB   Total Gain
-113 dB    (free space loss @5 km)
----------------
  -73 dB   (expected received signal level)
- -82 dBm  (sensitivity of Client)
----------------
    9 dB   (link margin)
```

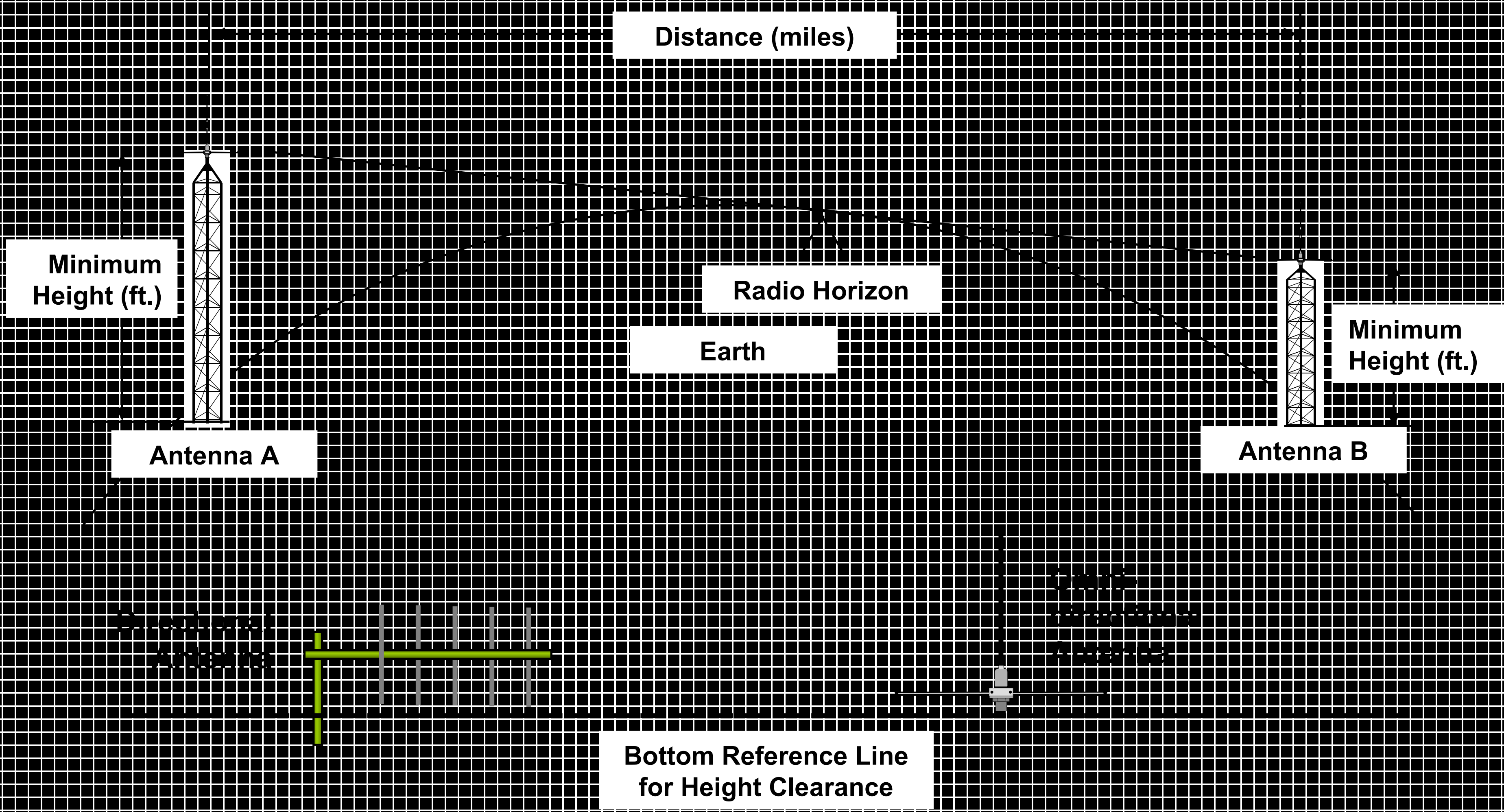
Opposite direction: Client to AP



Link budget: Client to AP link

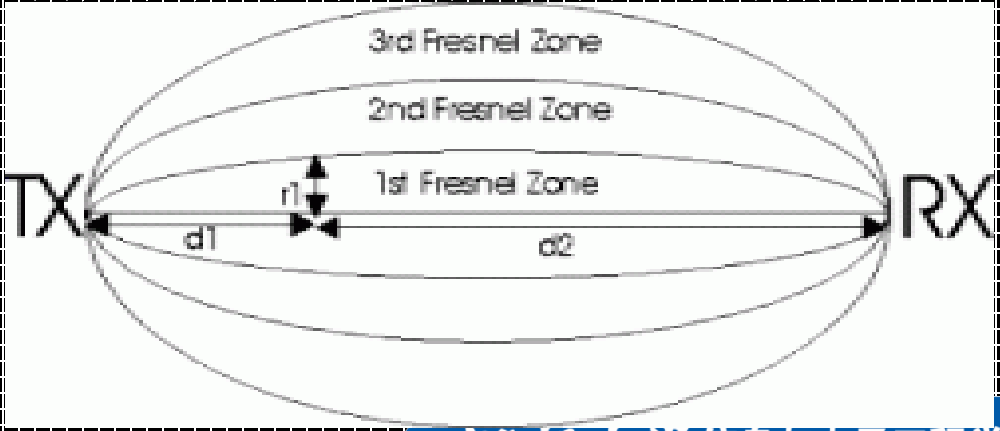
```
   15 dBm  (TX Power Client)
+  14 dBi  (Antenna Gain Client)
-   2 dB   (Cable Losses Client)
+  10 dBi  (Antenna Gain AP)
-   2 dB   (Cable Losses AP)
----------------
   35 dB   Total Gain
 -113 dB   (free space loss @5 km)
----------------
  -78 dB   (expected received signal level)
 --89 dBm  (sensitivity of AP)
----------------
   11 dB   (link margin)
```

Minimum Antenna Height Required to Clear the Radio Horizon



Fresnel Zone

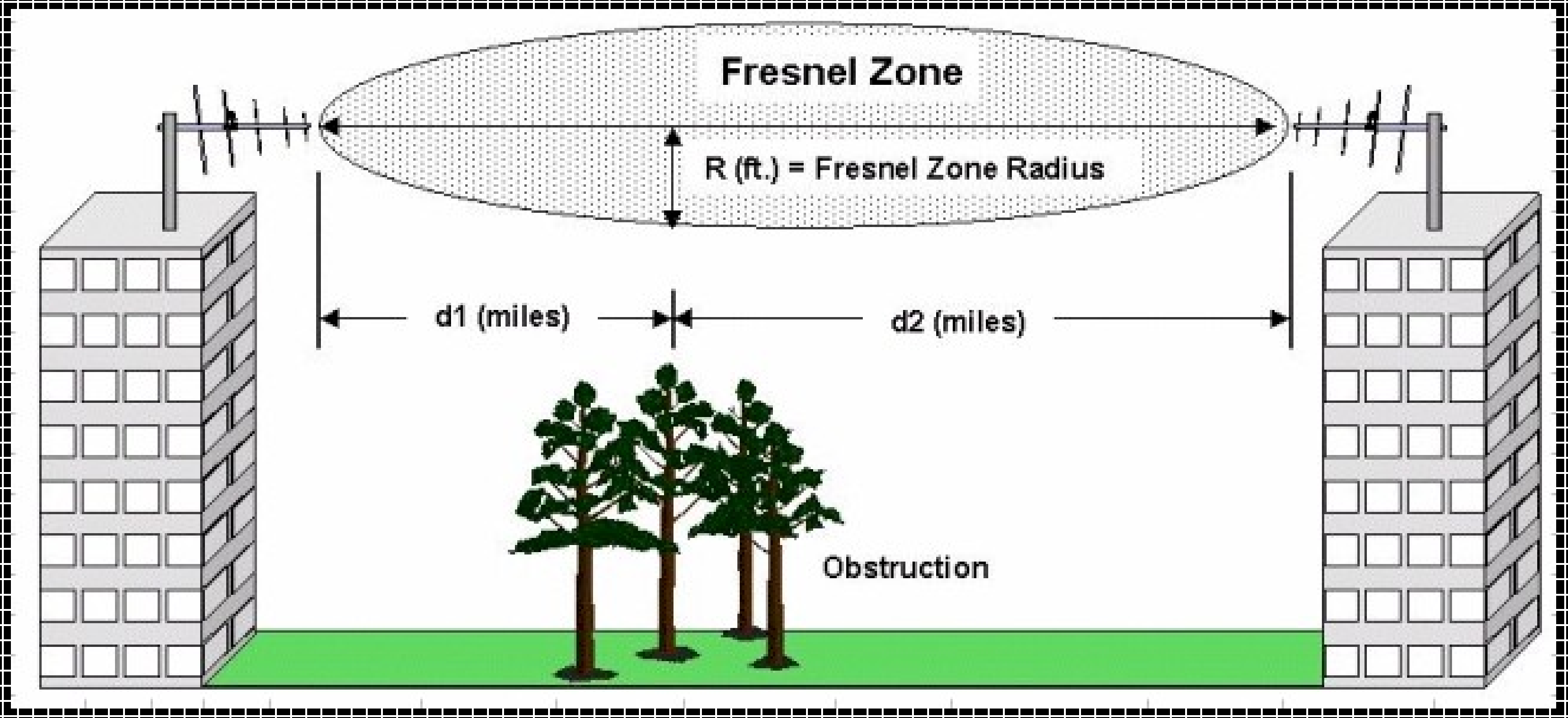
- In optics and radio communications
- In any situation that involves the radiation of waves including optics and radio communications, a Fresnel zone named from physicist Augustin-Jean Fresnel, is one of a (theoretically infinite) number of concentric ellipsoids which define volumes in the radiation pattern of a (usually) circular aperture.
- The cross section of the first (innermost) Fresnel zone is circular. Subsequent Fresnel zones are annular (doughnut-shaped) in
  with the first.



Source: Wikipedia

Fresnel Zone

- Fresnel Zone shows the ellipsoid spread of the radio waves
- Area must be clear of obstructions or signal strength will be reduced
- Blockage in 60% will induce significant signal losses
- Use for frequencies above 900 MHz



Fresnel Zone

The general equation for calculating the Fresnel zone radius at any point P in between the endpoints of the link is the following:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

where,

F_n = The nth Fresnel Zone radius in metres

d_1 = The distance of P from one end in metres

d_2 = The distance of P from the other end in metres

λ = The wavelength of the transmitted signal in metres

For practical applications, it is often useful to know the maximum radius of the first Fresnel zone. From the above formula, the following formulas can be derived, using $d_1 = d_2$, $D = d_1 + d_2$ and $\lambda = \frac{c}{f}$

Source: Wikipedia

Fresnel Zone

Now we have an easy way to calculate the radius of the first Fresnel zone (F_1 in the above equation), knowing the distance between the two antennas and the frequency of the transmitted signal.

In SI:

$$r = 8.657\sqrt{\frac{D}{f}}$$

where

- r = radius in metres
- D = total distance in kilometres
- f = frequency transmitted in gigahertz.

Or in imperial units:

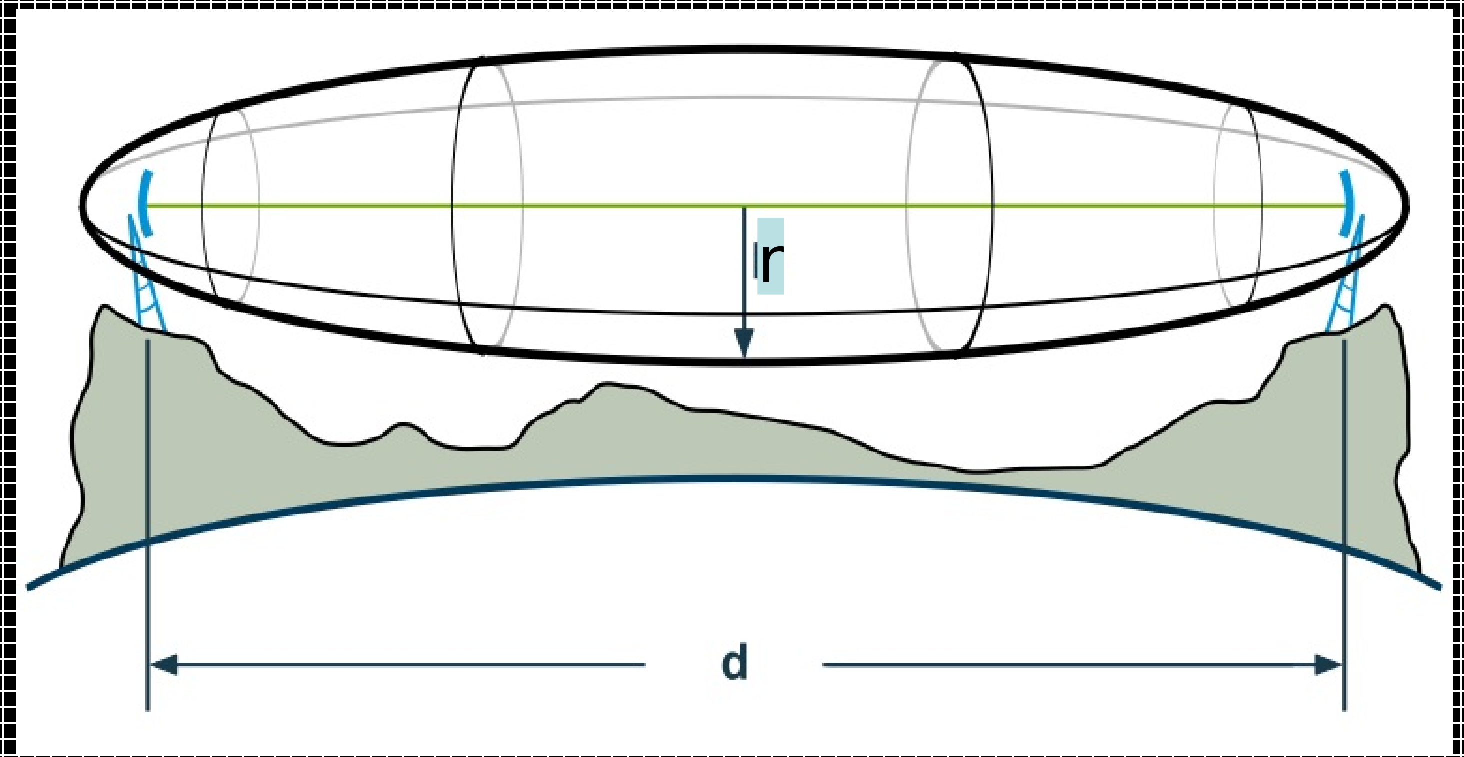
$$r = 36.03\sqrt{\frac{D}{f}}$$

where

- r = radius in feet
- D = total distance in miles
- f = frequency transmitted in Gigahertz.

Source: Wikipedia

Line of Sight and Fresnel Zones



- a free line of sight **IS NOT EQUAL TO** a free Fresnel Zone

Fresnel Zone

This table shows the height above ground required to clear 70% of the first Fresnel zone for various link distances at 2.4 GHz. Notice that earth curvature plays a small role at short distances, but becomes more important as the distance increases.

Distance (km)	1st zone (m)	70% (m)	Earth curvature (m)	Required height (m)
1	5.5	3.9	0.0	3.9
5	12.4	8.7	1.0	9.7
10	17.5	12.2	4.2	16.4
15	21.4	15.0	9.4	24.4
20	24.7	17.3	16.7	34.0
25	27.7	19.4	26.0	45.4
30	30.3	21.2	37.5	58.7

Fresnel Zone

- Considering the importance of the Fresnel Zone, it is important to quantify the degree to which it can be blocked.
- Typically, 20% - 40% Fresnel Zone blockage introduces little to no interference into the link.
- It is better to err to the conservative side allowing no more than 20% blockage of the Fresnel Zone.

GOSPELL — 3300C ku Tuner

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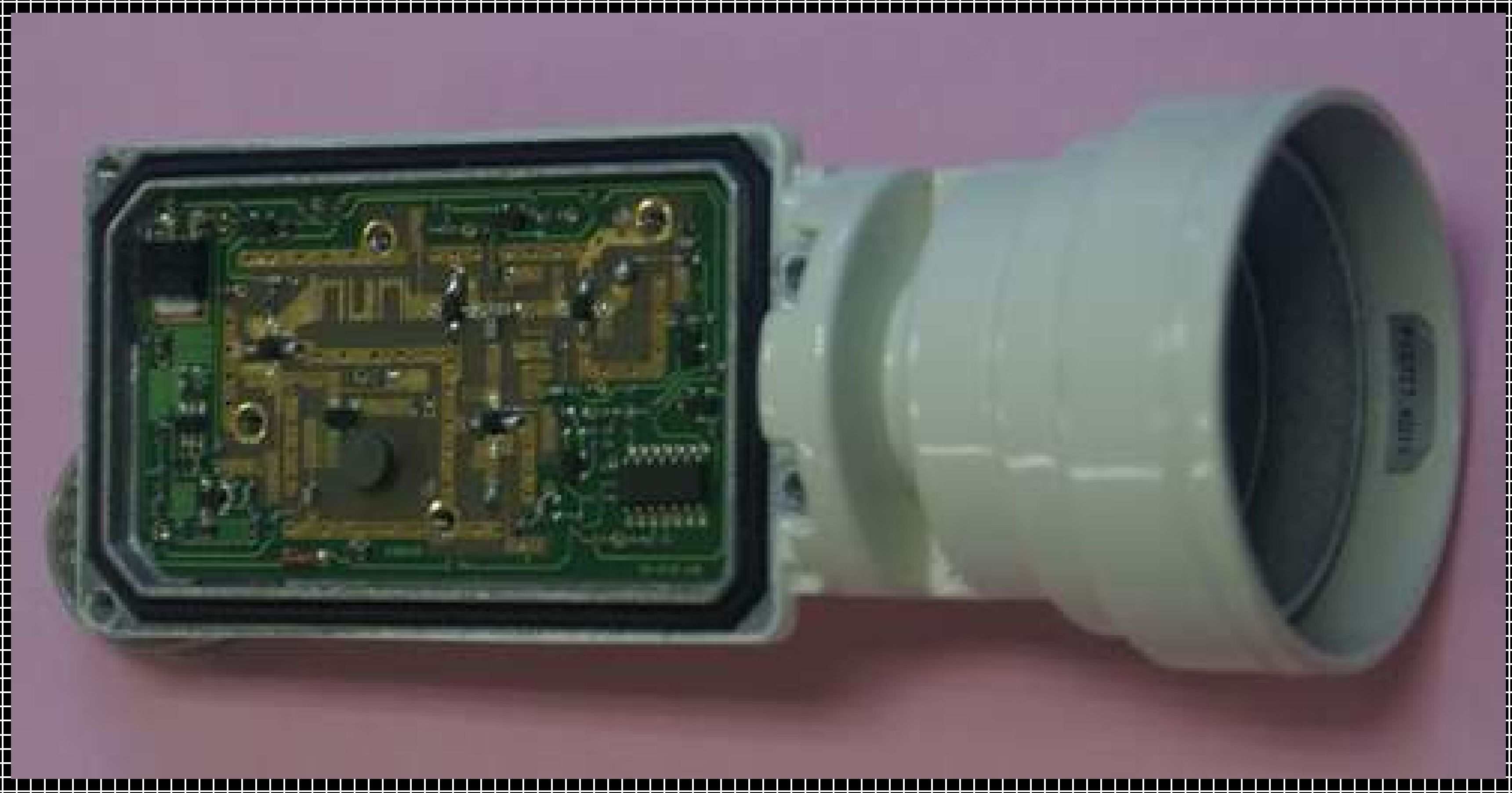
Ku — band L N B (Low Noise Block)

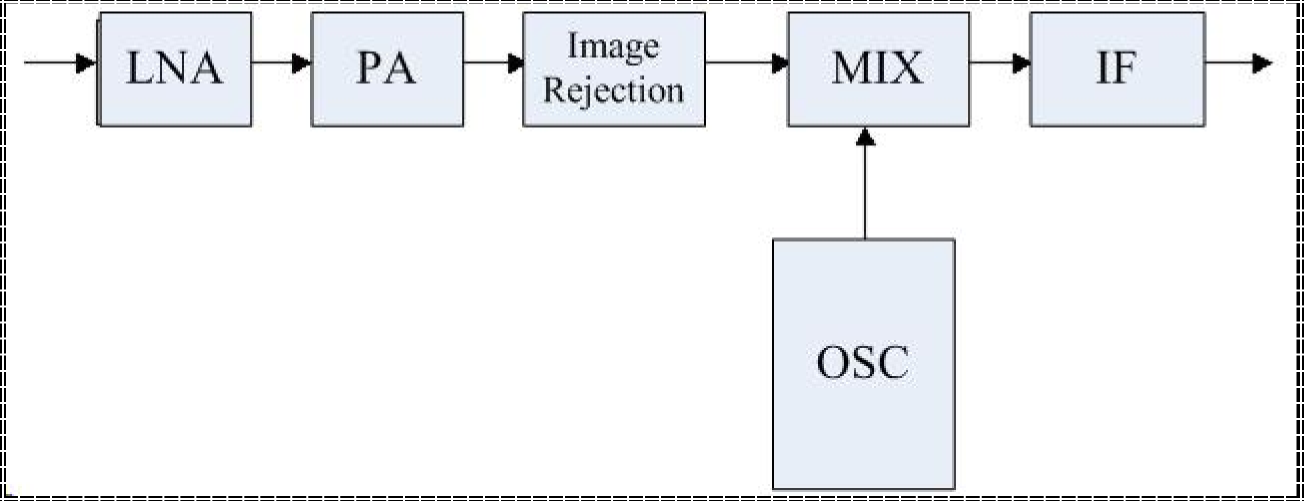
- SPECIFICATIONS

1) Input Frequency: 10.70~11.70GHz (LOW BAND);11.70~12.75GHz (HIGH BAND)
2) Output Frequency: 950~1950MHz (LOW BAND);1100~2150MHz (HIGH BAND)
3) LO Frequency: 9.75/10.6GHz&9.75/10.75GHz
4) Noise Figure: 0.3dB (Typ.)
5) Conversion Gain: 60dB (Typ.)
6) F/D Radio: 0.6
7) Input Interface: Wave guide WR-75
8) Cross-Pol. Isolation: 20dB (Typ.)
9) Image Rejection: 45dB (Min.)
10) Polarity Switching Voltage: Vertical: 12~14.5V ;Horizontal:16~19V
11) Operating Voltage: Vertical: 11.5 ~ 14 Vdc ;Horizontal: 16 ~ 19 Vdc
12) Band Switching Pulse: 22KHz tone
13) Gain Flatness: ±0.5dB/27MHz
14) D.C Current Consumption: 150mA (Max.)
15) LO phase noise: -70dBc/Hz at 10KHz; -90dBc/Hz at 100KHz; -110dBc/Hz at 1MHz
16) Output power (at 1dB gain compression): 10dB (Min.)
17) Output VSWR: 2.5:1 (Max.)
18) Output connector: 75Ω F-type female
19) Operating Temperature: -40°C ~ +60°C
20) Storage Temperature: -55°C ~ +80°C

Open shell

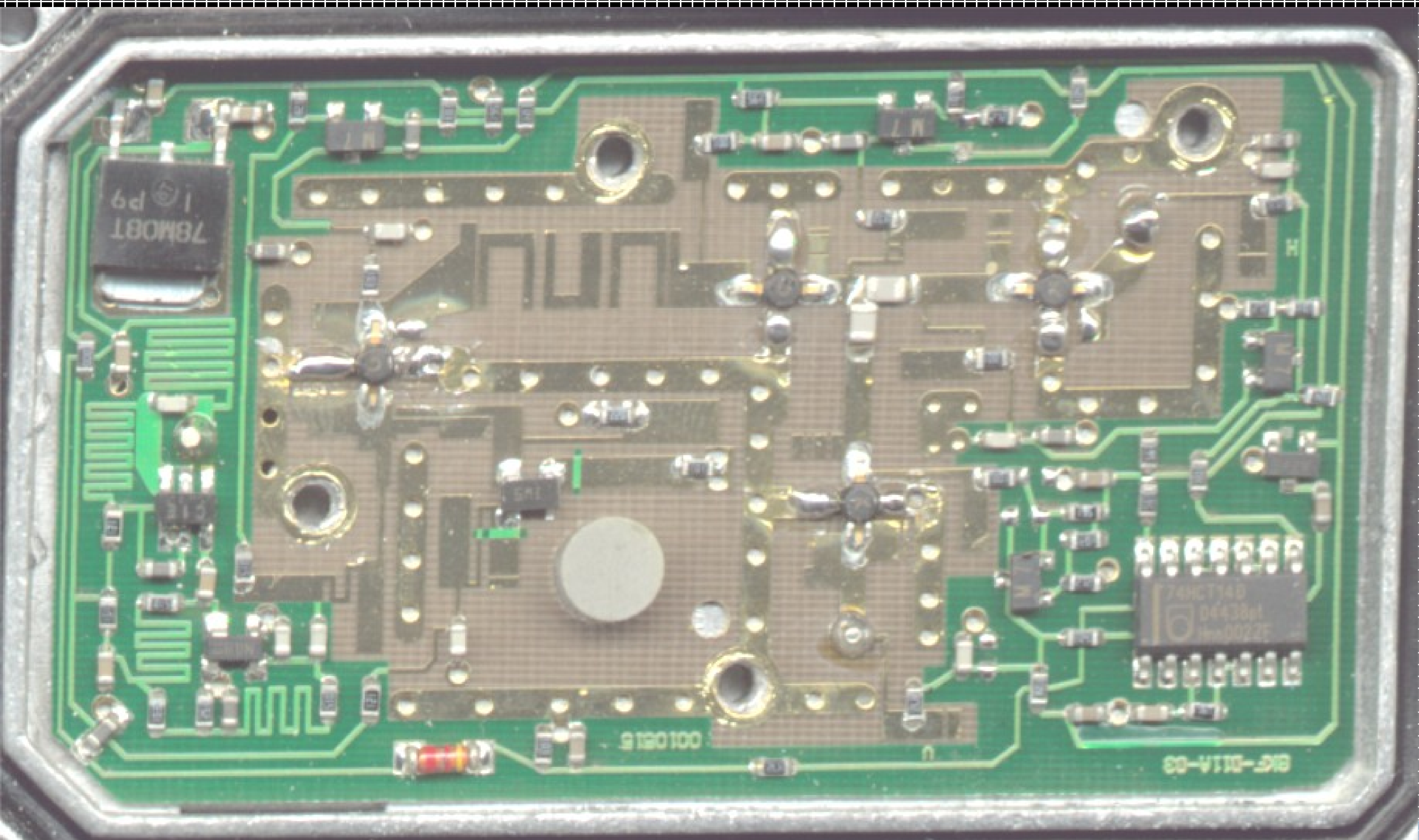


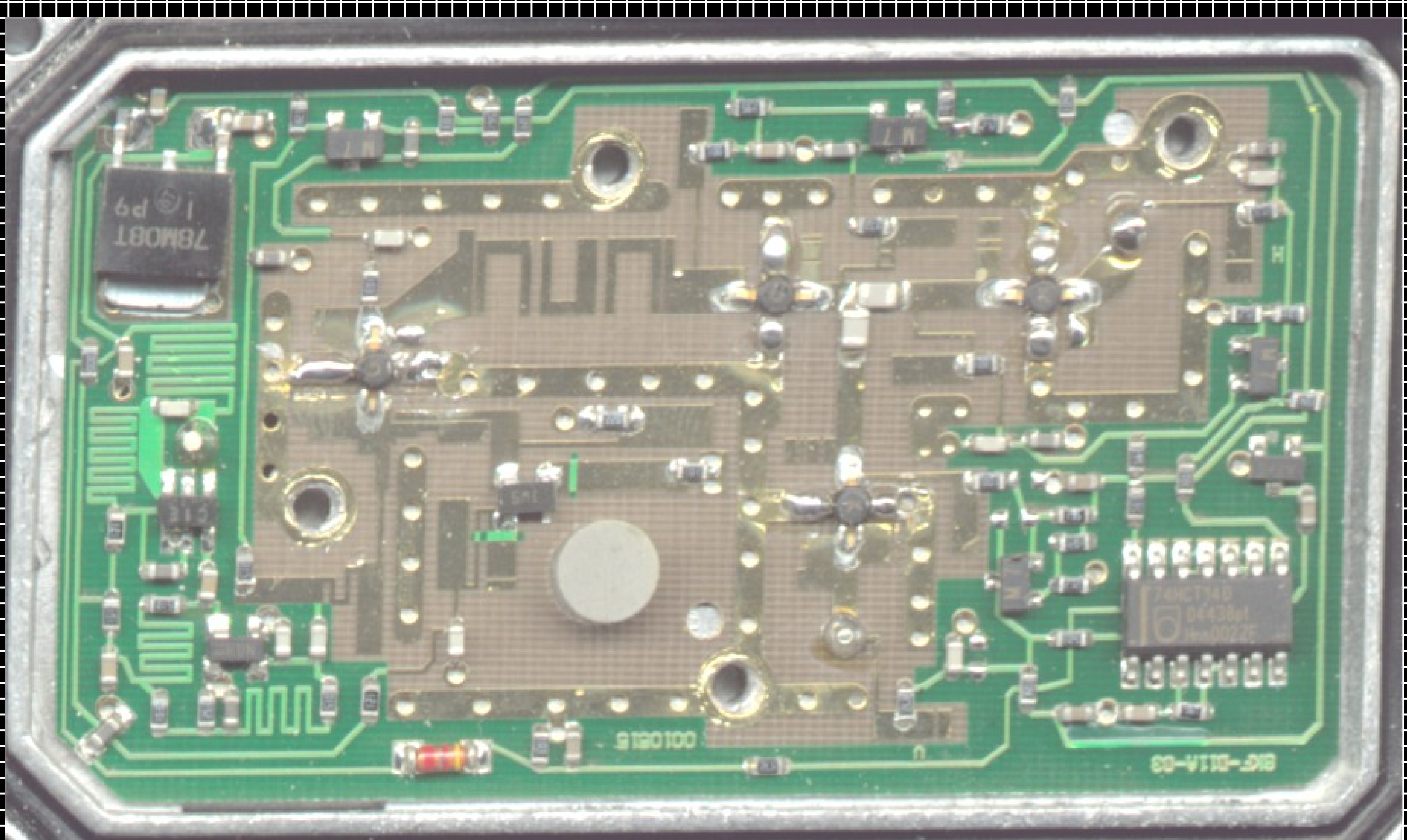
Circuit blocks



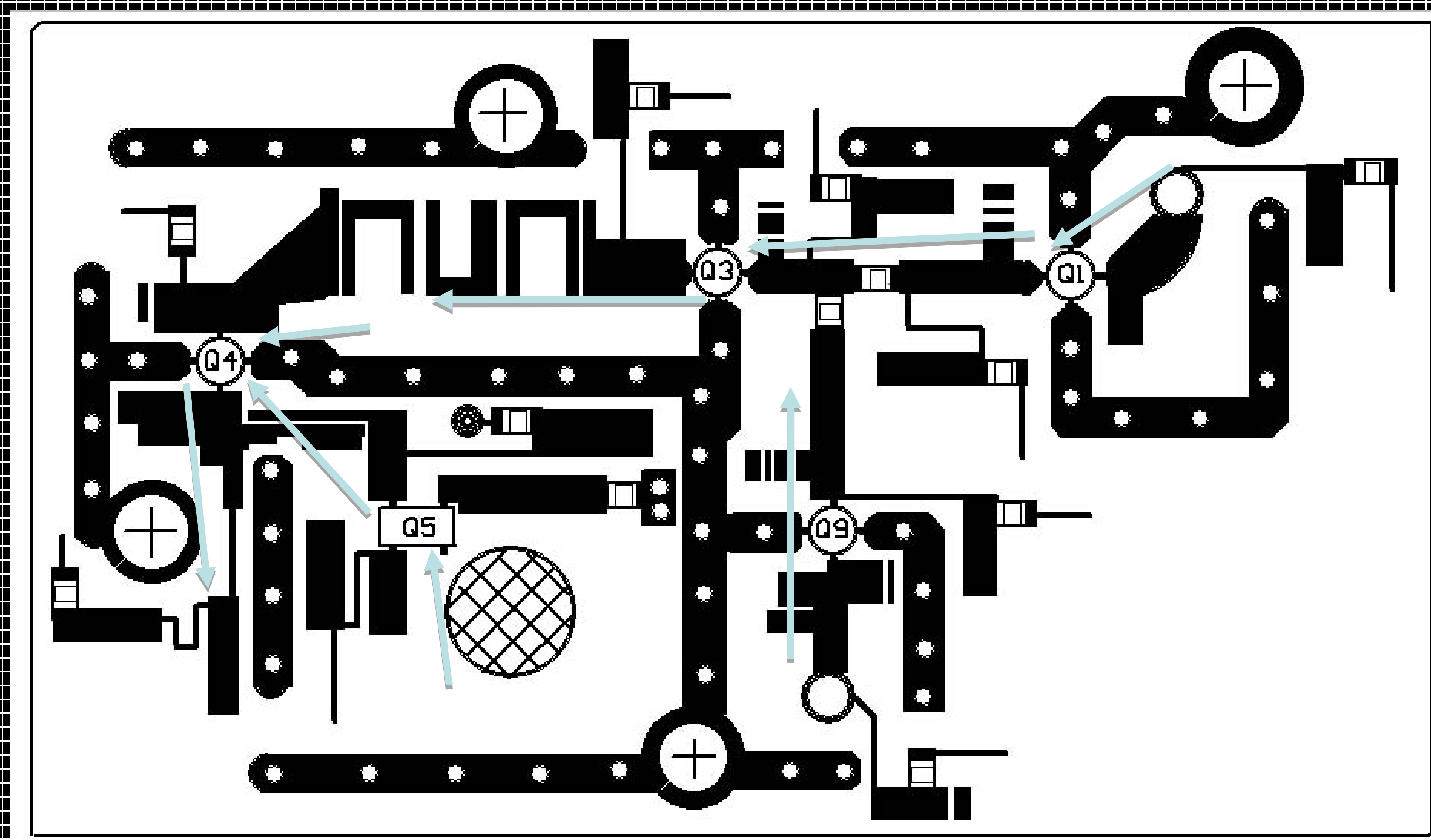
- waveguide-microstrip, LNA, MIXer, IF amplifier.
- 1、 Waveguide-microstrip converter :
- Waveguide - microstrip converter is to couple the received microwave signal (by a small antenna, coaxial low noise amplifier) to the microstrip circuit. Converter must be low VSWR, otherwise received signal will be reflected, equivalent to the received signal is attenuated, increasing system noise.
- 2、 LNA :
- Low-noise amplifier position is in the front of the system, this is because the noise figure of the system depends basically on its noise factor.
- Microstrip circuit is used as input matching circuit, interstage matching circuit and output matching circuit.
- The task of input matching circuit is to convert the complex impedance of microwave transistor to the source real impedance (50 ohm resistive source impedance). For low-noise amplifier, the starting point for the design is the low noise. The task of the interstage matching circuit is matching input impedance and output impedance between microwave transistors and obtain a higher gain.
- The output matching circuit is used to convert complex output impedance of microwave transistor to load real impedance 50Ω.

- 3、 Local Oscillator：
- Since the LNB is generally placed great outdoors, temperature has a great change. In order to obtain sufficient oscillation frequency stability of the system and make the structure simple, we commonly use dielectric resonator oscillators. Such oscillator has a high degree of stability.
- 4、 Mixer：
- Low-noise amplifier on LNB has more than 40dB of gain, so the mixer conversion hasn't noise and loss requirements. In order to simplify the circuit, we use the single mixer transistor and add the microstrip bandpass filter before the mixer. Because the image frequency is faraway from carrier, the filter is relatively easy to realize.
- 5、 IF Amplifier：
- We can use lumped components .



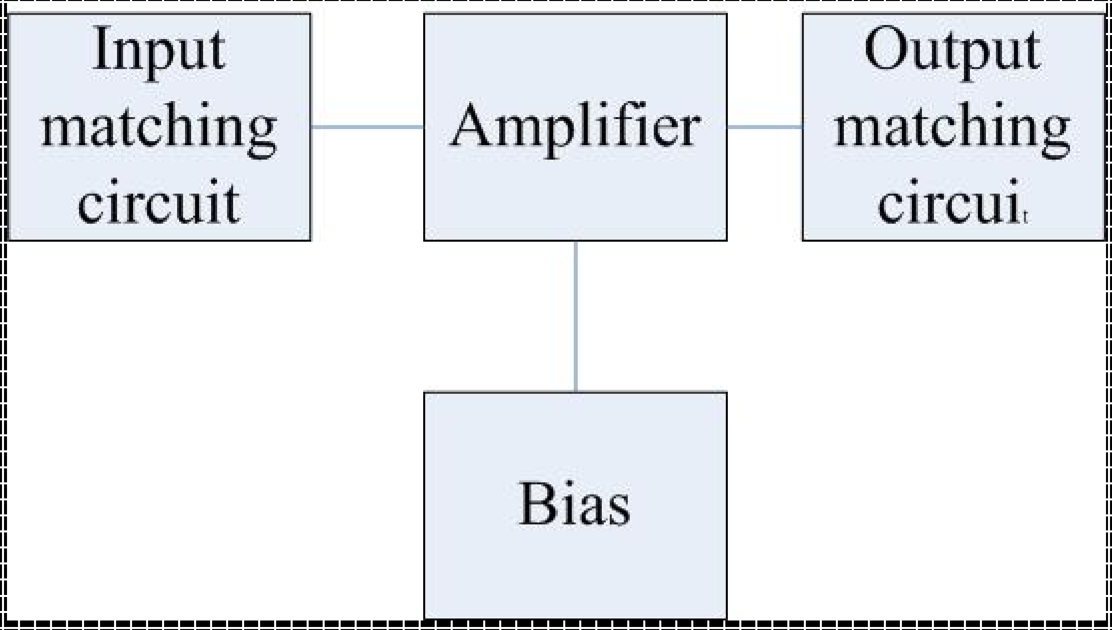


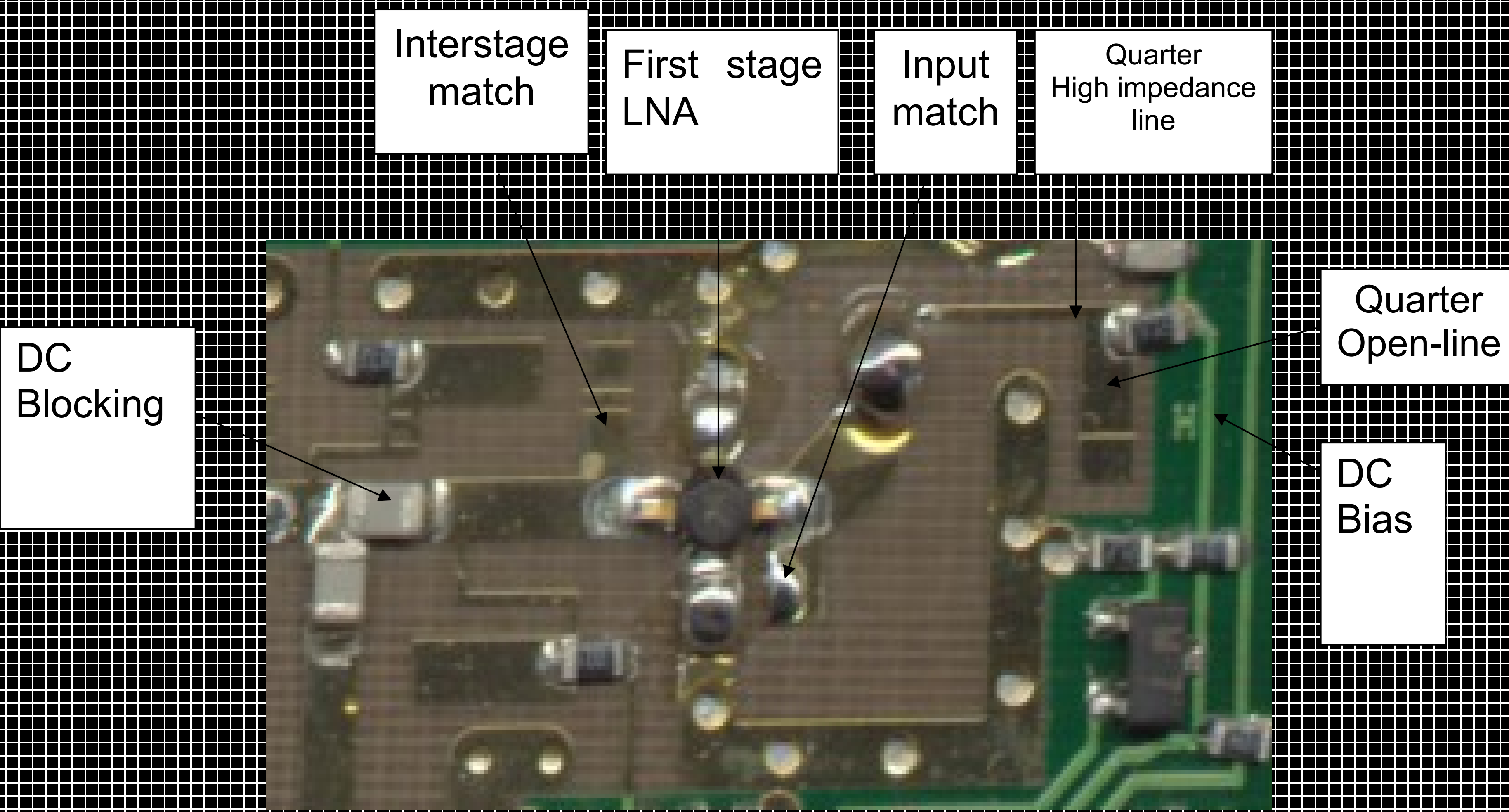
- We can see from feeds
- Signal coupled to two orthogonal small antennas. The orthogonally polarized signals are fed to the respective first-stage low-noise amplifier, and through the second stage amplifier, mirror filters, dielectric oscillator, mixer, IF filter circuit, IF amplifier
- The surrounding circuits include bias circuit, polarization selection circuit and power supplies.

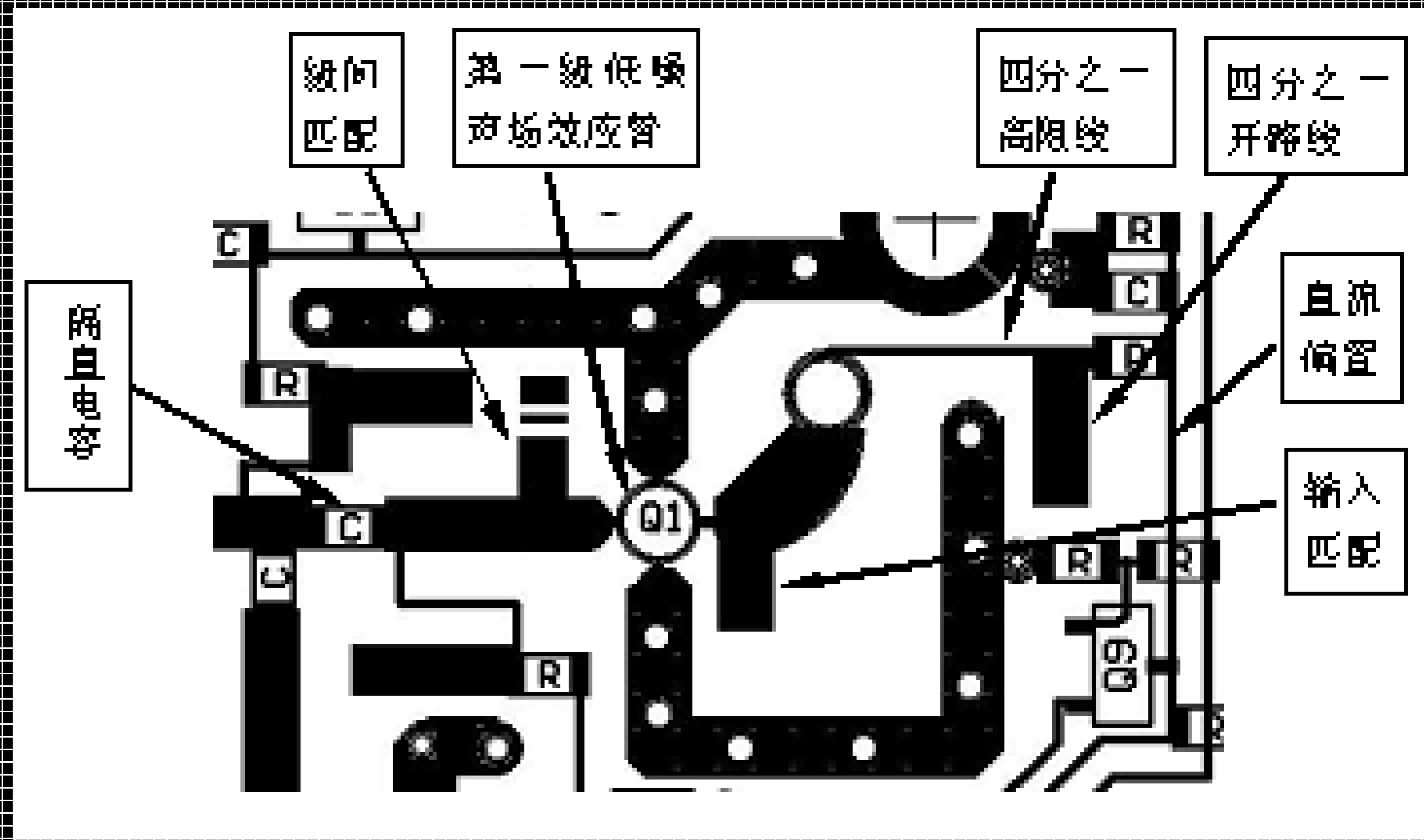

Q3
Q1
Q4
Q5
Q9

LNA

- The low-noise amplifier is composed by input matching circuit, amplifier, output matching circuit and the bias. The input matching circuit affect LNA noise figure, output matching circuit is related to the stability of the LNA gain and bias circuit give the working status of the amplifier.

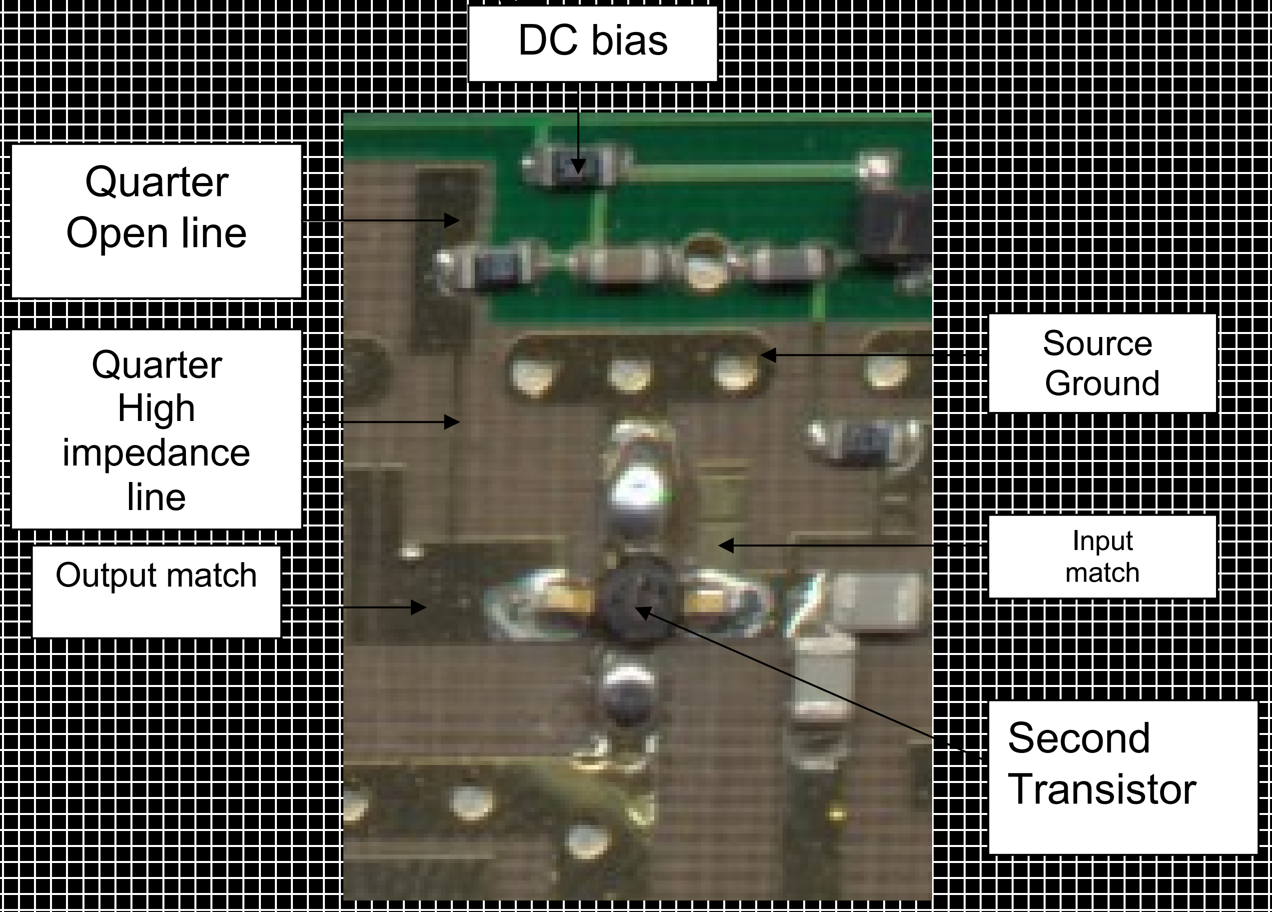



Interstage match
First stage LNA
Input match
Quarter High impedance line
Quarter Open-line
DC Blocking
DC Bias


级间匹配
第一级低噪声场效应管
四分之一高阻线
四分之一开路线
隔直电容
直流偏置
输入匹配
Q1

Second stage

- Have a little difference with LNA
- In the second stage, the input matching is not designed to get the minimum noise figure.

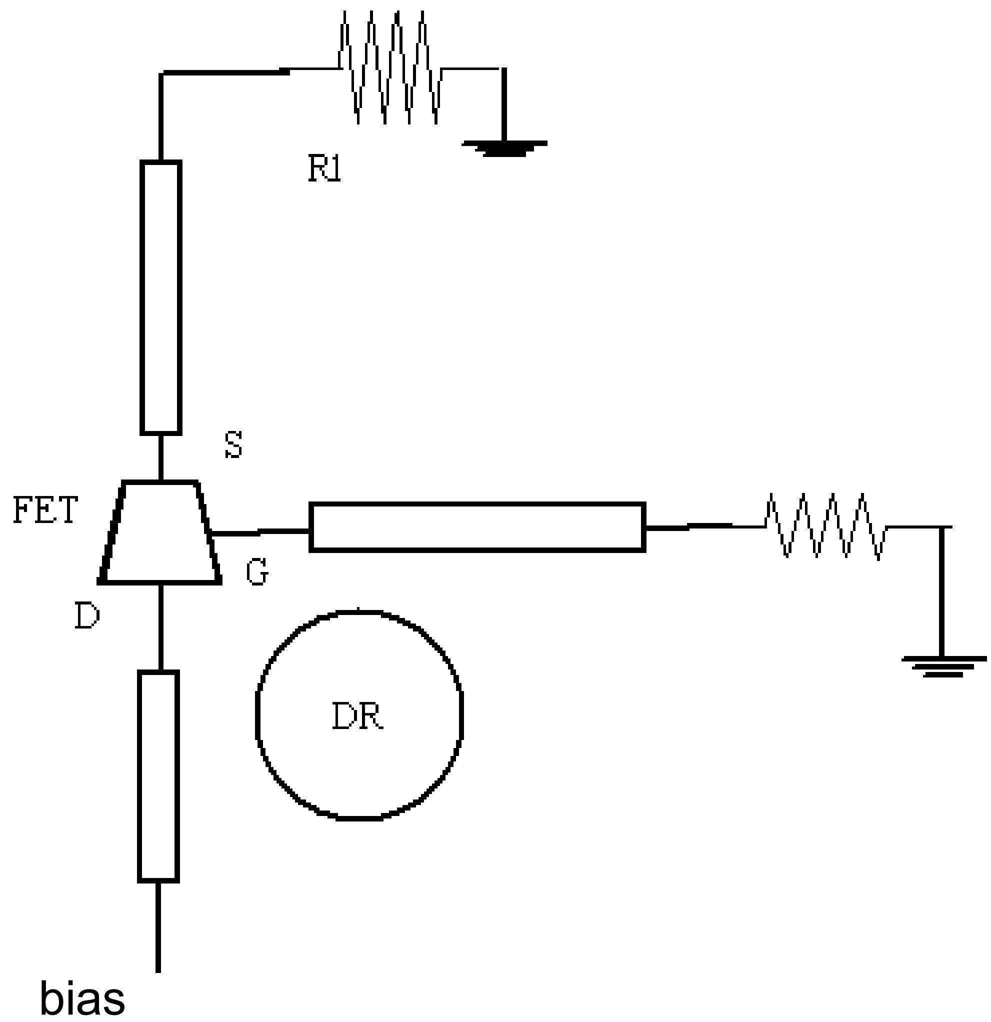


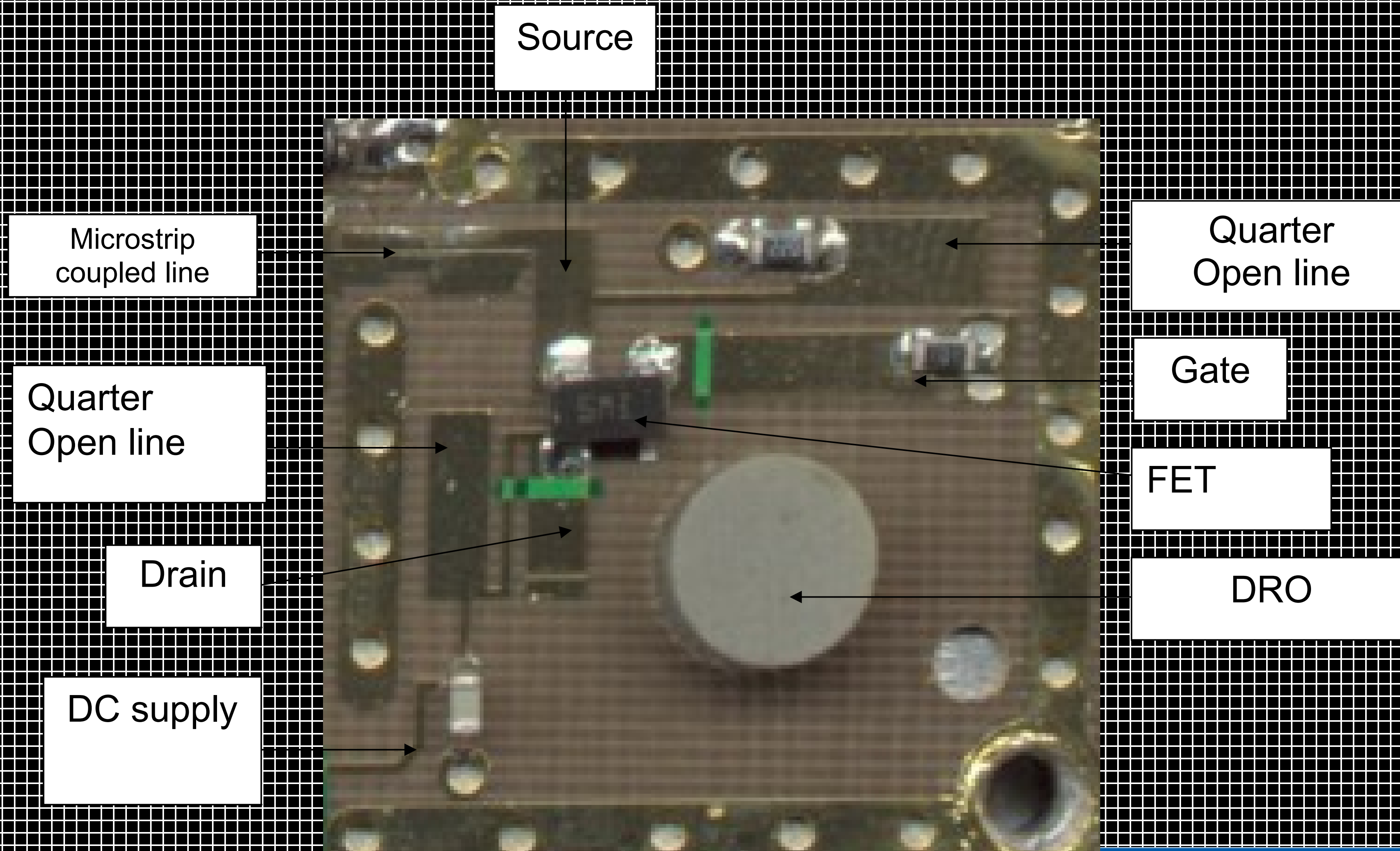
The purpose of input matching is to make the smallest S11. Output matching is conjugate matching, so we can make the maximum output power. Bias circuit determines working conditions, such as Class B or Class A amplifier.

- Hairpin band pass filter

dielectric resonator oscillators

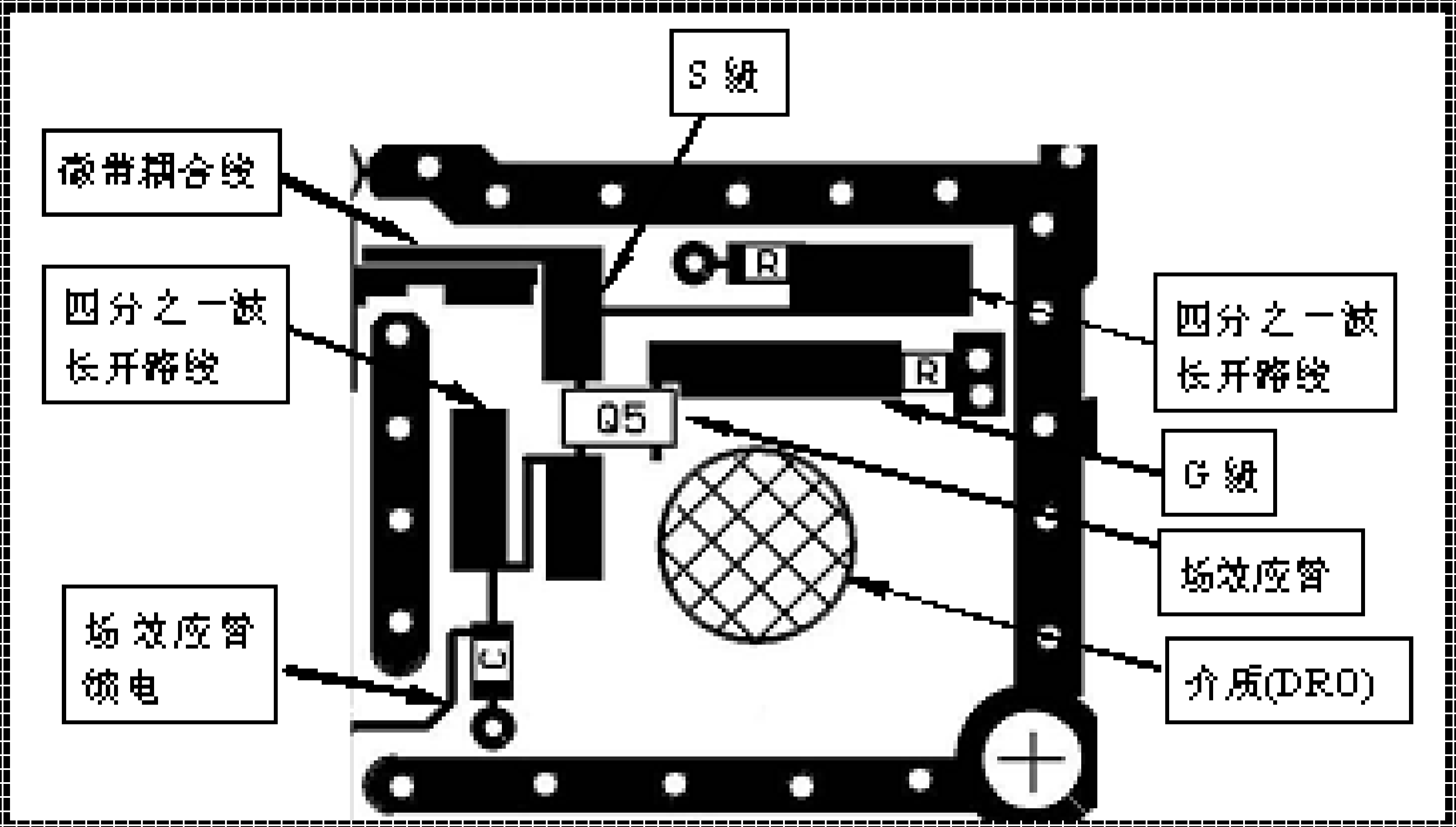
- The oscillator source is connected to ground, the oscillation signal is output from drain. The dielectric resonator placed between drain and gate, it as a band-pass filter and a feedback to form oscillator.
- Tapered microstrip line on Drain is used to match the impedance.
- The resistor is connected to gate in order to eliminate parasitic oscillations, which constitutes self biasing circuit with source.





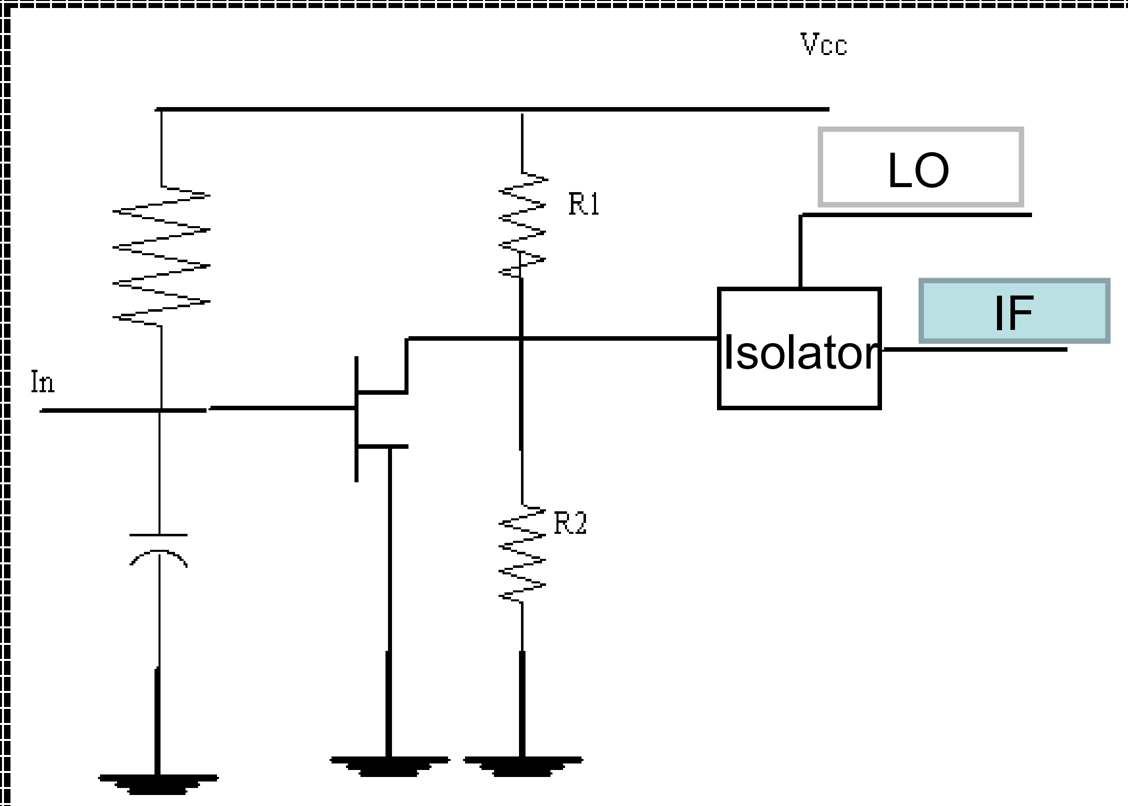
Source
Microstrip coupled line
Quarter Open line
Gate
Quarter Open line
FET
Drain
DRO
DC supply

Ku波段高频头电路—介质振荡器

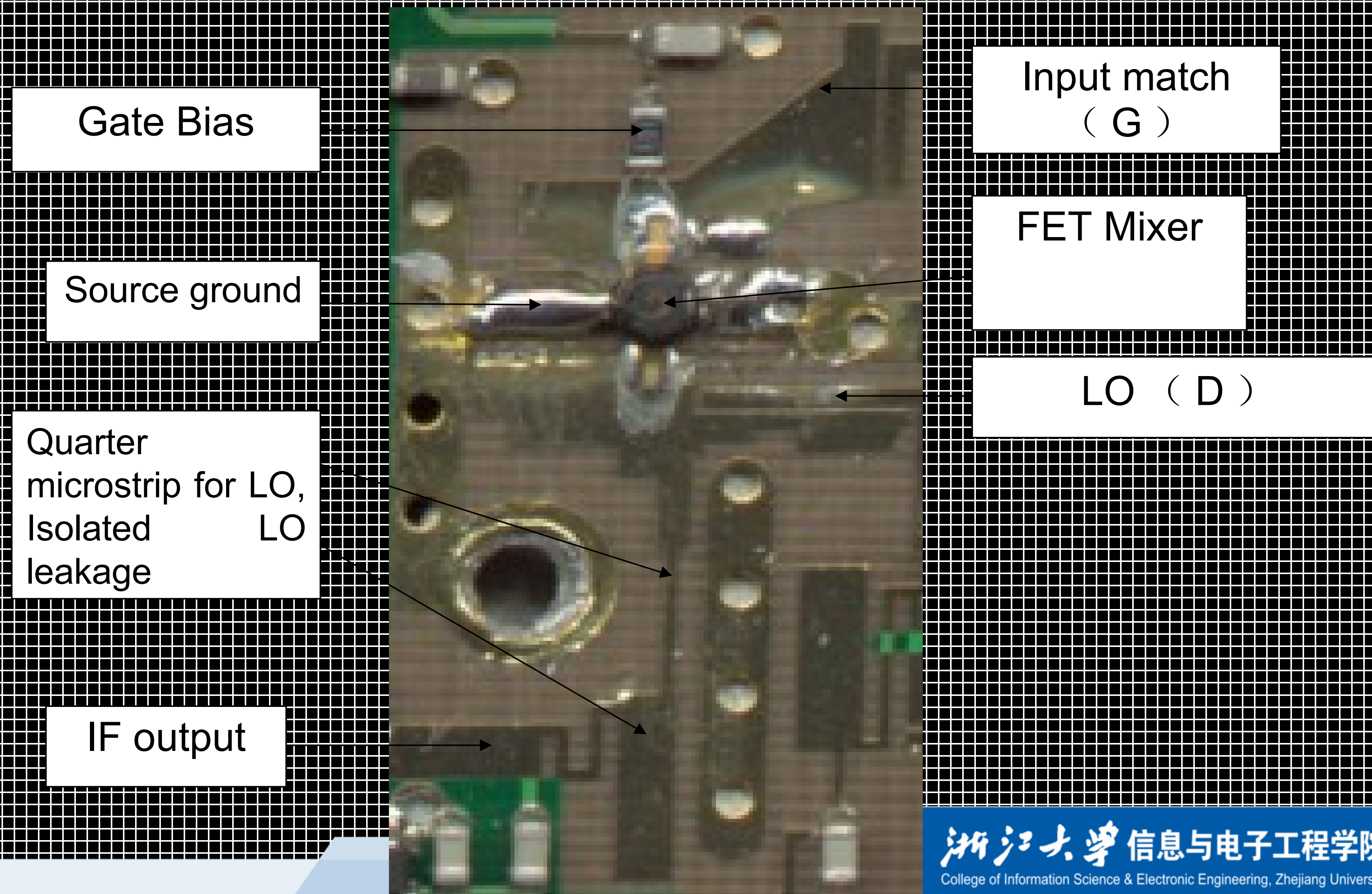


Mixer

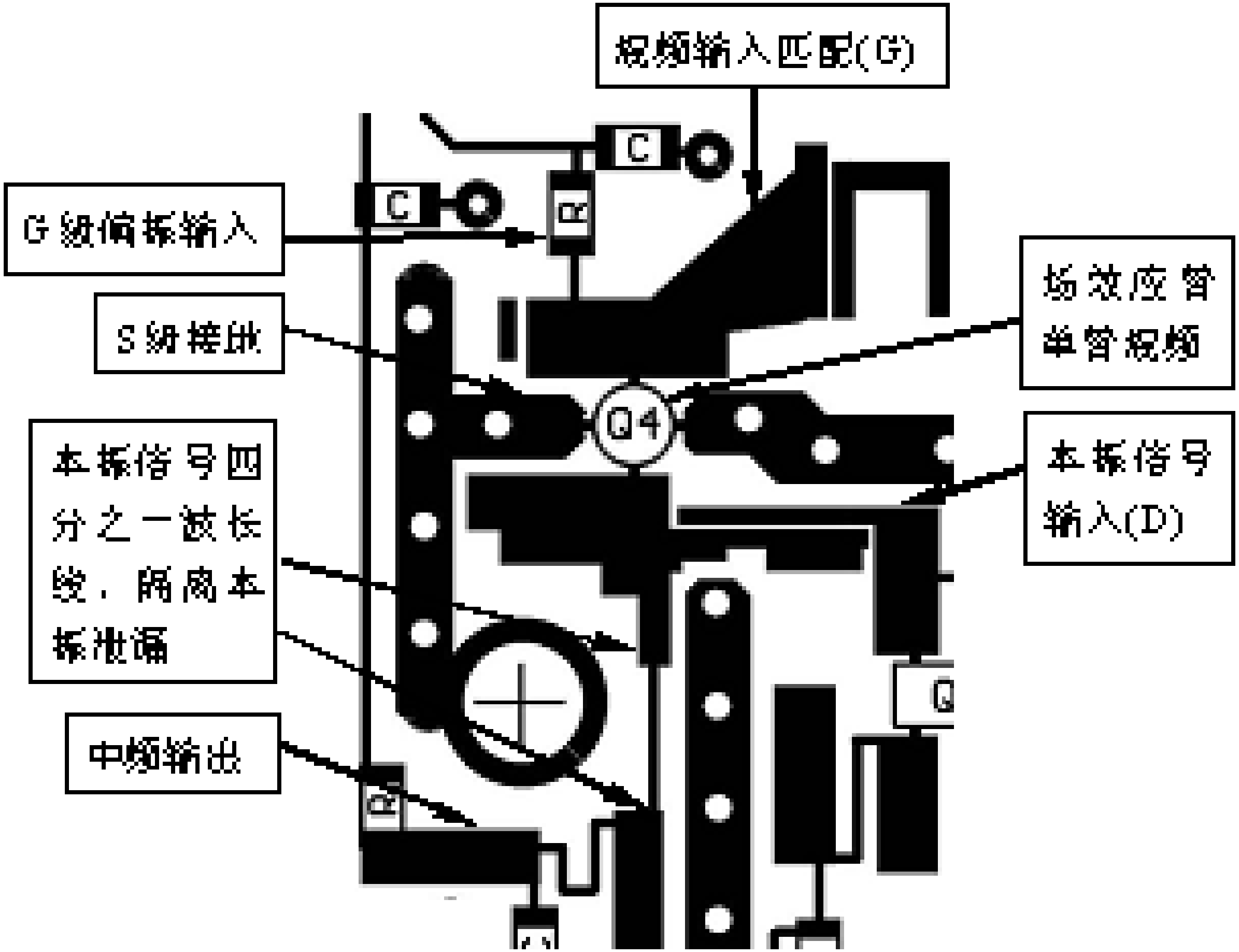
- For FET， nonlinear relationship between I_D and V_{GS}， high frequency signal is from Gate， LO signal is input from Drain. Then, we can use the nonlinear characteristics of channel resistance to realize .



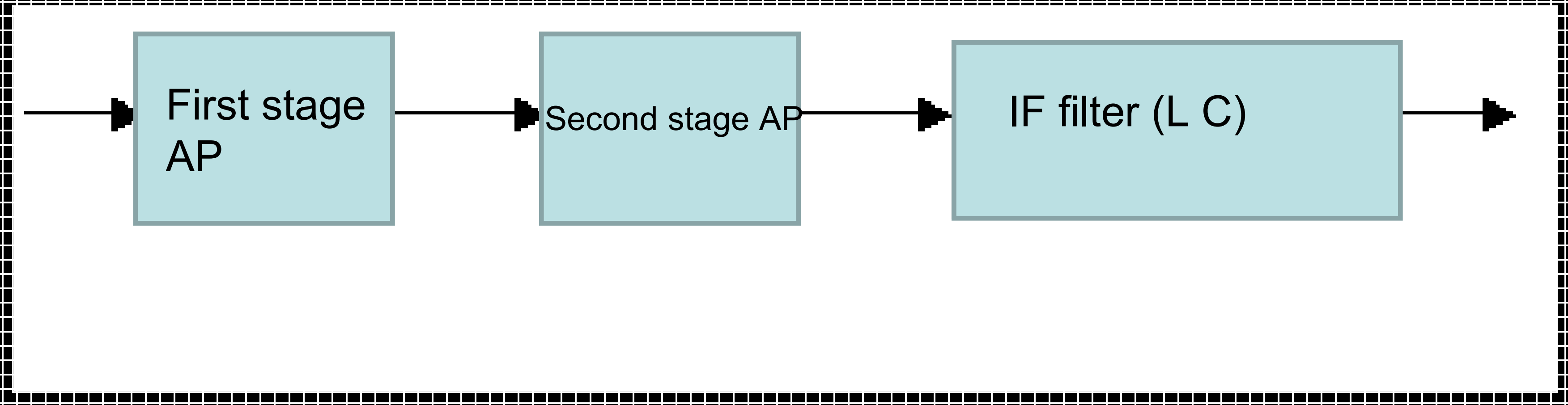
- High-frequency signal is directly into the gate, then it mix with local oscillator, so called drain mixer.


Gate Bias
Source ground
Quarter microstrip for LO, Isolated LO leakage
IF output
Input match （G）
FET Mixer
LO （D）

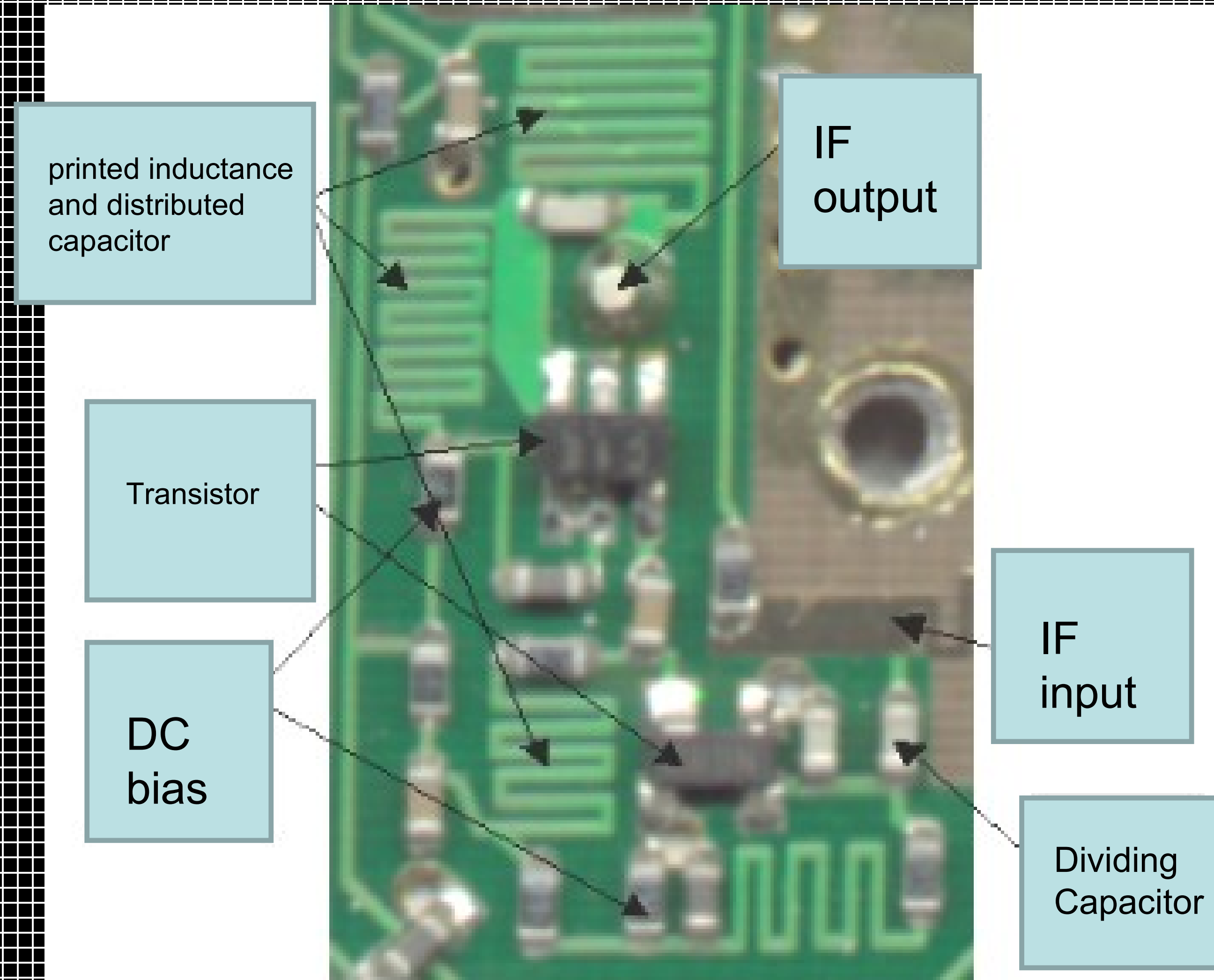
Mixer

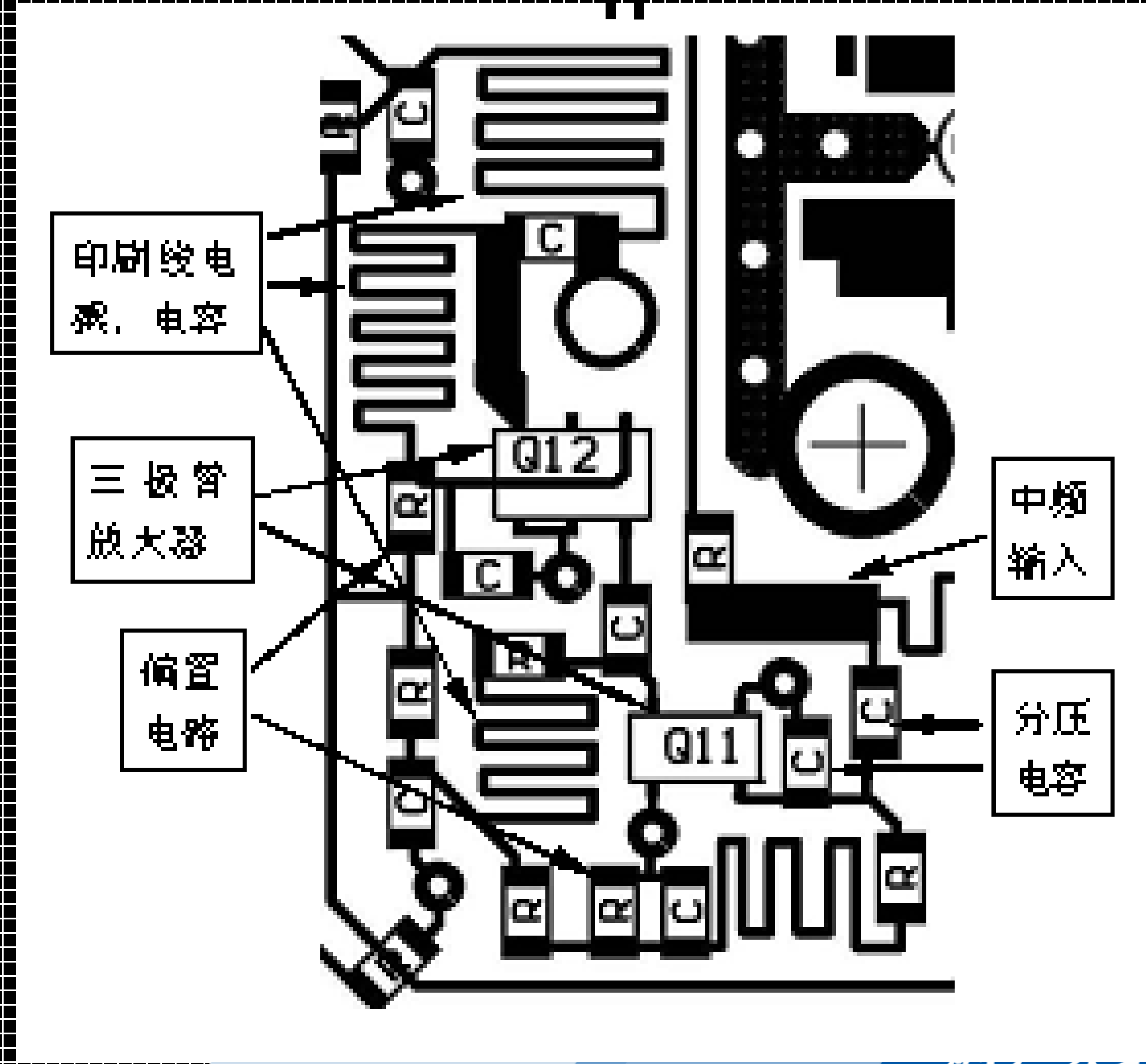

射频输入匹配(G)
G级偏振输入
S级接地
C
C
R
场效应管单管混频
Q4
本振信号四分之一波长线，隔离本振泄漏
本振信号输入(D)
中频输出
R

- Two transistors can compose an amplifier. Since the IF frequency of it is about 100MHz, the band-pass filter is produced by the printed inductance and distributed capacitor on circuit.



IF


printed inductance and distributed capacitor
IF output
Transistor
DC bias
IF input
Dividing Capacitor


印刷线电感，电容
三极管放大器
偏置电路
中频输入
分压电容
Q12
Q11

Circuit Schematic