Especificación de Sistemas

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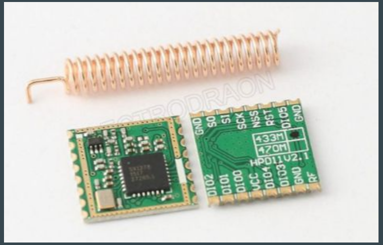
Comunicaciones Digitales

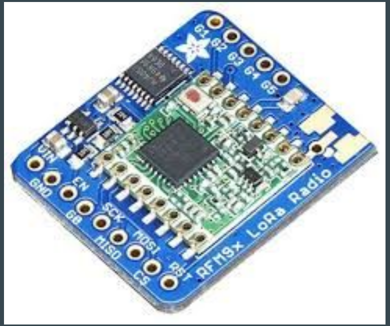
Temario

- Antenas
- Líneas de transmisión
- Linealidad
- Conceptos de Figura de Ruido
- Ruido de fase

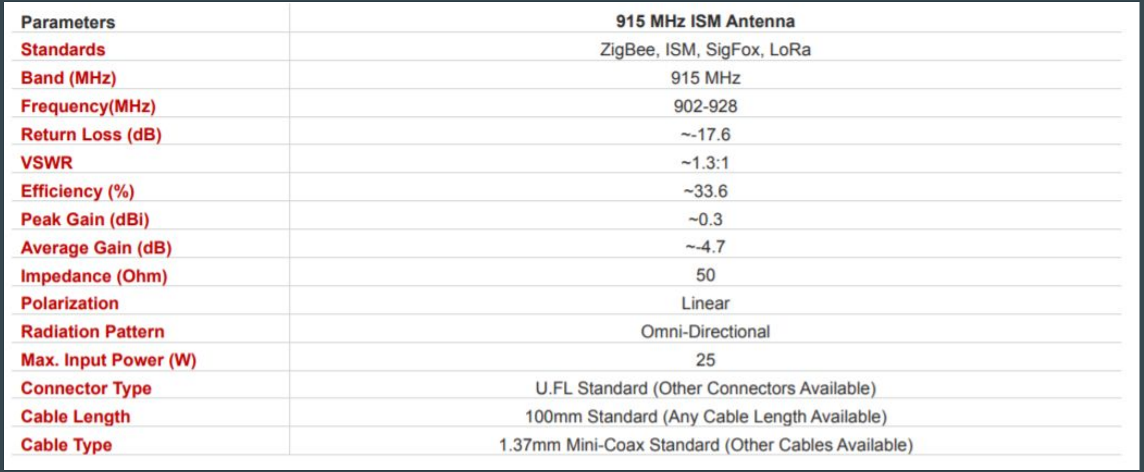
Antena para transceiver LoRa



- 915MHz SX1276
- Max power **20dBm**

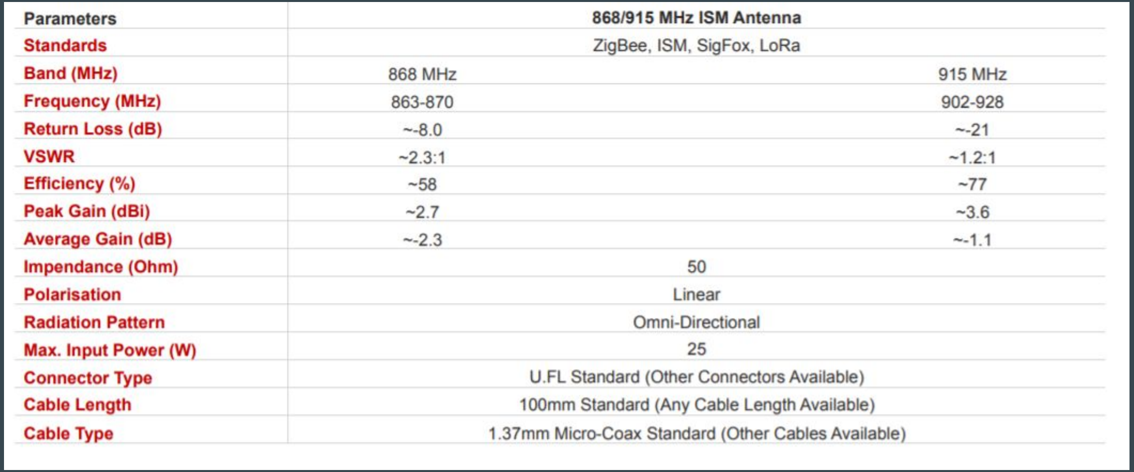


915MHz ISM Flexible Polymer



Parameters	915 MHz ISM Antenna
Standards	ZigBee, ISM, SigFox, LoRa
Band (MHz)	915 MHz
Frequency(MHz)	902-928
Return Loss (dB)	~-17.6
VSWR	~1.3:1
Efficiency (%)	~33.6
Peak Gain (dBi)	~0.3
Average Gain (dB)	~-4.7
Impedance (Ohm)	50
Polarization	Linear
Radiation Pattern	Omni-Directional
Max. Input Power (W)	25
Connector Type	U.FL Standard (Other Connectors Available)
Cable Length	100mm Standard (Any Cable Length Available)
Cable Type	1.37mm Mini-Coax Standard (Other Cables Available)

868/915 MHz ISM Adhesive Mount Flexible Polymer Embedded Antenna



Parameters	868/915 MHz ISM Antenna	
Standards	ZigBee, ISM, SigFox, LoRa	
Band (MHz)	868 MHz	915 MHz
Frequency (MHz)	863-870	902-928
Return Loss (dB)	~-8.0	~-21
VSWR	~2.3:1	~1.2:1
Efficiency (%)	~58	~77
Peak Gain (dBi)	~2.7	~3.6
Average Gain (dB)	~-2.3	~-1.1
Impendance (Ohm)	50	
Polarisation	Linear	
Radiation Pattern	Omni-Directional	
Max. Input Power (W)	25	
Connector Type	U.FL Standard (Other Connectors Available)	
Cable Length	100mm Standard (Any Cable Length Available)	
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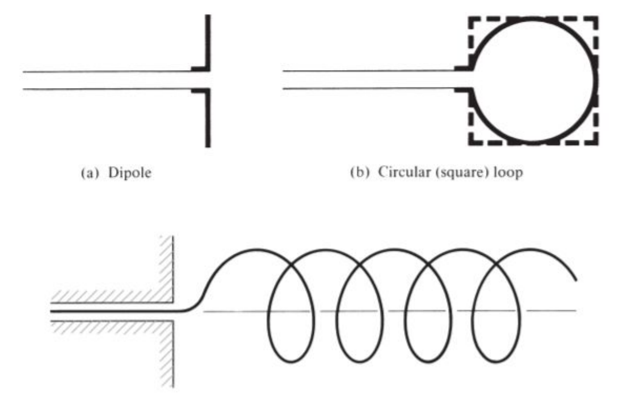
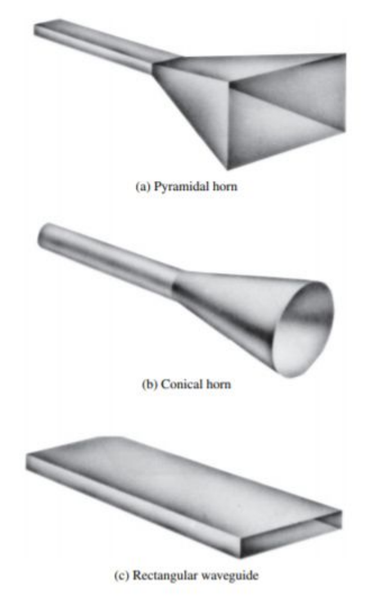
Tipos de antenas

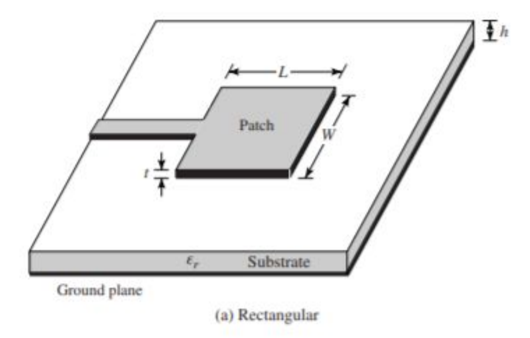

(a) Dipole

(b) Circular (square) loop


(a) Pyramidal horn

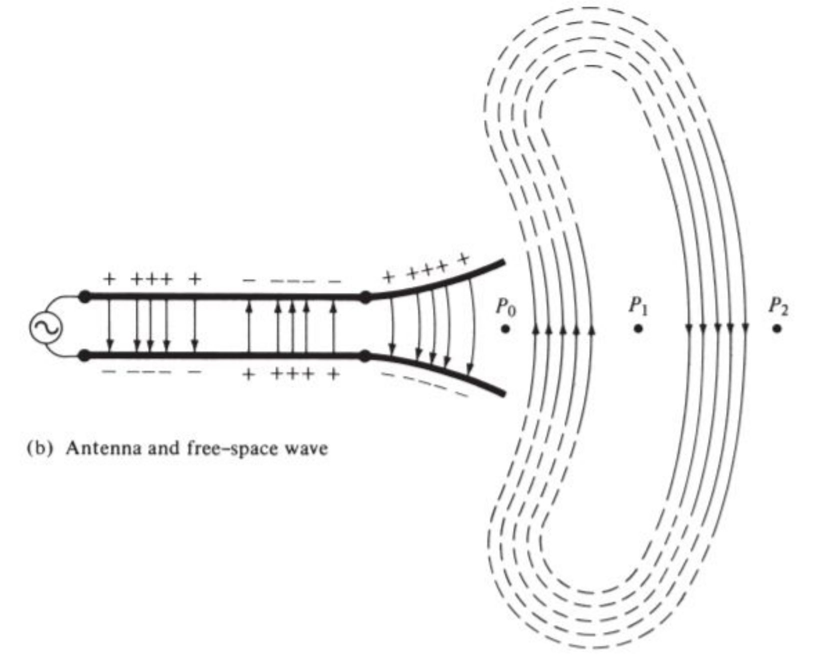
(b) Conical horn

(c) Rectangular waveguide



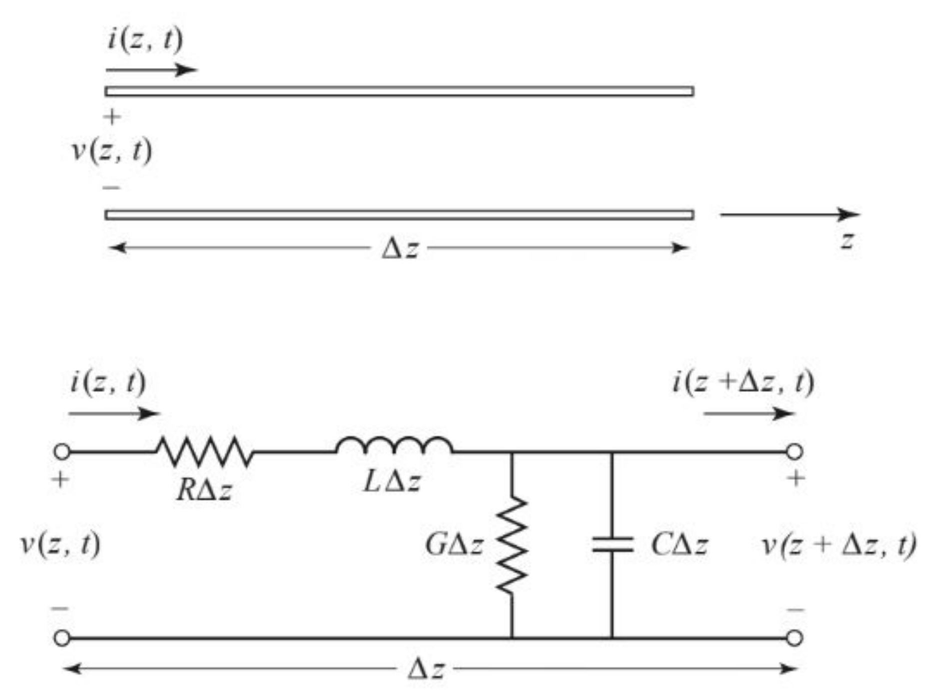
(a) Rectangular

Antena de 2 conductores



(b) Antenna and free–space wave

Ecuación del telegrafista



$$\frac{\partial v(z,t)}{\partial z} = -Ri(z,t) - L\frac{\partial i(z,t)}{\partial t},$$
$$\frac{\partial i(z,t)}{\partial z} = -Gv(z,t) - C\frac{\partial v(z,t)}{\partial t}.$$

$$\frac{dV(z)}{dz} = -(R + j\omega L)I(z),$$
$$\frac{dI(z)}{dz} = -(G + j\omega C)V(z).$$

$$V(z) = V_o^+ e^{-\gamma z} + V_o^- e^{\gamma z},$$
$$I(z) = I_o^+ e^{-\gamma z} + I_o^- e^{\gamma z},$$

Ecuaciones de línea (sin pérdidas)

$$\frac{V_o^+}{I_o^+} = Z_0 = \frac{-V_o^-}{I_o^-}.$$

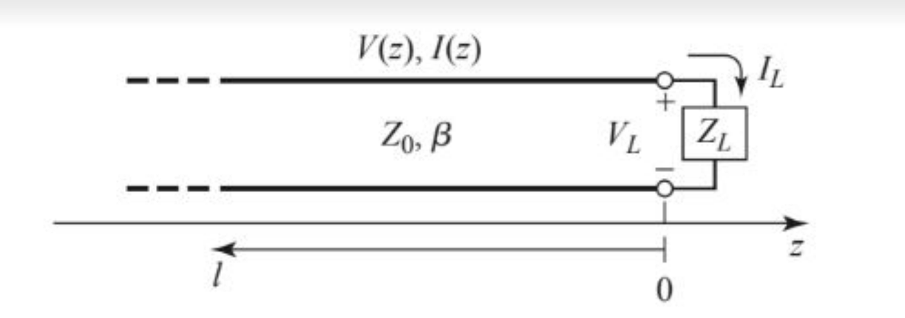
$$Z_0 = \sqrt{\frac{L}{C}},$$

$$\lambda = \frac{2\pi}{\beta},$$

$$\begin{aligned} V(z) &= V_o^+ e^{-j\beta z} + V_o^- e^{j\beta z}, \\ I(z) &= \frac{V_o^+}{Z_0} e^{-j\beta z} - \frac{V_o^-}{Z_0} e^{j\beta z}. \end{aligned}$$

Línea terminada sin pérdidas

$$V(z) = V_o^+ e^{-j\beta z} + V_o^- e^{j\beta z},$$
$$I(z) = \frac{V_o^+}{Z_0} e^{-j\beta z} - \frac{V_o^-}{Z_0} e^{j\beta z}.$$



$$Z_L = \frac{V(0)}{I(0)} = \frac{V_o^+ + V_o^-}{V_o^+ - V_o^-} Z_0.$$

$$V(z) = V_o^+ \left(e^{-j\beta z} + \Gamma e^{j\beta z}\right),$$
$$I(z) = \frac{V_o^+}{Z_0} \left(e^{-j\beta z} - \Gamma e^{j\beta z}\right).$$

$$\Gamma = \frac{V_o^-}{V_o^+} = \frac{Z_L - Z_0}{Z_L + Z_0}.$$

Coeficiente de reflección de voltaje

Onda estacionaria

$$V(z) = V_o^+ e^{-j\beta z} + V_o^- e^{j\beta z},$$

$$I(z) = \frac{V_o^+}{Z_0} e^{-j\beta z} - \frac{V_o^-}{Z_0} e^{j\beta z}.$$

$$P_{\text{avg}} = \frac{1}{2}\text{Re}\left\{V(z)I(z)^*\right\} = \frac{1}{2}\frac{|V_o^+|^2}{Z_0}\text{Re}\left\{1 - \Gamma^* e^{-2j\beta z} + \Gamma e^{2j\beta z} - |\Gamma|^2\right\},$$

$$P_{\text{avg}} = \frac{1}{2}\frac{|V_o^+|^2}{Z_0}\left(1 - |\Gamma|^2\right),$$

Onda estacionaria

$$V(z) = V_o^+ e^{-j\beta z} + V_o^- e^{j\beta z},$$

$$I(z) = \frac{V_o^+}{Z_0} e^{-j\beta z} - \frac{V_o^-}{Z_0} e^{j\beta z}.$$

Return Loss

$$\mathrm{RL} = -20 \log |\Gamma| \ \mathrm{dB},$$

Carga adaptada **Γ** = 0 → RL= ∞ dB (no reflejada)

Se refleja toda la potencia incidente |**Γ**| = 1 → RL=0 dB

$$|V(z)| = |V_o^+||1 + \Gamma e^{2j\beta z}| = |V_o^+||1 + \Gamma e^{-2j\beta \ell}|$$

$$V_{\max} = |V_o^+|(1 + |\Gamma|).$$

$$V_{\min} = |V_o^+|(1 - |\Gamma|).$$

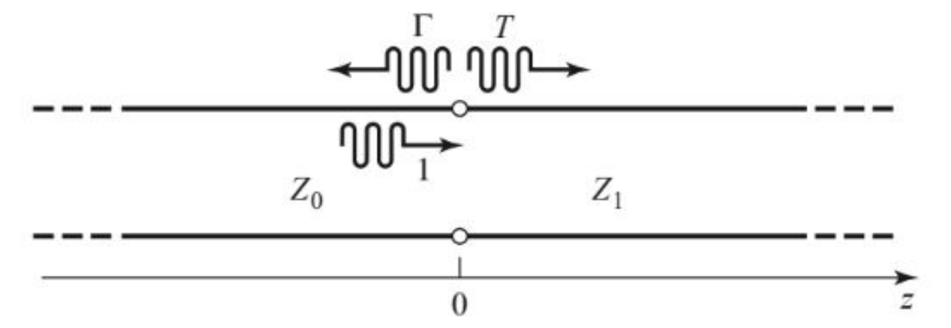
Voltage Standing Wave Ratio (VSWR)

$$\mathrm{SWR} = \frac{V_{\max}}{V_{\min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}.$$

$1 \leq \mathrm{SWR} \leq \infty$

Pérdidas de inserción

$$\Gamma = \frac{V_o^-}{V_o^+} = \frac{Z_L - Z_0}{Z_L + Z_0}.$$



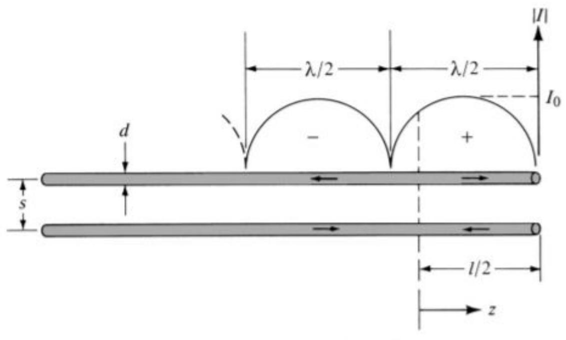
$$\Gamma = \frac{Z_1 - Z_0}{Z_1 + Z_0}.$$

$$V(z) = V_o^+ T e^{-j\beta z} \quad \text{for } z > 0.$$

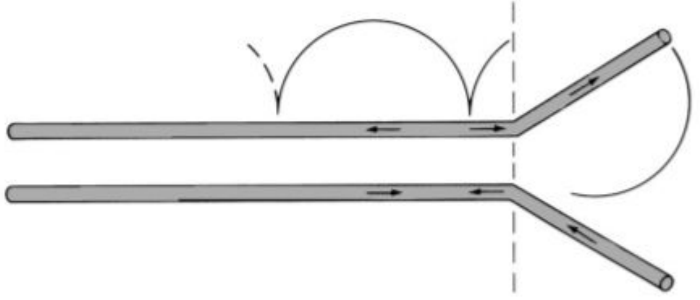
$$T = 1 + \Gamma = 1 + \frac{Z_1 - Z_0}{Z_1 + Z_0} = \frac{2Z_1}{Z_1 + Z_0}.$$

$$\text{IL} = -20 \log |T| \text{dB}.$$

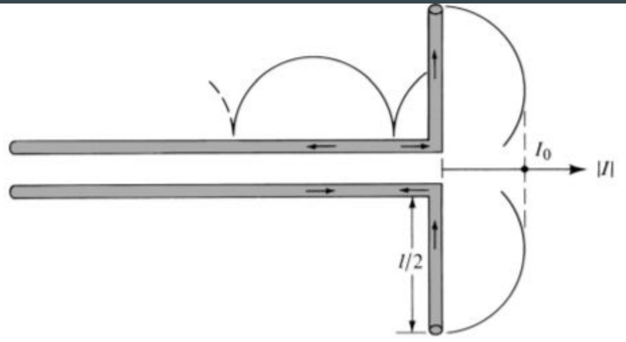
Distribución de corriente (línea sin pérdidas)



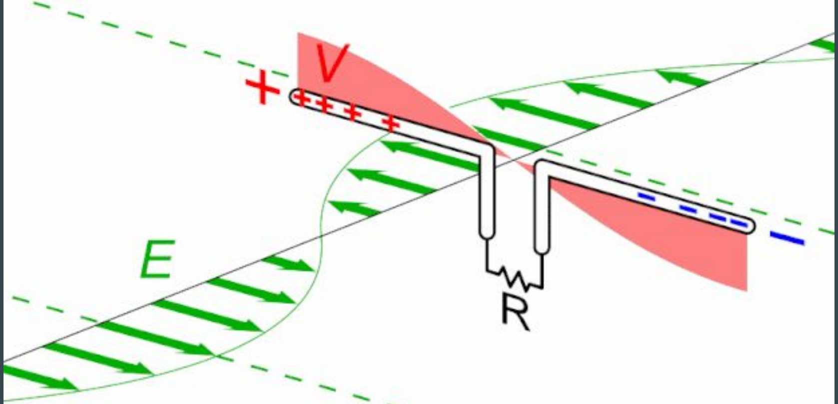
(a) Two-wire transmission line



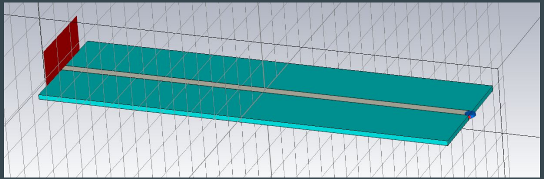
(b) Flared transmission line

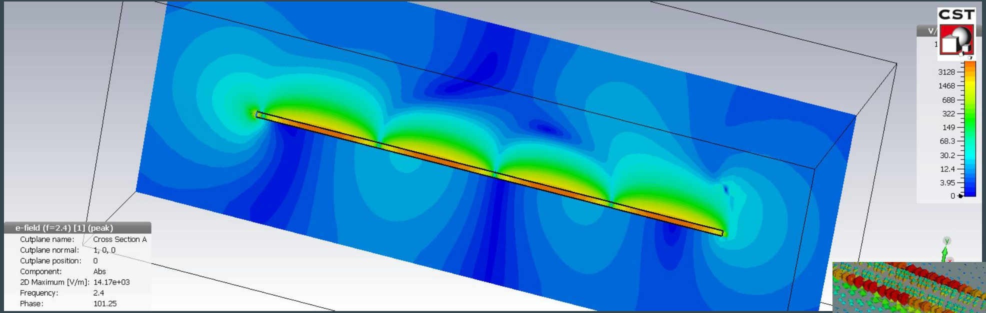


(c) Linear dipole



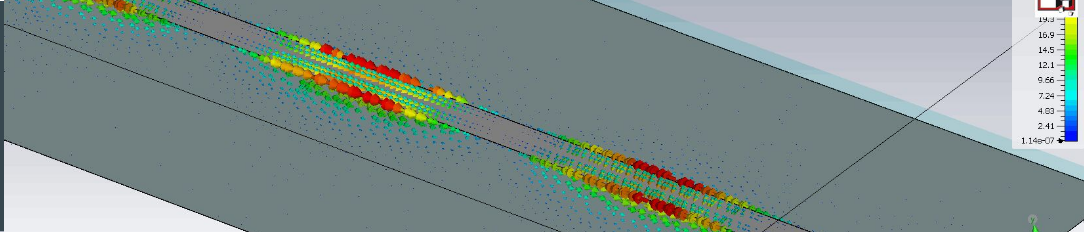
Microstripline





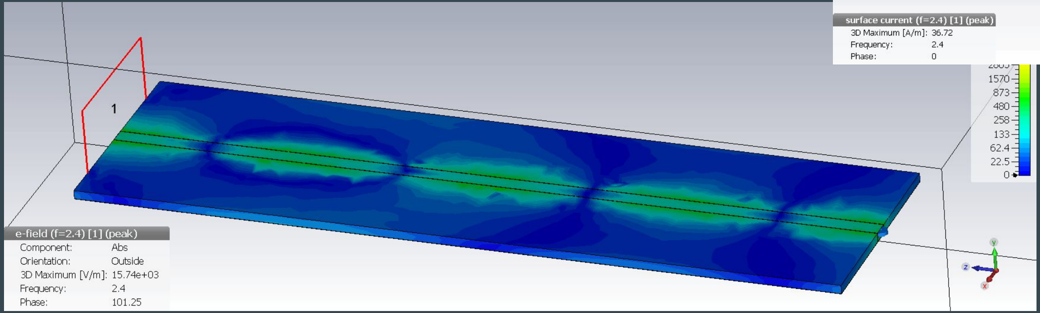
e-field (f=2.4) [1] (peak)

Cutplane name: Cross Section A
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: Abs
2D Maximum [V/m]: 14.17e+03
Frequency: 2.4
Phase: 101.25



surface current (f=2.4) [1] (peak)

3D Maximum [A/m]: 36.72
Frequency: 2.4
Phase: 0



e-field (f=2.4) [1] (peak)

Component: Abs
Orientation: Outside
3D Maximum [V/m]: 15.74e+03
Frequency: 2.4
Phase: 101.25

Directividad

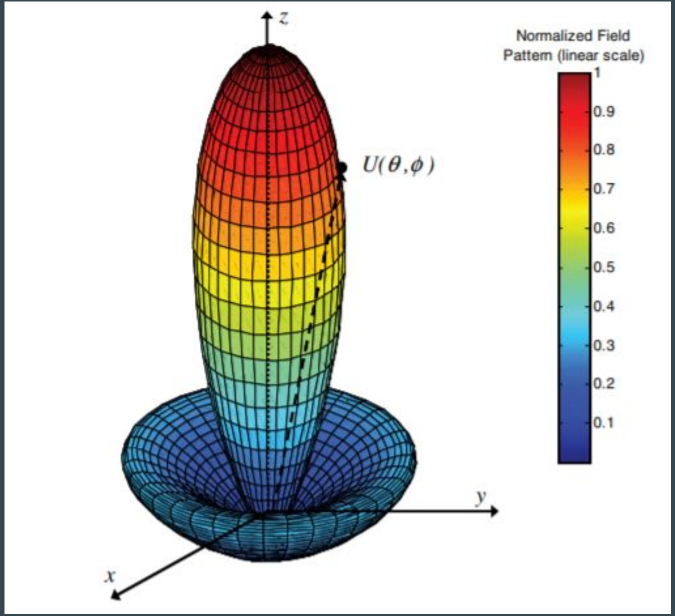
$$P_{\text{rad}} = \oiint_{\Omega} U \, d\Omega$$

$$U = r^2 W_{\text{rad}}$$

- **Radiation intensity** U: potencia radiada de una antena por unidad de ángulo sólido (W/unit solid angle)
- **Radiation density** Wrad: (W/m2)

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}$$

- **Directivity**: Relación entre la intensidad de radiación en una dirección y el promedio de intensidad de radiación en todas las direcciones (U0/4pi)

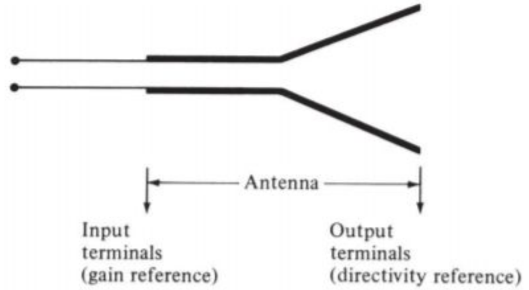


$$e_0 = e_r e_c e_d$$

$$e_0 = e_r e_{cd} = e_{cd}(1 - |\Gamma|^2)$$

$$P_{\text{rad}} = e_{cd} P_{in}$$

$$e_{cd} = e_c e_d = \text{antenna radiation efficiency},$$



(a) Antenna reference terminals

(b) Reflection, conduction, and dielectric losses

$$\text{Gain} = 4\pi \frac{\text{radiation intensity}}{\text{total input (accepted) power}} = 4\pi \frac{U(\theta, \phi)}{P_{in}}$$

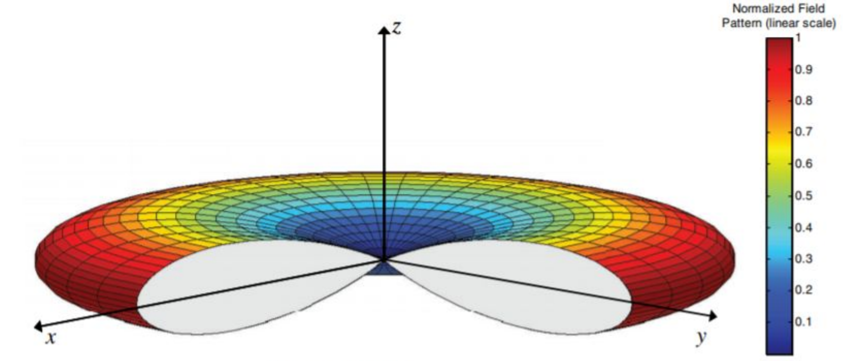
EEE Standards, : la ganancia no incluye pérdidas por desadaptación

$$G(\theta, \phi) = e_{cd} D(\theta, \phi)$$

$$\begin{aligned} G_{re}(\theta, \phi) &= e_r G(\theta, \phi) = (1 - |\Gamma|^2) G(\theta, \phi) \\ &= e_r e_{cd} D(\theta, \phi) = e_o D(\theta, \phi) \end{aligned}$$

Realized Gain

- Directivity de un radiador isotrópico es la unidad porque radia por igual en todas las direcciones



(b) Without minor lobes

Figure 2.17 Omnidirectional patterns with and without minor lobes.

Antena LoRa

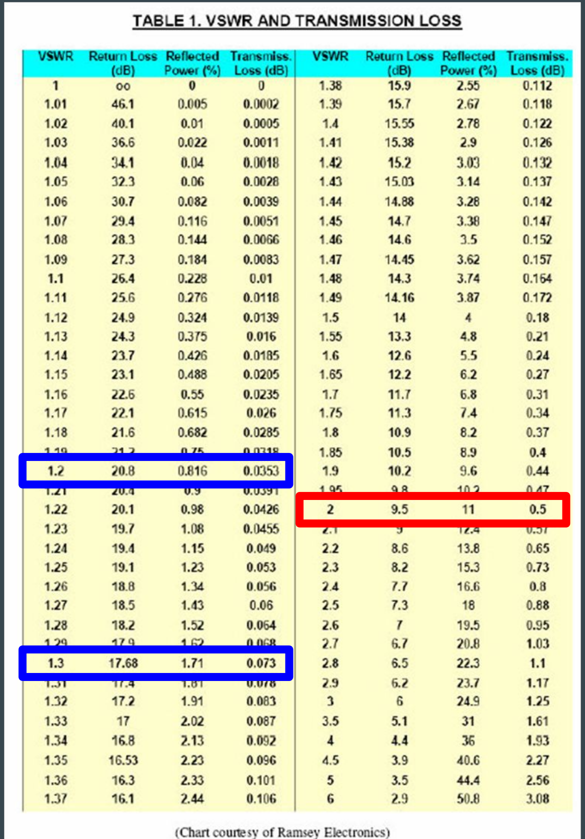
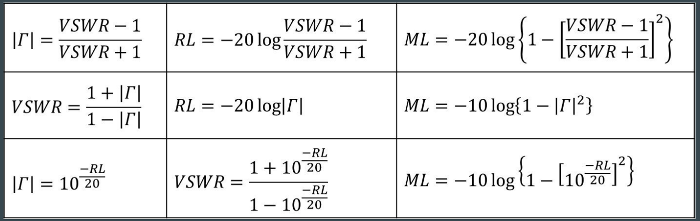


TABLE 1. VSWR AND TRANSMISSION LOSS

VSWR	Return Loss (dB)	Reflected Power (%)	Transmiss. Loss (dB)	VSWR	Return Loss (dB)	Reflected Power (%)	Transmiss. Loss (dB)
1	oo	0	0	1.38	15.9	2.55	0.112
1.01	46.1	0.005	0.0002	1.39	15.7	2.67	0.118
1.02	40.1	0.01	0.0005	1.4	15.55	2.78	0.122
1.03	36.6	0.022	0.0011	1.41	15.38	2.9	0.126
1.04	34.1	0.04	0.0018	1.42	15.2	3.03	0.132
1.05	32.3	0.06	0.0028	1.43	15.03	3.14	0.137
1.06	30.7	0.082	0.0039	1.44	14.88	3.28	0.142
1.07	29.4	0.116	0.0051	1.45	14.7	3.38	0.147
1.08	28.3	0.144	0.0066	1.46	14.6	3.5	0.152
1.09	27.3	0.184	0.0083	1.47	14.45	3.62	0.157
1.1	26.4	0.228	0.01	1.48	14.3	3.74	0.164
1.11	25.6	0.276	0.0118	1.49	14.16	3.87	0.172
1.12	24.9	0.324	0.0139	1.5	14	4	0.18
1.13	24.3	0.375	0.016	1.55	13.3	4.8	0.21
1.14	23.7	0.426	0.0185	1.6	12.6	5.5	0.24
1.15	23.1	0.488	0.0205	1.65	12.2	6.2	0.27
1.16	22.6	0.55	0.0235	1.7	11.7	6.8	0.31
1.17	22.1	0.615	0.026	1.75	11.3	7.4	0.34
1.18	21.6	0.682	0.0285	1.8	10.9	8.2	0.37
1.19	21.2	0.75	0.0318	1.85	10.5	8.9	0.4
1.2	20.8	0.816	0.0353	1.9	10.2	9.6	0.44
1.21	20.4	0.9	0.0391	1.95	9.8	10.2	0.47
1.22	20.1	0.98	0.0426	2	9.5	11	0.5
1.23	19.7	1.08	0.0455	2.1	9	12.4	0.57
1.24	19.4	1.15	0.049	2.2	8.6	13.8	0.65
1.25	19.1	1.23	0.053	2.3	8.2	15.3	0.73
1.26	18.8	1.34	0.056	2.4	7.7	16.6	0.8
1.27	18.5	1.43	0.06	2.5	7.3	18	0.88
1.28	18.2	1.52	0.064	2.6	7	19.5	0.95
1.29	17.9	1.62	0.068	2.7	6.7	20.8	1.03
1.3	17.68	1.71	0.073	2.8	6.5	22.3	1.1
1.31	17.4	1.81	0.078	2.9	6.2	23.7	1.17
1.32	17.2	1.91	0.083	3	6	24.9	1.25
1.33	17	2.02	0.087	3.5	5.1	31	1.61
1.34	16.8	2.13	0.092	4	4.4	36	1.93
1.35	16.53	2.23	0.096	4.5	3.9	40.6	2.27
1.36	16.3	2.33	0.101	5	3.5	44.4	2.56
1.37	16.1	2.44	0.106	6	2.9	50.8	3.08

(Chart courtesy of Ramsey Electronics)



$\lvert\Gamma\rvert = \frac{VSWR-1}{VSWR+1}$	$RL = -20\log\frac{VSWR-1}{VSWR+1}$	$ML = -20\log\left\{1-\left[\frac{VSWR-1}{VSWR+1}\right]^2\right\}$
$VSWR = \frac{1+\lvert\Gamma\rvert}{1-\lvert\Gamma\rvert}$	$RL = -20\log\lvert\Gamma\rvert$	$ML = -10\log\{1-\lvert\Gamma\rvert^2\}$
$\lvert\Gamma\rvert = 10^{\frac{-RL}{20}}$	$VSWR = \frac{1+10^{\frac{-RL}{20}}}{1-10^{\frac{-RL}{20}}}$	$ML = -10\log\left\{1-\left[10^{\frac{-RL}{20}}\right]^2\right\}$

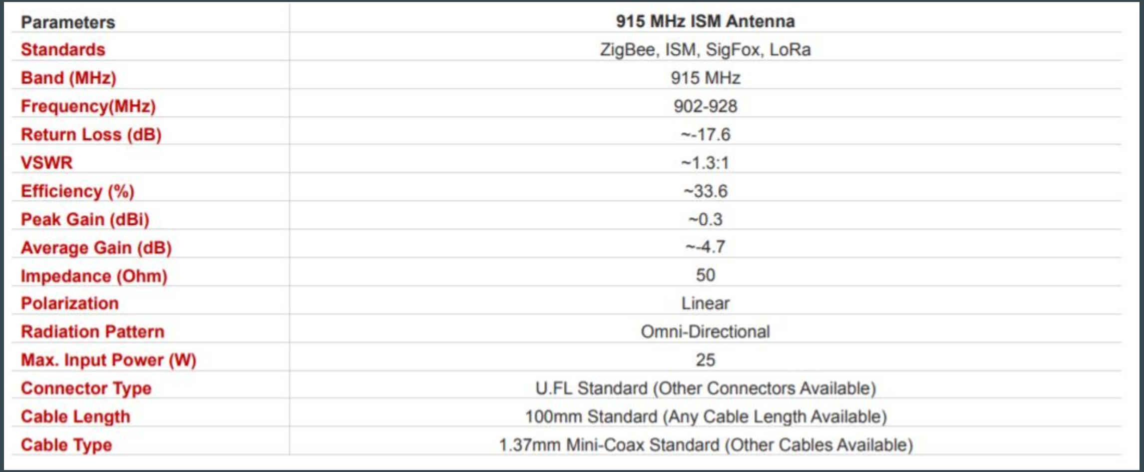
SWR =1.2 $\lvert\Gamma\rvert$ =0.091 RL =20.8dB Pr =0.826%

SWR =1.3 $\lvert\Gamma\rvert$ =0.13 RL =17.68dB Pr =1.71%

G1= 10log(0.336) -4.7dBi -0.036dB= -9.5dBi

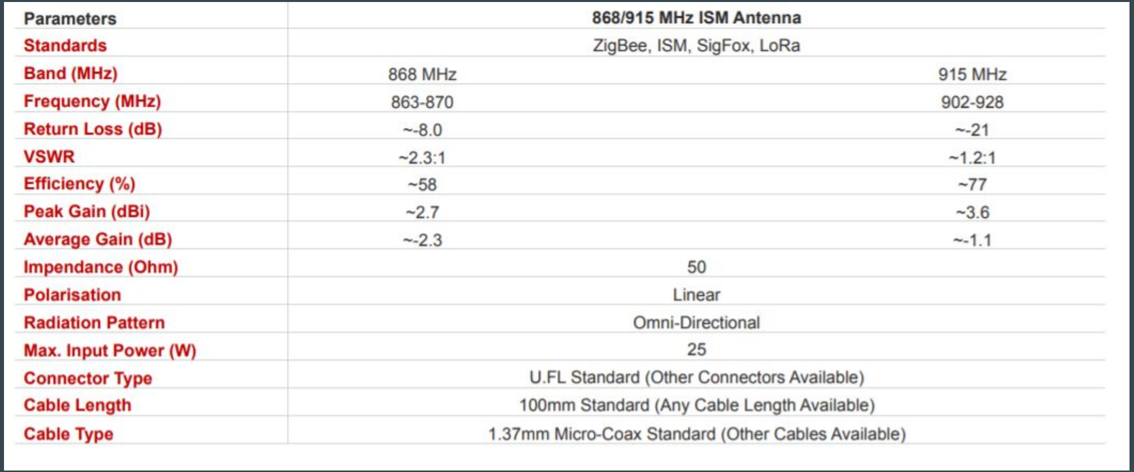
G2= 10log(0.77) -1.1dBi -0.074dB= -2.3dBi

915MHz ISM Flexible Polymer



Parameters	915 MHz ISM Antenna
Standards	ZigBee, ISM, SigFox, LoRa
Band (MHz)	915 MHz
Frequency(MHz)	902-928
Return Loss (dB)	~-17.6
VSWR	~1.3:1
Efficiency (%)	~33.6
Peak Gain (dBi)	~0.3
Average Gain (dB)	~-4.7
Impedance (Ohm)	50
Polarization	Linear
Radiation Pattern	Omni-Directional
Max. Input Power (W)	25
Connector Type	U.FL Standard (Other Connectors Available)
Cable Length	100mm Standard (Any Cable Length Available)
Cable Type	1.37mm Mini-Coax Standard (Other Cables Available)

868/915 MHz ISM Adhesive Mount Flexible Polymer Embedded Antenna



Parameters	868/915 MHz ISM Antenna	
Standards	ZigBee, ISM, SigFox, LoRa	
Band (MHz)	868 MHz	915 MHz
Frequency (MHz)	863-870	902-928
Return Loss (dB)	~-8.0	~-21
VSWR	~2.3:1	~1.2:1
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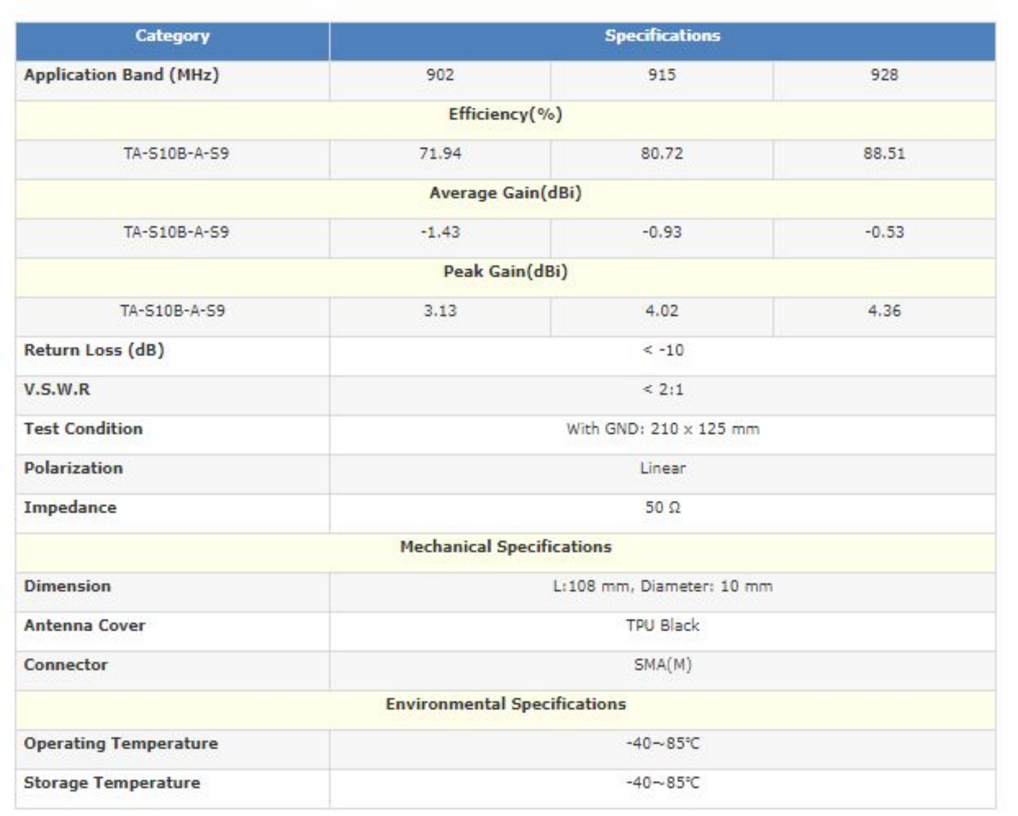
https://www.mouser.com/Search/Refine?N=14930470

https://www.2j-antennas.com/media/original/datasheets/2jf05

https://www.2j-antennas.com/media/original/datasheets/2jf04

ISM 915Mhz Band Hinge Rotatable Terminal Antenna



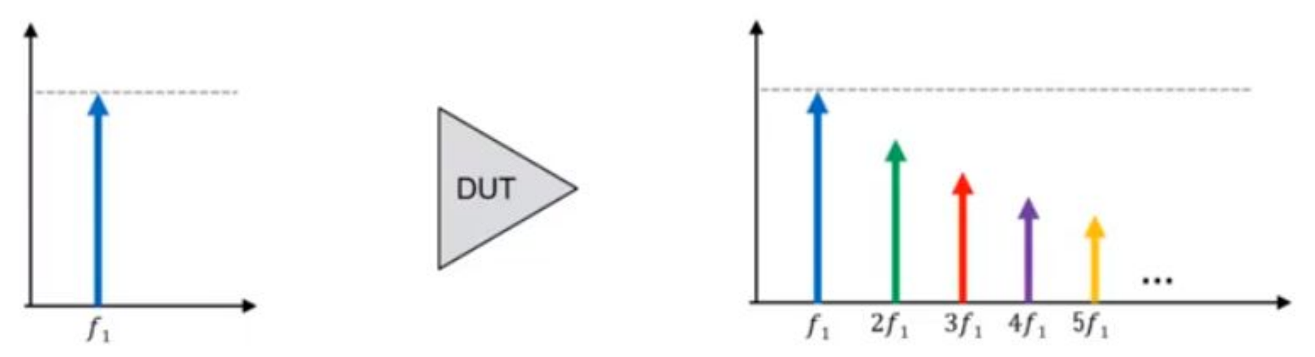
Category	Specifications		
Application Band (MHz)	902	915	928
Efficiency(%)			
TA-S10B-A-S9	71.94	80.72	88.51
Average Gain(dBi)			
TA-S10B-A-S9	-1.43	-0.93	-0.53
Peak Gain(dBi)			
TA-S10B-A-S9	3.13	4.02	4.36
Return Loss (dB)	< -10		
V.S.W.R	< 2:1		
Test Condition	With GND: 210 x 125 mm		
Polarization	Linear		
Impedance	50 Ω		
Mechanical Specifications			
Dimension	L:108 mm, Diameter: 10 mm		
Antenna Cover	TPU Black		
Connector	SMA(M)		
Environmental Specifications			
Operating Temperature	-40~85℃		
Storage Temperature	-40~85℃		

Linealidad

- Salida es directamente proporcional a la entrada
- Típicamente lineal para un rango de potencia de entrada
- Si el dispositivo opera en la zona no-lineal puede crear distorsión en la forma de armónicos y productos de intermodulación

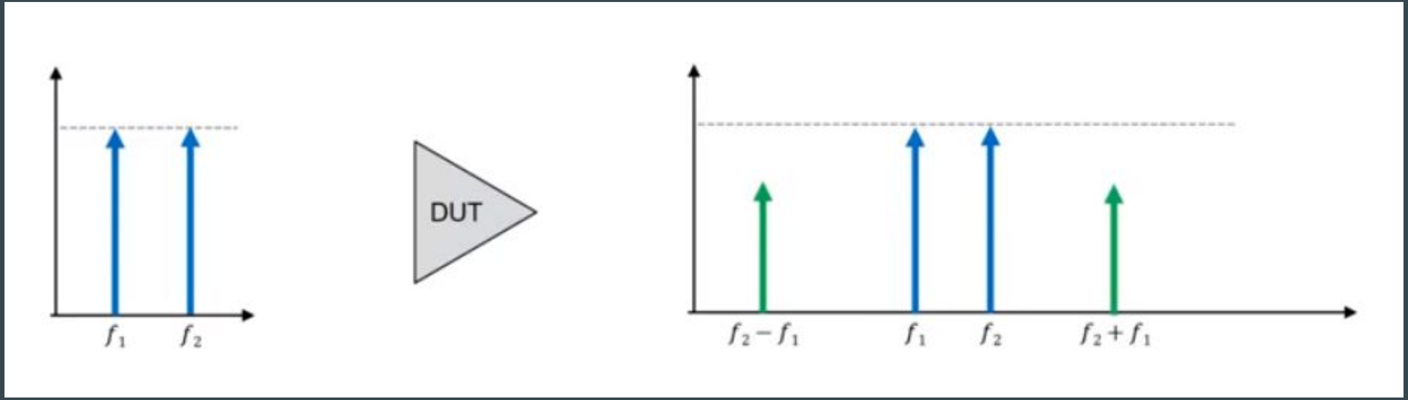
Armónicos

- Copias de la señal en múltiplos enteros de la fundamental
- Amplitud del armónico típicamente decrece cuando aumenta su orden



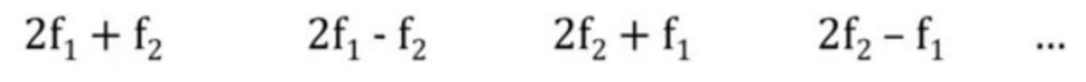
Intermodulación

- Intermodulación ocurre cuando dos (o más) señales se **mezclan** en un dispositivo no-lineal
- La multiplicación (mezcla) produce nuevas señales en la **suma** y en la **diferencia** de sus frecuencias



Orden de los productos

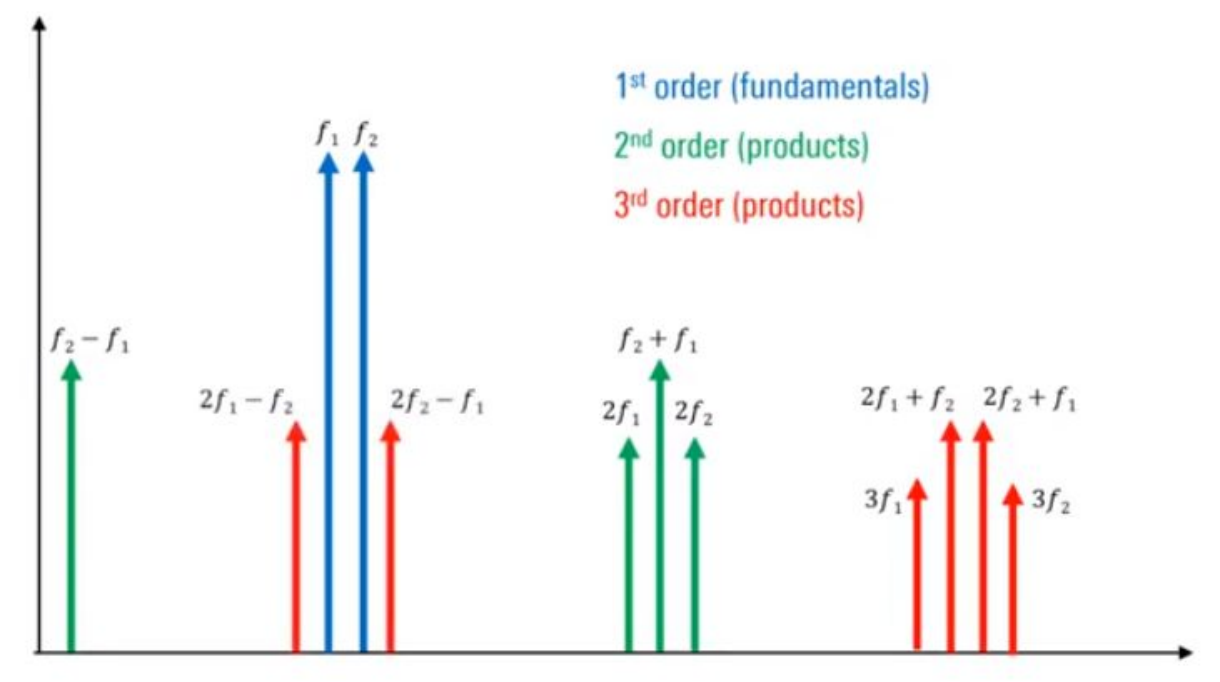
- Los tonos f_1 y f_2 se mezclan entre sí
- Se pueden mezclar con sus armónicos como ser $2f_1$ y $2f_2$
- Productos adicionales en:



$2f_1 + f_2$ $2f_1 - f_2$ $2f_2 + f_1$ $2f_2 - f_1$ ...

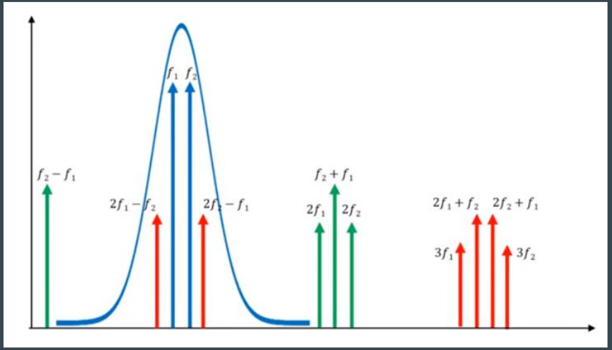
- El orden es la suma sin signo de los coeficientes
    - $2f_1$ es segundo orden (2)
    - $f_1 + f_2$ es segundo orden (1+1)
    - $3f_1$ es tercer orden (3)
    - $2f_1 - f_2$ es tercer orden (2+1)

Armónicos y productos de intermodulación



Problemas con los productos

- Armónicos y los productos son indeseables
    - Generan interferencia en los canales adyacentes, ruido o distorsión
- Intermodulación indeseable ----> se la refiere como IMD
- Algunos productos son fáciles de manejar
    - Armónicos de alto orden tienen baja amplitud
    - Productos de alta frecuencia caen fuera del ancho de banda del amp, o fuera del BPF



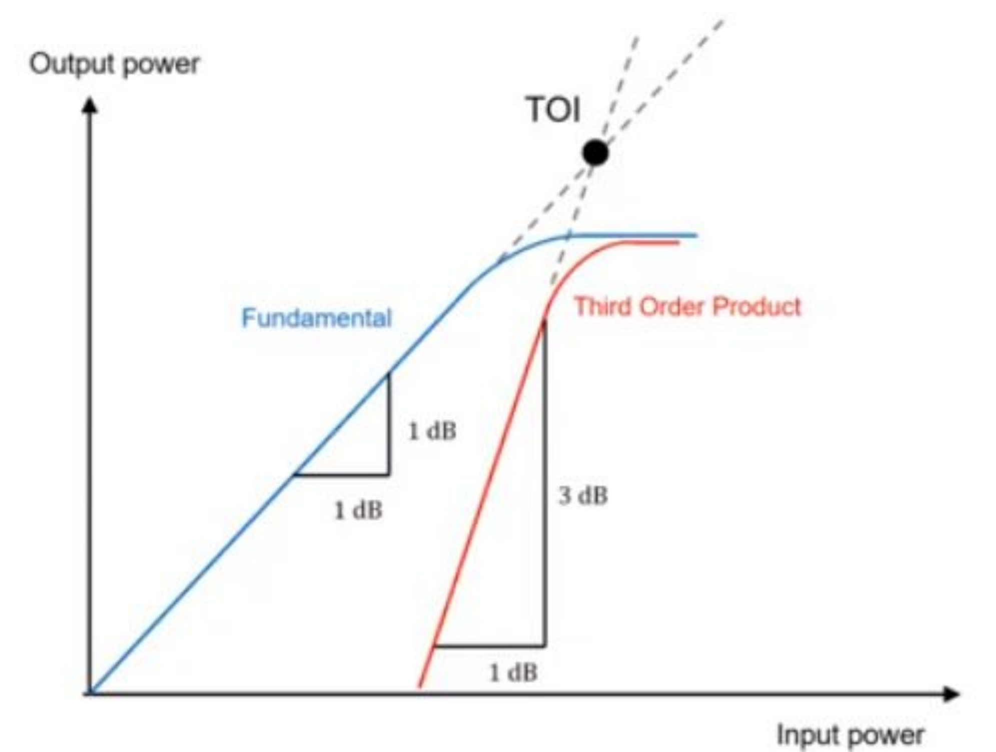
Productos difícil de sacar

- Los productos de orden 3

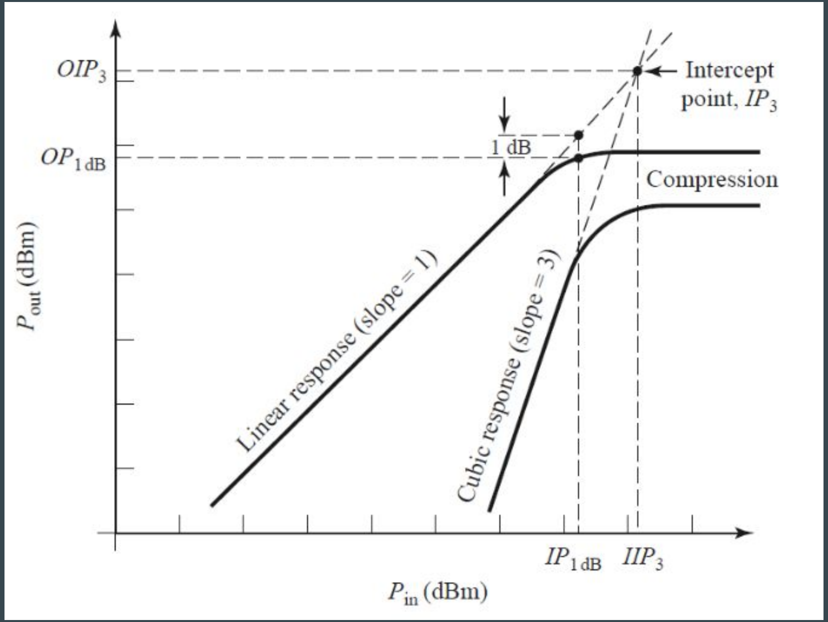
$$2f_1 - f_2$$
$$2f_2 - f_1$$

- Si incremento 1dB en la fundamental y se incrementan 3dB en los productos

- Las líneas se intersectan en TOI (third order intercept) pero antes se llega a la compresión, es un punto teórico



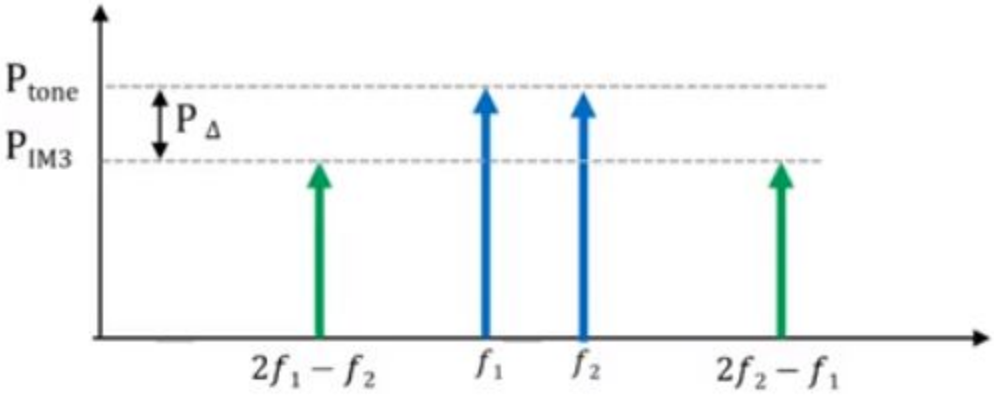
Compresión de 1dB



Usos del TOI

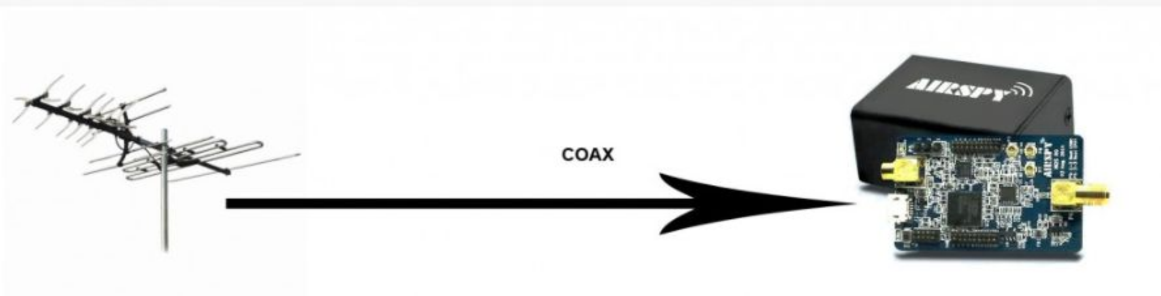
- Figura de mérito de la linealidad, cuanto más alto mejor!
- Muchas hojas de datos se refieren al TOI como IP3

Medida

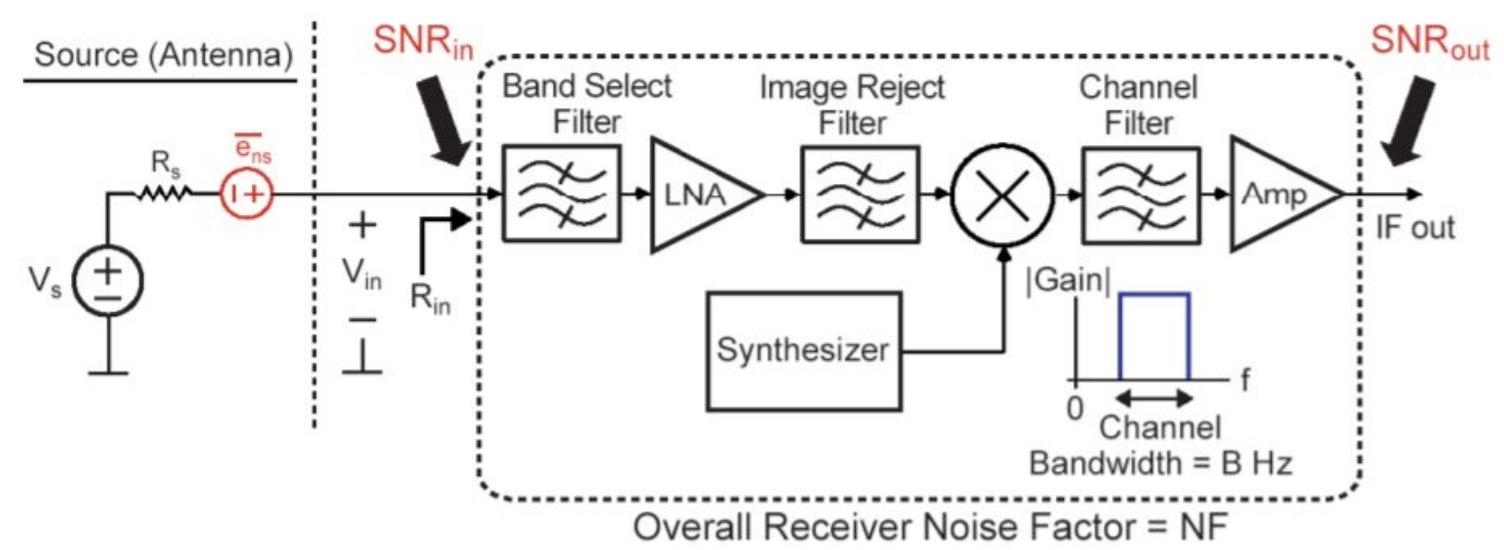


$$TOI = Ptone + \frac{P_{\Delta}}{2}$$

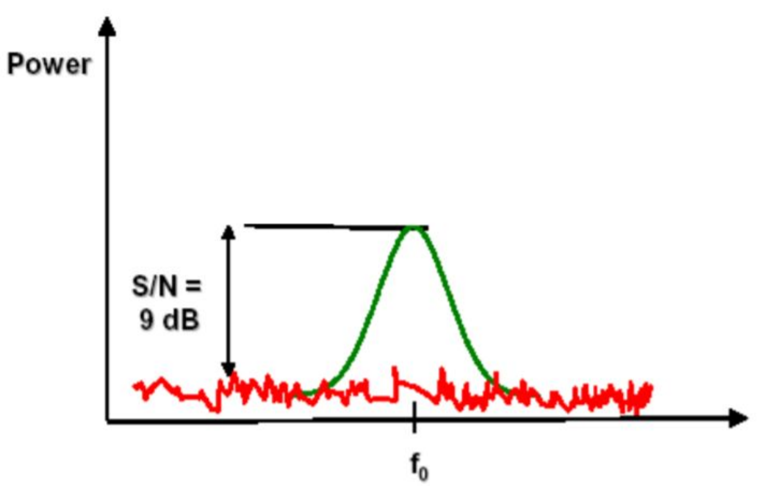
Quiero recibir con un SDR



Receptor “SDR”



SNR en detección (salida)



Especificaciones

- Pot. recibida (sensibilidad) : **Prx= -108dBm**
- Ganancia de la antena **Ga = 10dB**
- Ancho del canal: **BW=200kHz**
- Para **BER < 10^-3** se necesita **SNR >9dB**
- Figura de ruido del sistema **NFsys= 6dB**
- SFDR del SDR 76dB

$$NF = (S/N)_i - (S/N)_o$$

$$P_N = 10\log(kTB) = -174dBm + 10\log(B)$$

$$MDS = F_{sys}kT_0B = \text{-174dBm} + NF_{sys} + 10\log(B)$$

$$P_N = -174dBm + 10\log(200k) = -174 + 53 = -121dBm$$

$$(S/N)_i = P_{rx} - P_N = -108 - (-121) = 13dB$$

$$(S/N)_o = (S/N)_i - NF_{sys} = 13 - 6 = 7dB$$

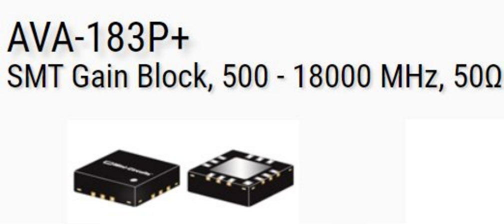
$$NF_{sys} = 4dB$$

La sensibilidad del sistema es = -106dBm

$$P_{in,min} = -174 + 10\log(B) + NF + (SNR)_{o,min}$$

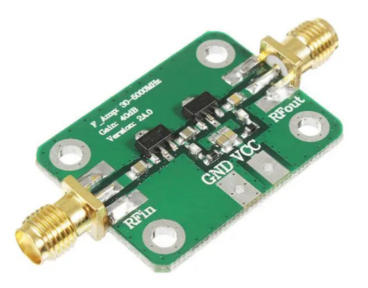
Aumentemos la sensibilidad

- Si coloco un amplificador para aumentar la potencia de la señal recibida, que sucede?


AVA-183P+

SMT Gain Block, 500 - 18000 MHz, 50Ω

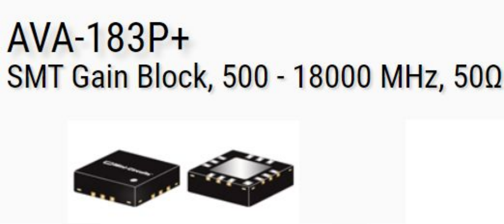
G= 30dB (1000)
NF= 3.1dB (2.04)
IIP3= 20dBm (100)



G= 6dB (3.98)
NF=3.5dB (2.24)
IIP3= 20dBm (100)

Aumentemos la sensibilidad

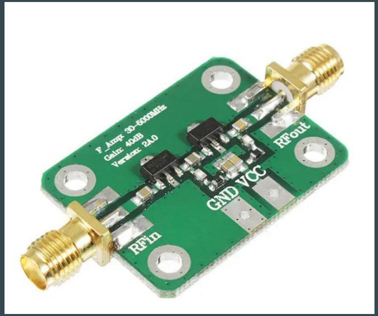
- Si coloco un amplificador para aumentar la potencia de la señal recibida, que sucede?


AVA-183P+
SMT Gain Block, 500 - 18000 MHz, 50Ω

G= 30dB (1000)
NF= 3.1dB (2.04)
IIP3= 20dBm (100)

→

NFsys= 3.1dB (2.04)
SFDR = 56dB
IIP3= -17dBm

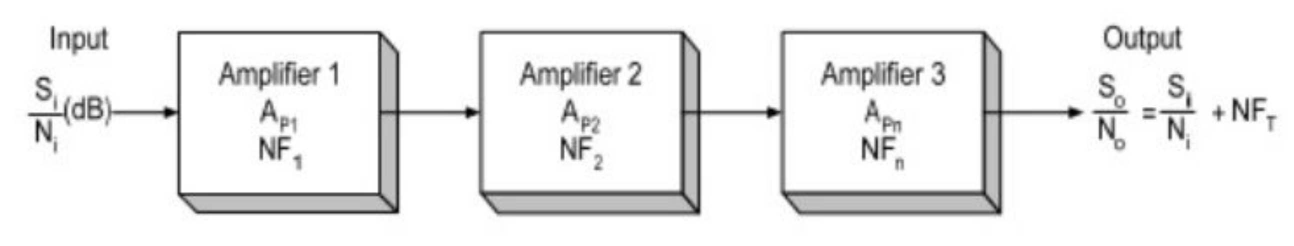


G= 6dB (3.98)
NF=3.5dB (2.24)
IIP3= 20dBm (100)

→

NFsys= 4.75 dB (2.04)
SFDR= 74dB
IIP3= 6.8 dBm

Si utilizamos un amp?



$$F_T = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2} + \frac{F_n - 1}{A_1 A_2 \ldots\ldots A_{n-1}} \quad \text{[unitless]}$$

$$\frac{1}{IIP3} = \frac{1}{I_1} + \frac{G_1}{I_2} + \frac{G_1 G_2}{I_3} + \ldots$$

Spurious Free Dynamic Range

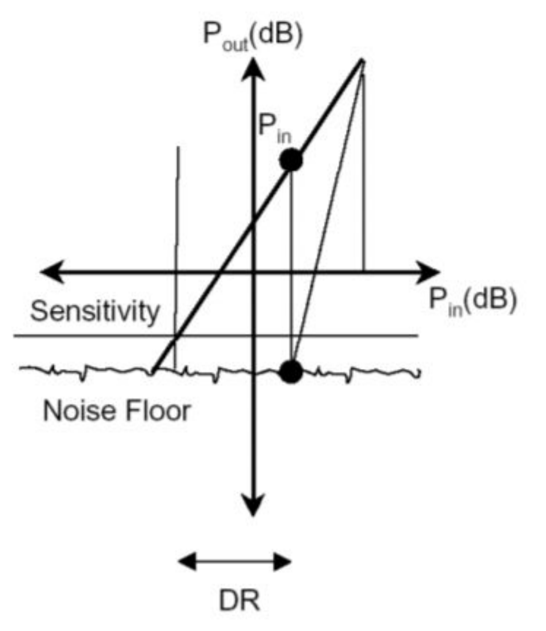
$$P_{IM} = 3P_{IN} - 2IIP3 = F + KTB$$

$$MDS = F + KTB$$

$$P_{in,sens} = MDS + (SNR)_{o,min}$$

$$SFDR = P_{in} - P_{in,sens}$$

$$SFDR = \frac{2}{3}(IIP3 - MDS) - (SNR)_{o,min}$$



Este funciona?

G= 10dB (3.98)
NF=1.5dB (2.24)
IIP3= 20dBm (100)

Este funciona?

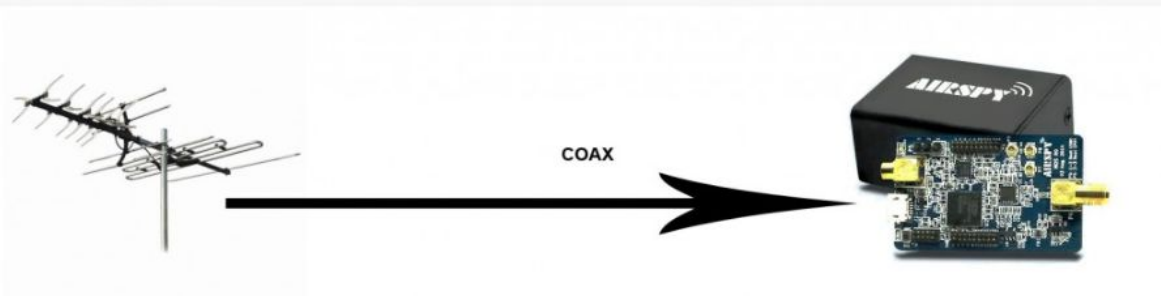
G= 10dB (3.98)
NF=1.5dB (2.24)
IIP3= 20dBm (100)

→

NFsys= 2.33 dB (1.71)
SFDR= 70dB
IIP3= 2.91 dBm

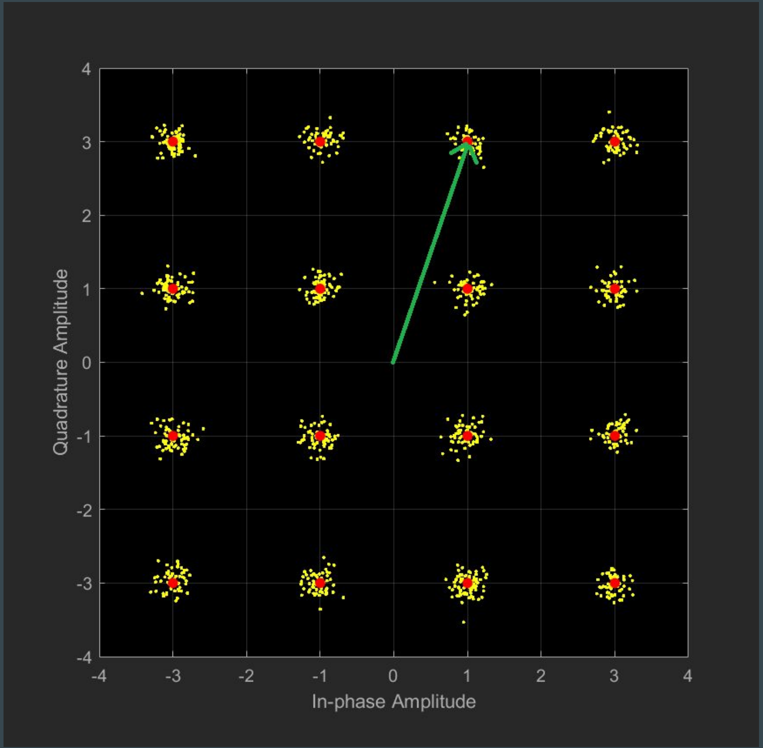
☺

Si tengo un cable largo, que sucede?

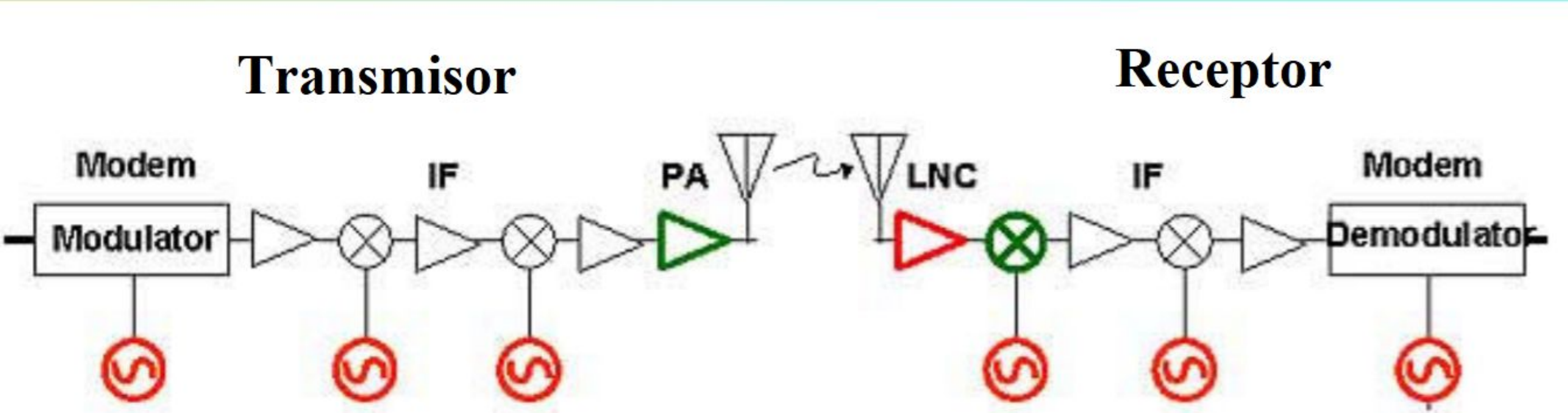


Modulación de vectores

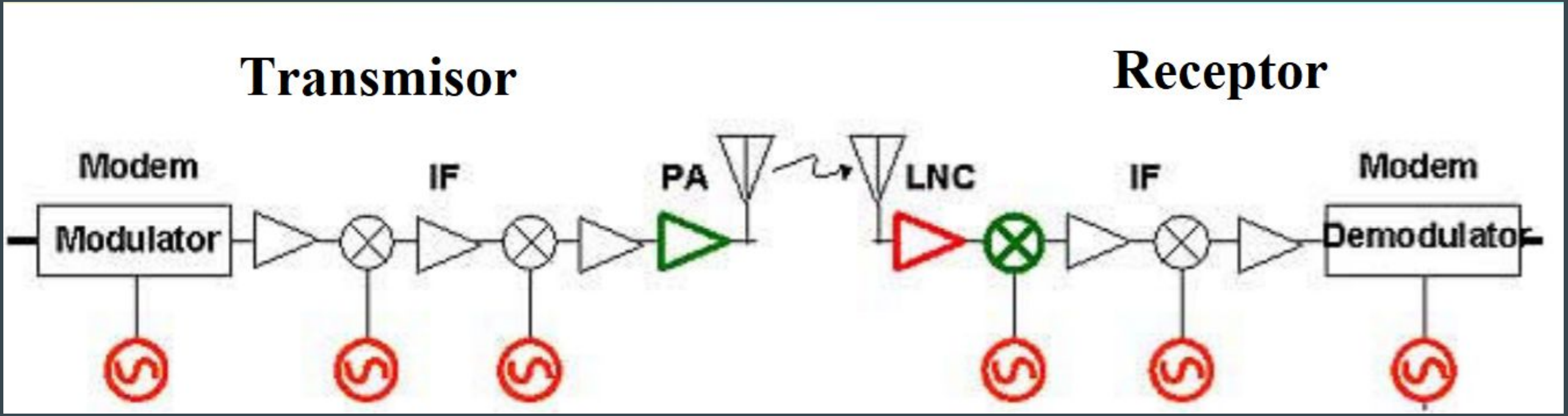
- Mod analógica mayor S/N que digital
- Eficiencia en Digital
  - ❖ Maximizada utilizando amplitud y fase vector
  - ❖ La posición del vector define el símbolo



Fuentes primarias de ruido y distorsión



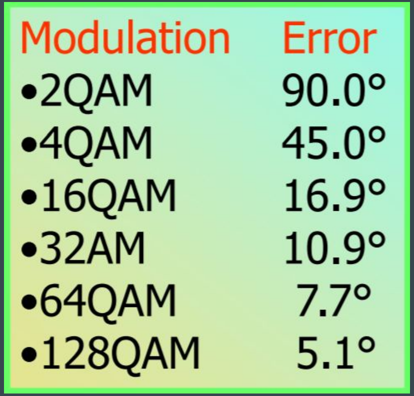
Fuentes primarias de ruido y distorsión



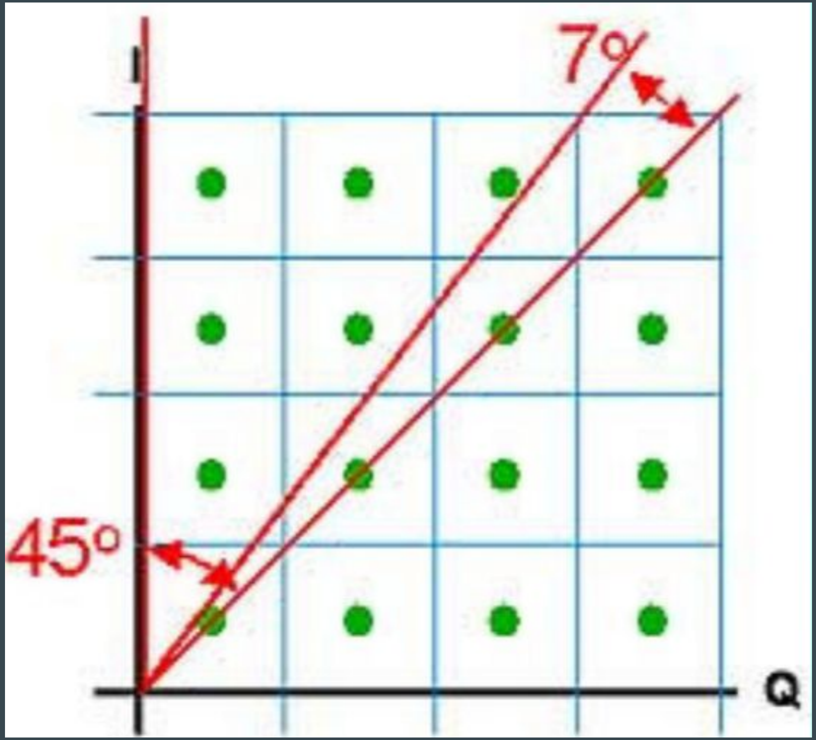
- Ruido
    - LO
    - LNA
- Distorsión
    - Mixer
    - PA
    - Filtros

El ángulo máximo de error depende de la posición del símbolo

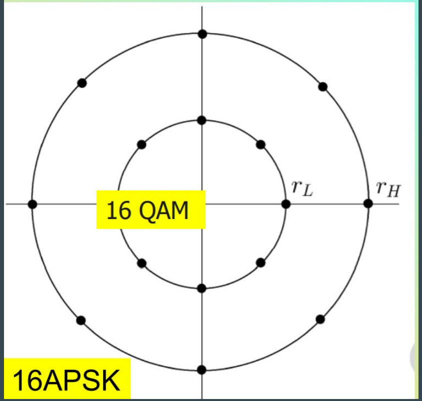
Los símbolos de afuera toleran menos



Modulation	Error
•2QAM	90.0°
•4QAM	45.0°
•16QAM	16.9°
•32AM	10.9°
•64QAM	7.7°
•128QAM	5.1°



16APSK es más inmune al ruido de fase que 16QAM



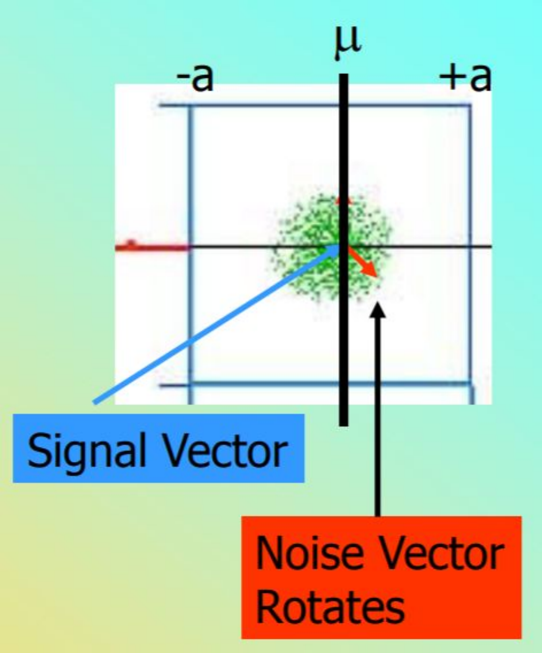
- 16QAM ± 16.9°
- 16APSK ± 22.5°

Standard Deviation & RMS Noise

σ=1   RMS Noise

µ es la señal ideal

P(a=|4 σ|) Bit Error = 6.3x10-5 -



Group Delay Distortion

La quadratura es afectada

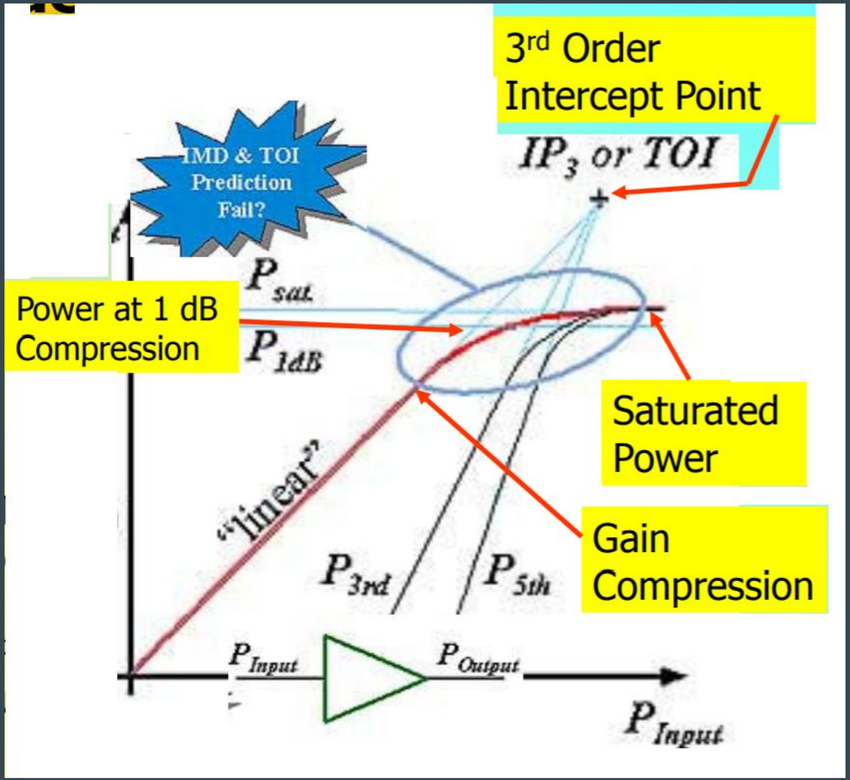
Group Delay Distortion es determinístico

Es función de la frecuencia

Distorsión de amplitud

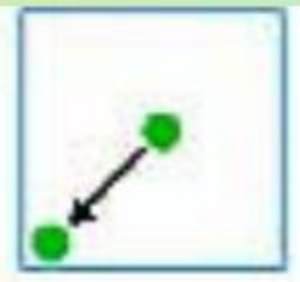
- Si la señal se incrementa
    - Amplitude se comprime: AM/AM Distortion
    - Cambia la fase: AM/PM Distortion

- IMD Distortion
    - Se "crean" 2 tonos
    - Productos de 3er y 5to orden

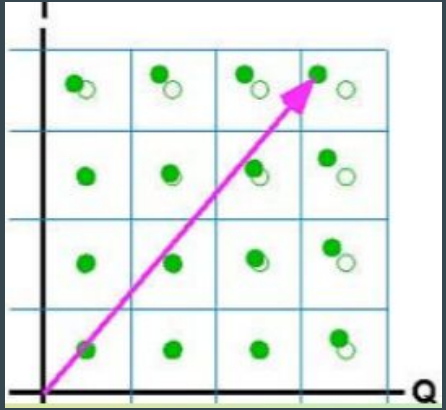


Distorsión de amplitud

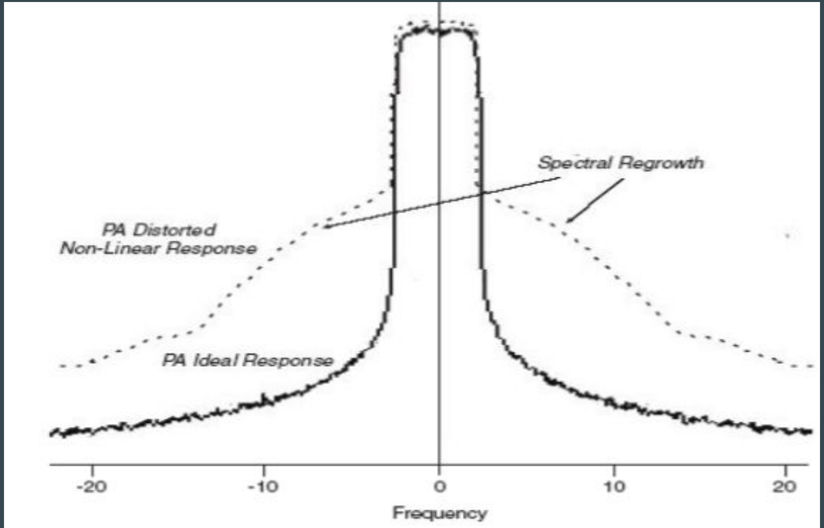
- AM/AM
  - Clipping
  - Compresión de ganancia



- AM/PM
  - Offset crea AM/PM
  - Fase cambia con la amplitud
  - AM/PM ocurre antes que AM/AM
  - AM/PM es más pronunciado en los símbolos alejados
  - Peak to Average ratio has a pronounced effect on phase distortion

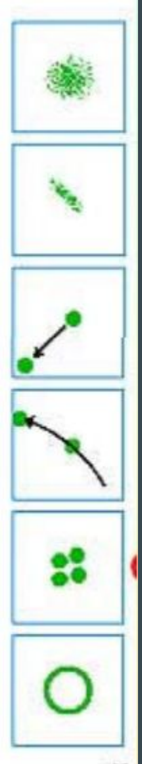


- IMD


Spectral Regrowth
PA Distorted
Non-Linear Response
PA Ideal Response
-20
-10
0
10
20
Frequency

Errores Determinísticos

- Deterministic Effects:
  - Predictable & Correctable
- AM/AM Distortion
  - Power Amplifier
  - ADC Quantization
- AM/PM Distortion
  - Power Amplifier
- Group Delay Distortion
  - Filters
- Interference-Spurious
  - Power Supply
  - 3rd Order Interference



Errores aleatorios

- Caracterizados por la distribución de probabilidad y su desviación estándar
- Estos errores son estadísticos
- Función de múltiplos de σ al umbral

- Thermal Noise – Low Noise Amplifier
- Phase Noise-Local Oscillator

Oscillator Stability

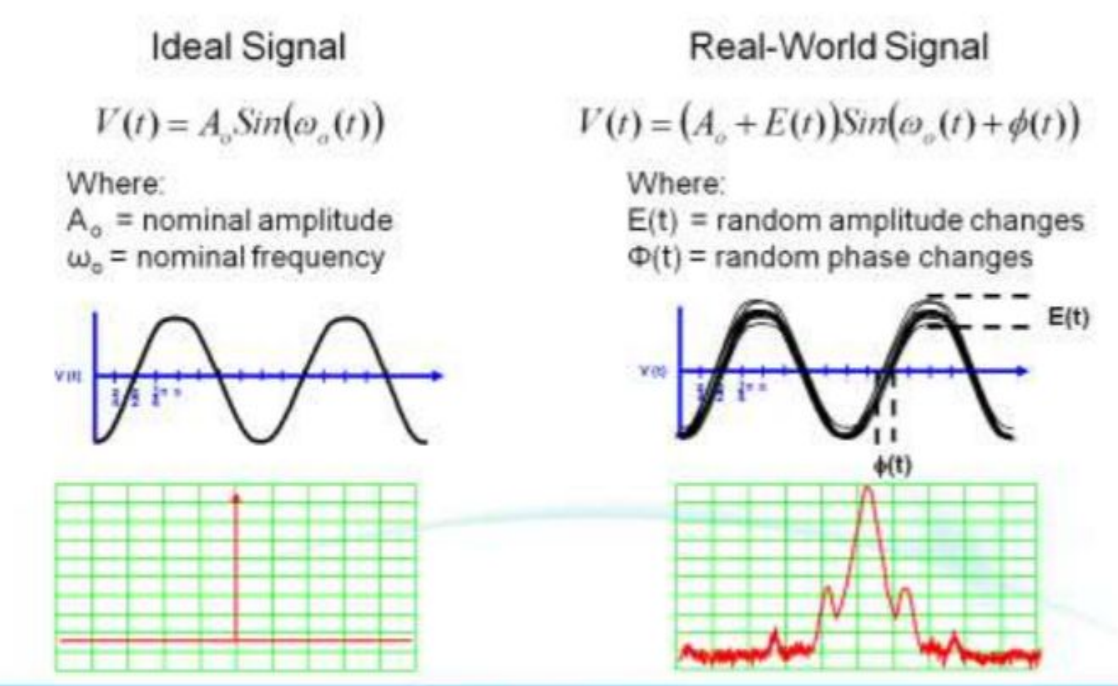
- Long Term Frequency Stability
    - Típicamente horas o años
    - Variación con la temperatura: ΔF / Fo Parts Per Million (PPM)

- Short Term Frequency Stability
    - Residual FM
    - Allen Variance
    - Phase Noise:

Phase Noise - Short Term Stability

- El ruido varía la phase/frequency del oscilador
- El nivel de ruido se incrementa en las proximidades de la portadora
  - La estabilidad cerca del “carrier” se mide utilizando la “Allen Variance”
- Rango típico de interés: **10Hz to 10MHz**
- El ruido más allá del carrier es usualmente enmascarado por ruido AM y ruido térmico
- El ruido de fase no puede ser eliminado o afectado por medio del filtrado
- Fase y frecuencia están relacionadas: Frecuencia es el cambio en la fase con respecto al tiempo **$d\varphi/dt$**

Phase Noise - Short Term Stability



Ideal Signal

$$V(t) = A_o Sin(\omega_o(t))$$

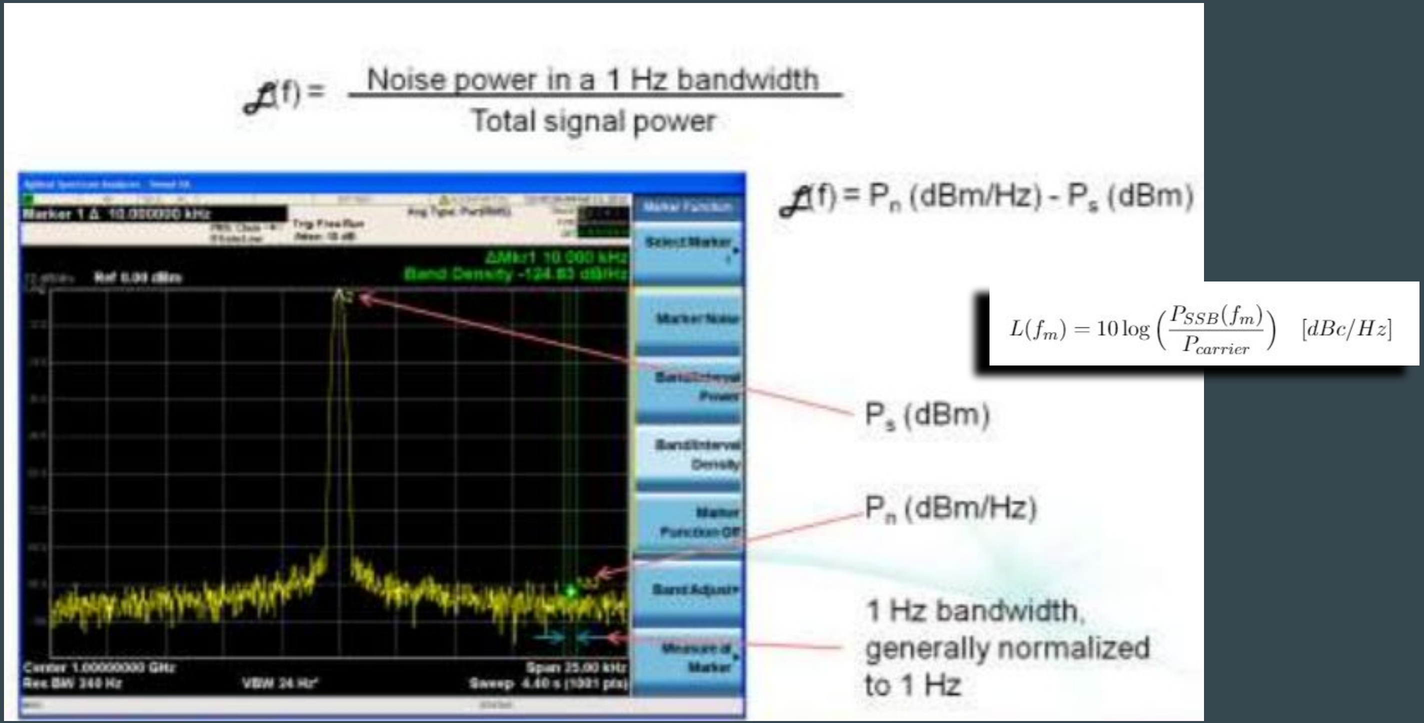
Where:
A_o = nominal amplitude
ω_o = nominal frequency

Real-World Signal

$$V(t) = (A_o + E(t)) Sin(\omega_o(t) + \phi(t))$$

Where:
E(t) = random amplitude changes
Φ(t) = random phase changes

Single Side Band (SSB) Phase Noise

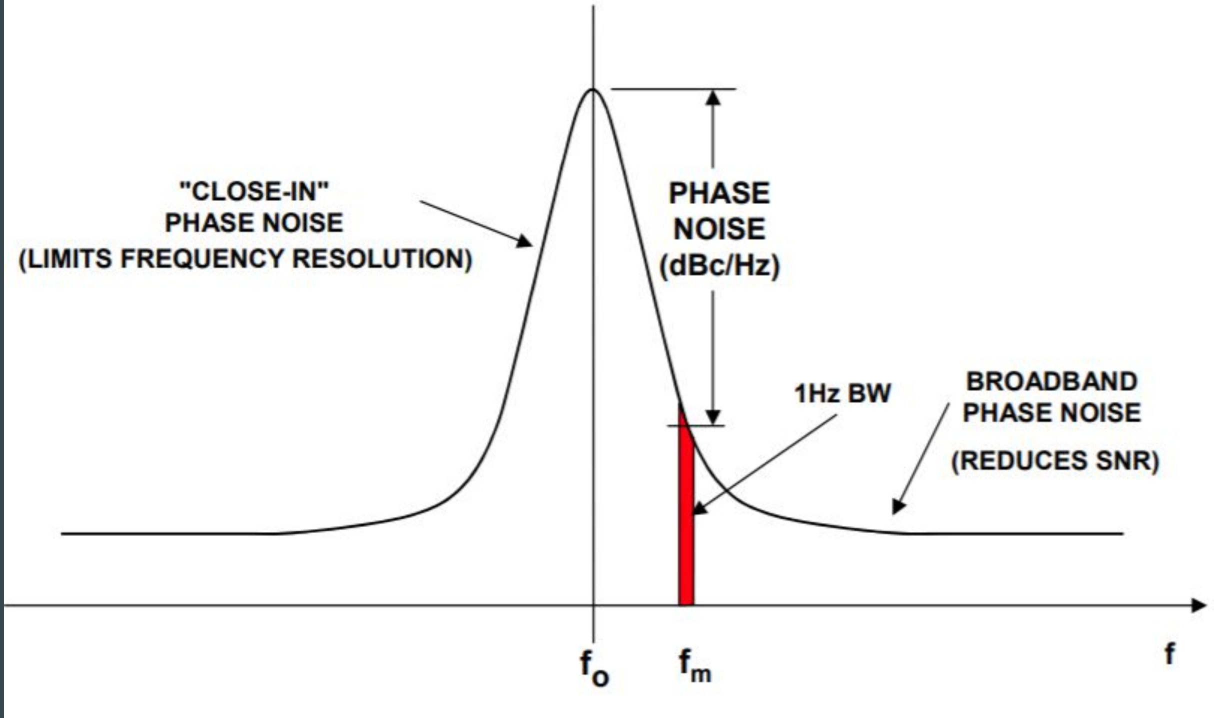


$$\mathcal{L}(f) = \frac{\text{Noise power in a 1 Hz bandwidth}}{\text{Total signal power}}$$

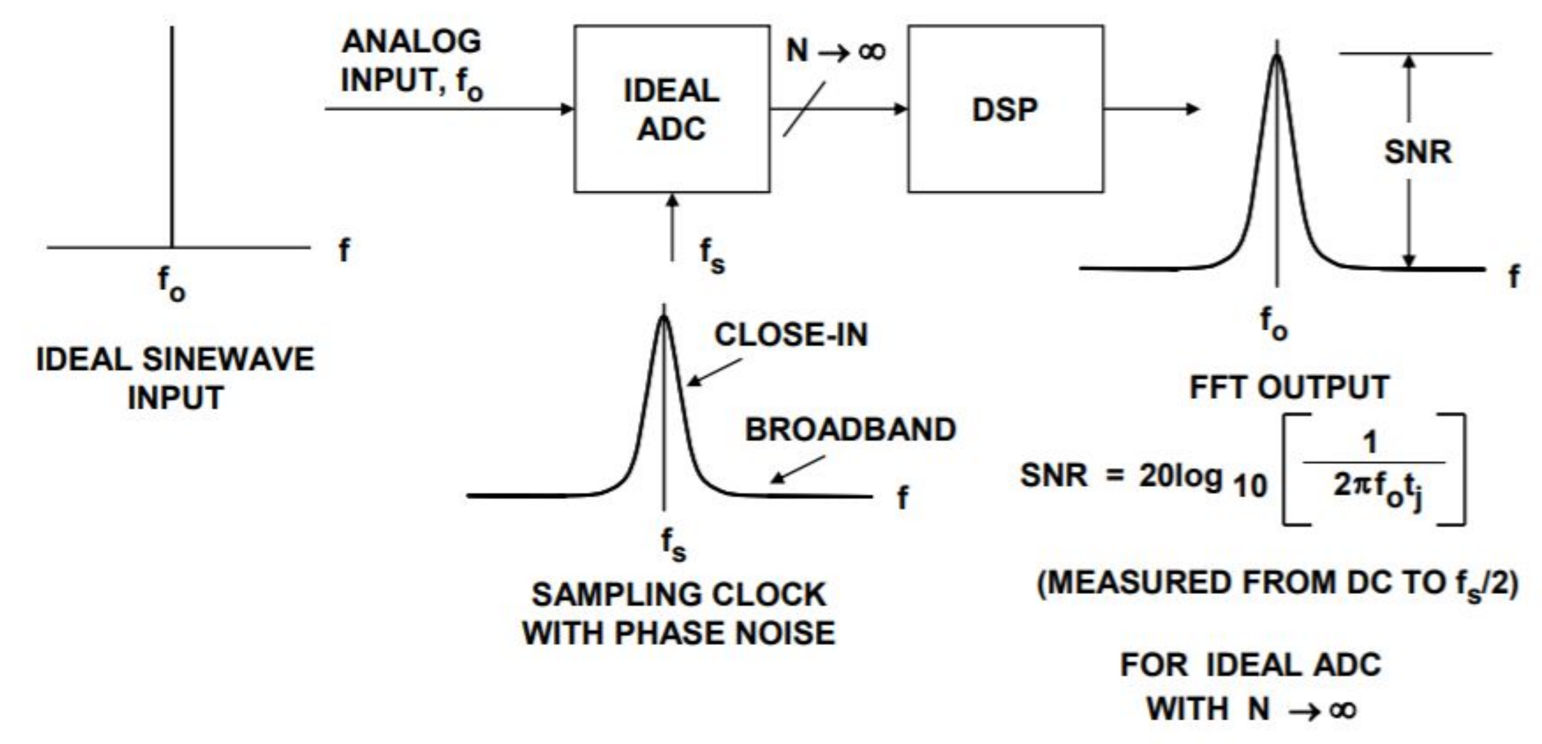
$$\mathcal{L}(f) = P_n\ (\text{dBm/Hz}) - P_s\ (\text{dBm})$$

$$L(f_m) = 10\log\left(\frac{P_{SSB}(f_m)}{P_{carrier}}\right) \quad [dBc/Hz]$$

L(f)= Densidad espectral de potencia de las fluctuaciones de fase


"CLOSE-IN"
PHASE NOISE
(LIMITS FREQUENCY RESOLUTION)
PHASE
NOISE
(dBc/Hz)
1Hz BW
BROADBAND
PHASE NOISE
(REDUCES SNR)
f_o
f_m
f

Que sucede en un ADC?

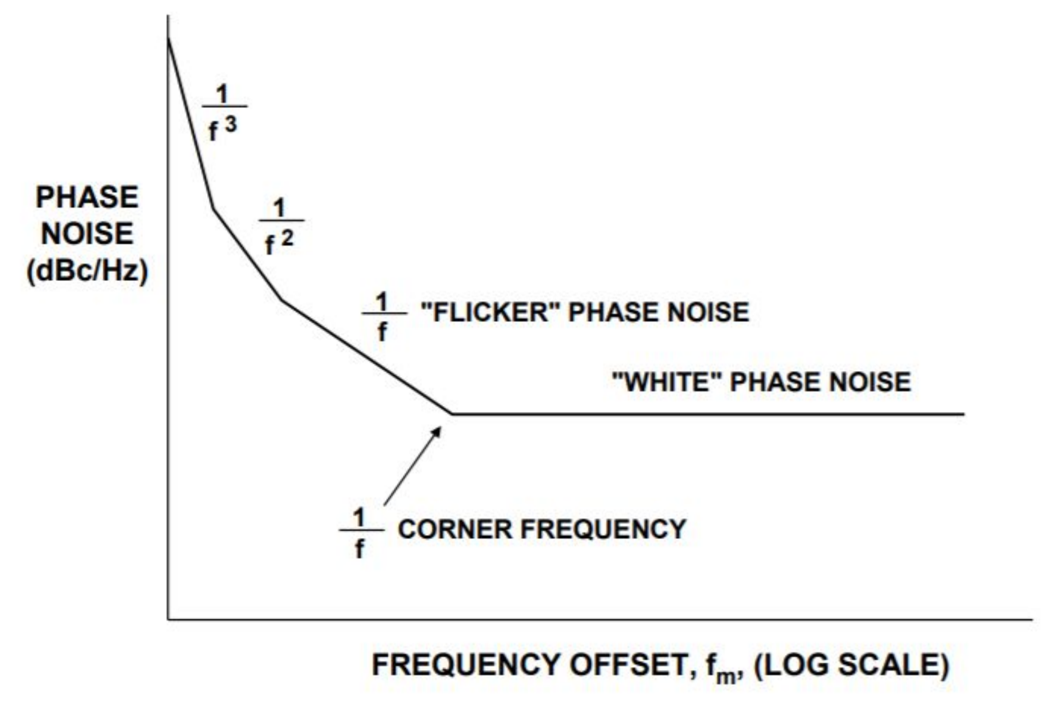


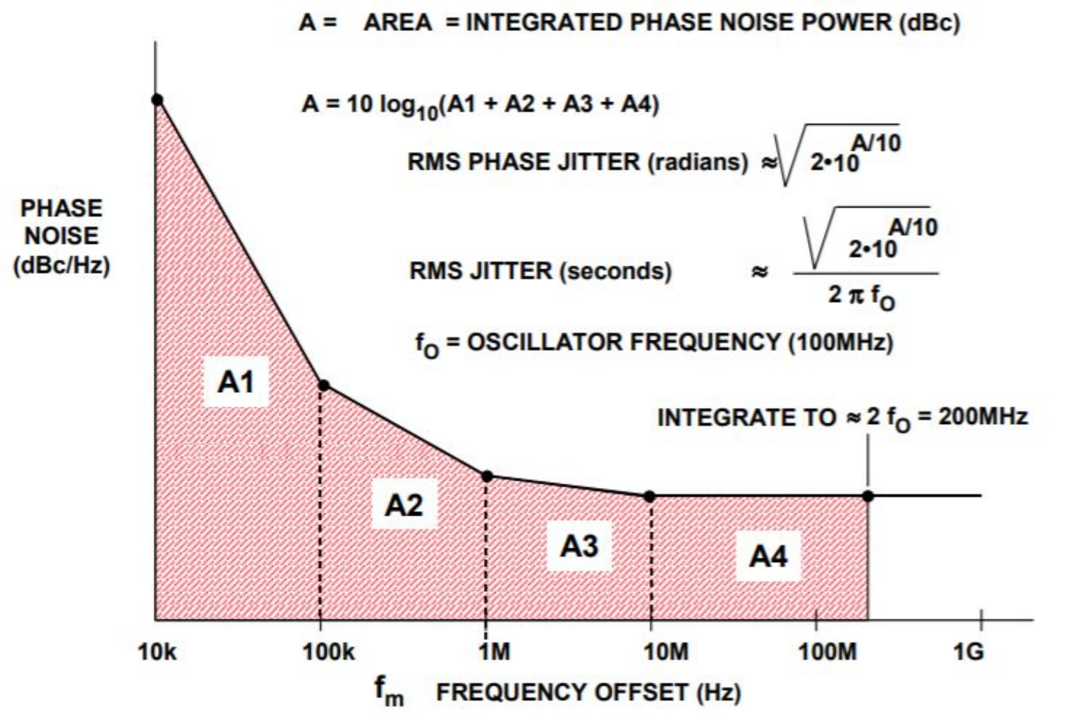
$$\mathrm{SNR} = 20\log_{10}\left[\frac{1}{2\pi f_o t_j}\right]$$

(MEASURED FROM DC TO $f_s/2$)

FOR IDEAL ADC WITH $N \to \infty$

SSB Phase Noise



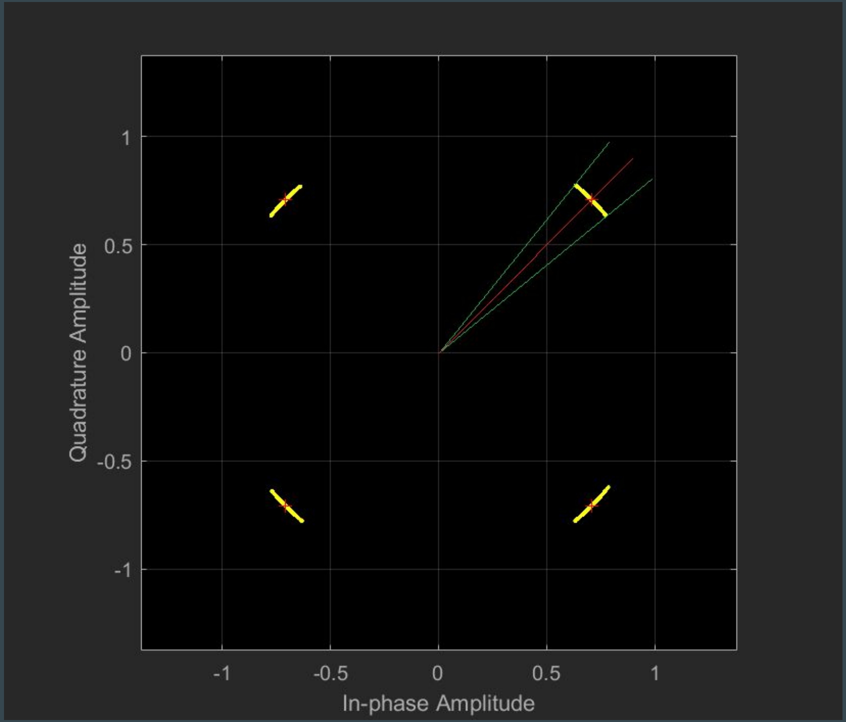

A = AREA = INTEGRATED PHASE NOISE POWER (dBc)
$A = 10\log_{10}(A1 + A2 + A3 + A4)$
RMS PHASE JITTER (radians) $\approx \sqrt{2 \cdot 10^{A/10}}$
RMS JITTER (seconds) $\approx \frac{\sqrt{2 \cdot 10^{A/10}}}{2\pi f_O}$
f_O = OSCILLATOR FREQUENCY (100MHz)
INTEGRATE TO $\approx 2 f_O$ = 200MHz
PHASE NOISE (dBc/Hz)
A1
A2
A3
A4
10k
100k
1M
10M
100M
1G
f_m FREQUENCY OFFSET (Hz)

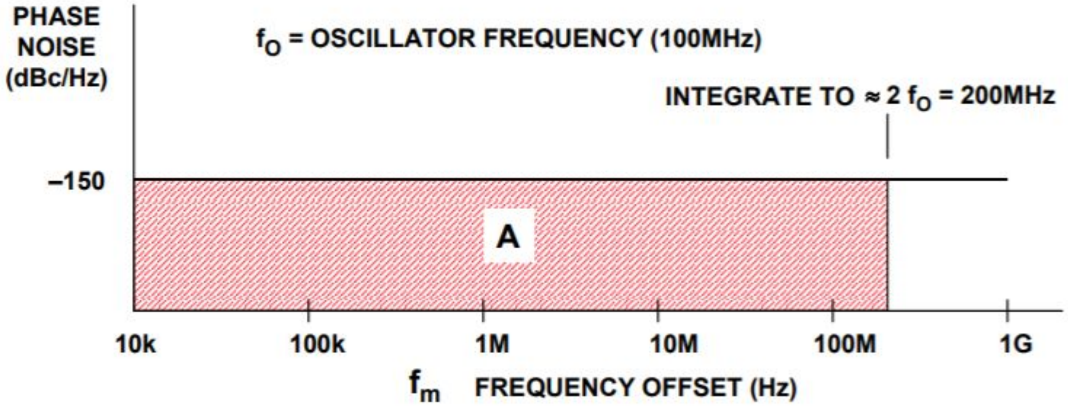
Ejemplo

- L(f)=-60dBc/Hz

$$\Delta\phi^2 = 2\int_{f_a}^{f_b} L(f_m)\,df_m \quad (rms)$$

$$\Delta\phi = 3.6^\circ \mathrm{rms}$$

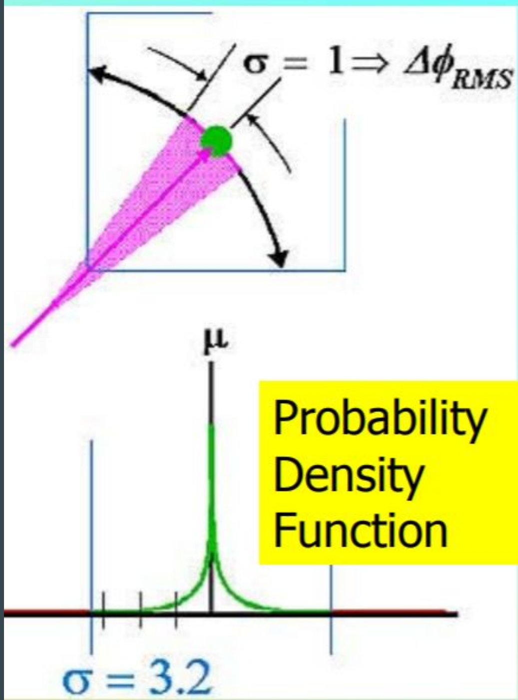




$$A = -150\text{dBc} + 10\log_{10}\left[200\times10^{6} - 0.01\times10^{6}\right] = -150\text{dBc} + 83\text{dB} = -67\text{dBc}$$

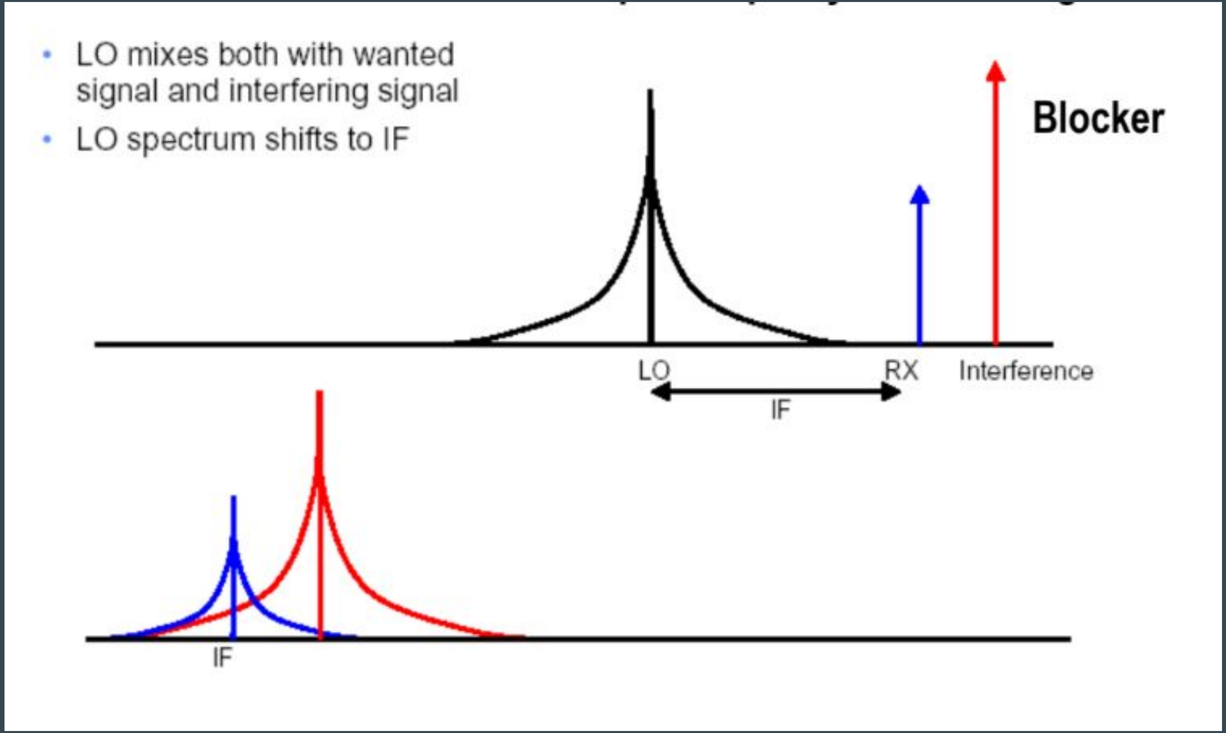
$$\text{RMS PHASE JITTER (radians)} \approx \sqrt{2\cdot10^{A/10}} = 6.32\times10^{-4}\ \text{radians}$$

$$\text{RMS JITTER (seconds)} = \frac{\text{RMS PHASE JITTER (radians)}}{2\,\pi\, f_O} = 1\text{ps}$$



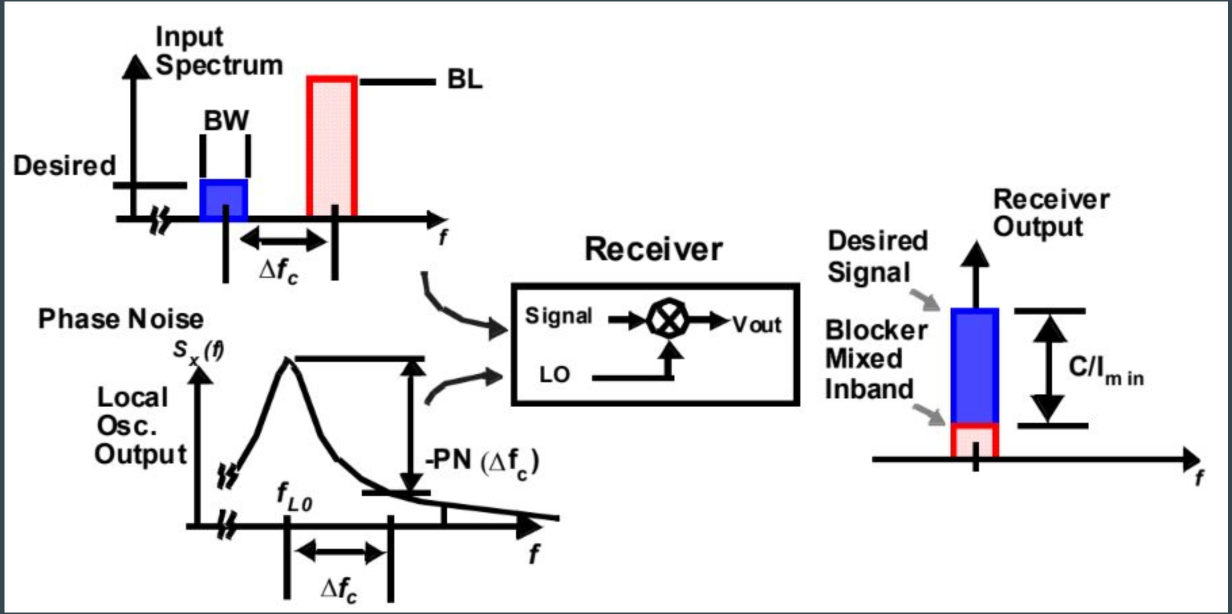
Probability
Density
Function

Carrier / Interferer ratio



- LO mixes both with wanted signal and interfering signal
- LO spectrum shifts to IF

Carrier / Interferer ratio



$$PN_{\Delta fc}(dBc/Hz) = S_{signal} - S_{block} - C/I_{\min}(dB) - 10\log(BW)$$

C/I$_{min}$ (Carrier / Interferer ratio)