RF System Aspects for SDR

A Tutorial

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Cosite Examples

Desensitization

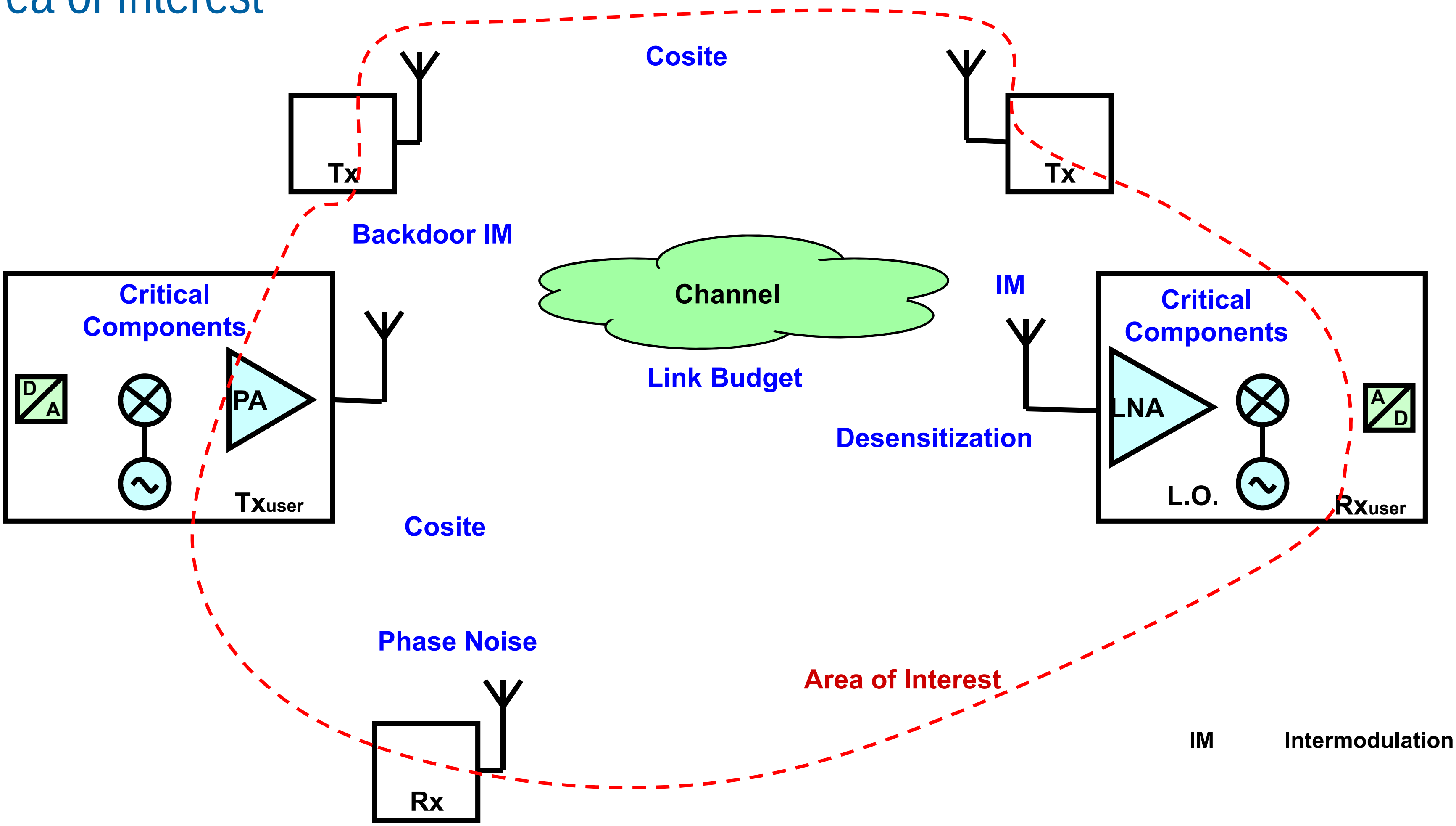
- Blocking, Transmitter Noise, Reciprocal Mixing

Intermodulation

- Receiver IM, Backdoor IM,

Some Conclusions and Recommendations

Radio System
Area of Interest



Basics
Power, Gain and Decibel

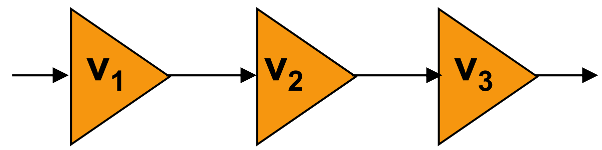
Remember Logarithm?

log(a*b) = log(a) + log(b)

Helps to calculate the gain of a chain of components

- **Linear representation (W)**

P_{in}

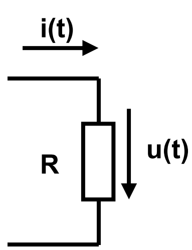


$P_{out} = P_{in}*v_1*v_2*v_3$

- **Logarithmic representation (dB)**

$$10*\log(Pout) = 10*\log(P_{in}) + 10*\log(v_1) + 10*\log(v_2) + 10*\log(v_3)$$

Remember dBm?



$$P = U^2/R$$

A power P_0 of 1 mW on 50 Ohm is defined to correspond with 0 dBm

$$P[dBm] = 10*\log_{10}(P/P_0)$$

Basics
Receiver Noise

Input noise of a receiving system (Nyquist formula)

Linear representation:

$$P_N = k*T*F*\Delta f$$

where

k Boltzmann's constant 1,38 * 10^{-23} Ws/K
T absolute temperature, here 290 K
F Noise figure of the receiver (linear)
Δf considered bandwidth

Much easier to handle in logarithmic representation:

$$P_N \text{ [dBm]} = -174 \text{ [dBm/Hz]} + F\text{[dB]} + 10*\log(\Delta f) \text{ [dBHz]}$$

Basic Terms
Desensitization, Intermodulation, Cosite

Receiver Desensitization

- Desensitization is a form of electromagnetic interference where a radio experiences a severe decrease of the receiver SNR

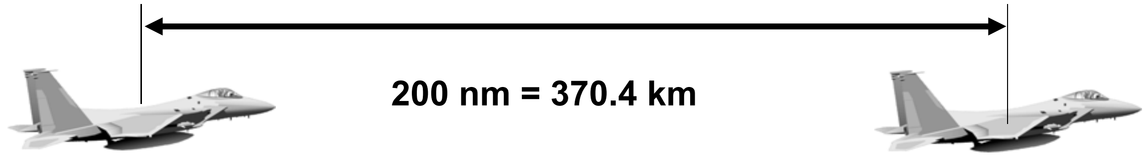
Intermodulation

- Intermodulation is the creation of unwanted signals at new frequencies due to non-linearities of radio devices

Cosite

- Collocation of electronic equipment on the same vehicle, station, or base
- Two or more radio lines shall be operated simultaneously

Simple Example for Link budget



Tx Power 10W (+40 dBm)

Losses: 2.5 dB

Effective Tx Power: 37.5 dBm

Free Space Attenuation @ 200nm/300 MHz: 129 dB

Rx-Signal at Antenna: -91.5 dBm

Losses: 2.5 dB

Rx-Signal at Receiver: -94 dBm

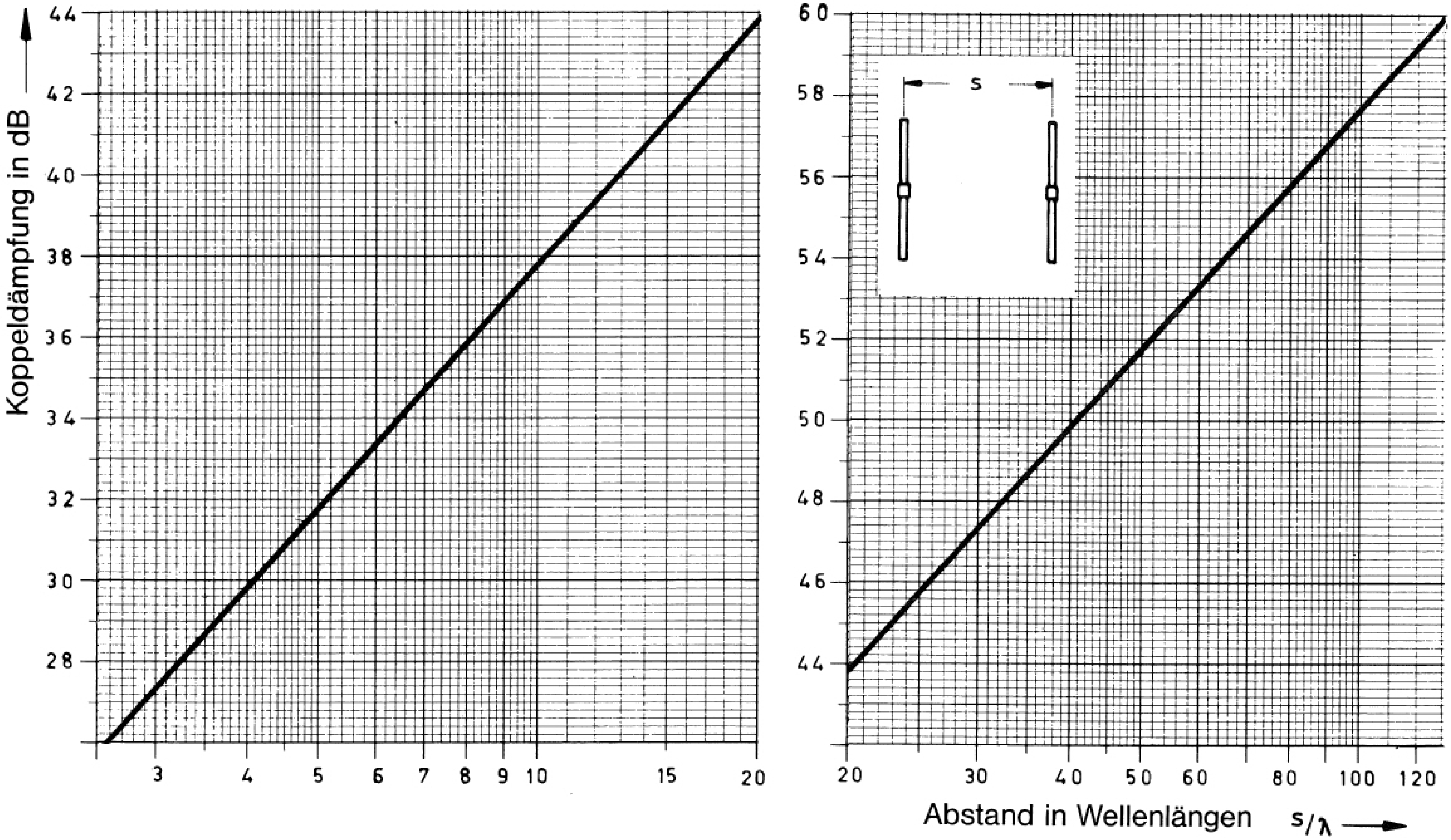
Margin: 11 dB

Required Rx-Sensitivity = -105 dBm

$$A[\text{dB}] = 28.1 + 20 \ast \log(d[\text{km}]) + 20 \ast \log(f[\text{MHz}])$$

(Minimum attenuation between two dipoles)

Isolation by Horizontal Separation of Two Vertical Polarized Dipoles

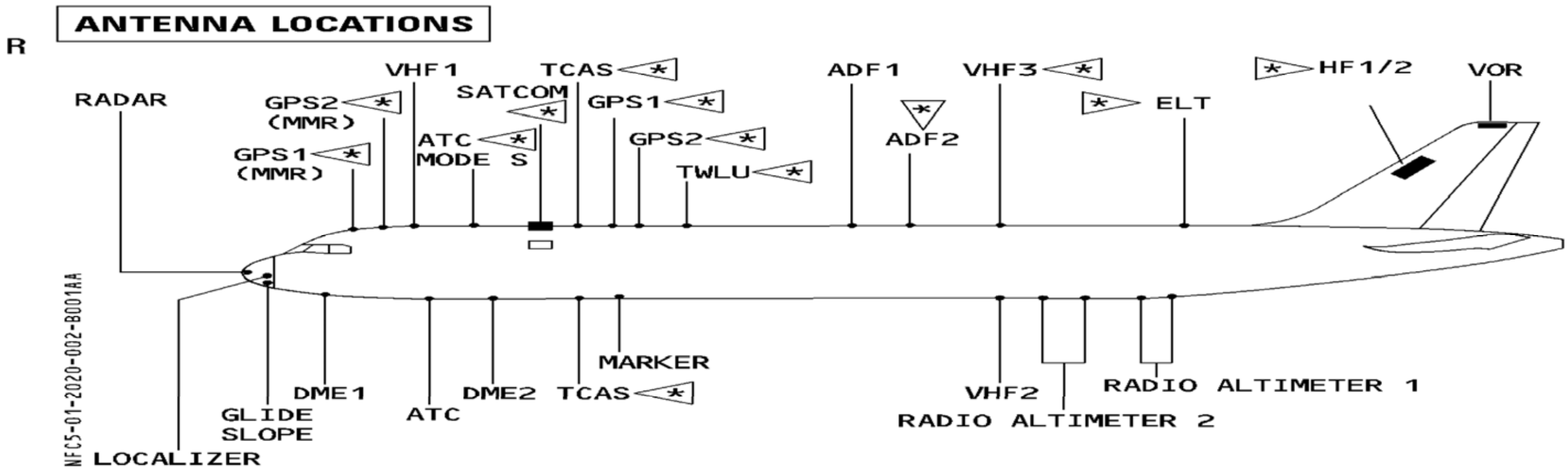


Source: Kathrein; Antennas for Mobile Radio

Cosite
Example Ships

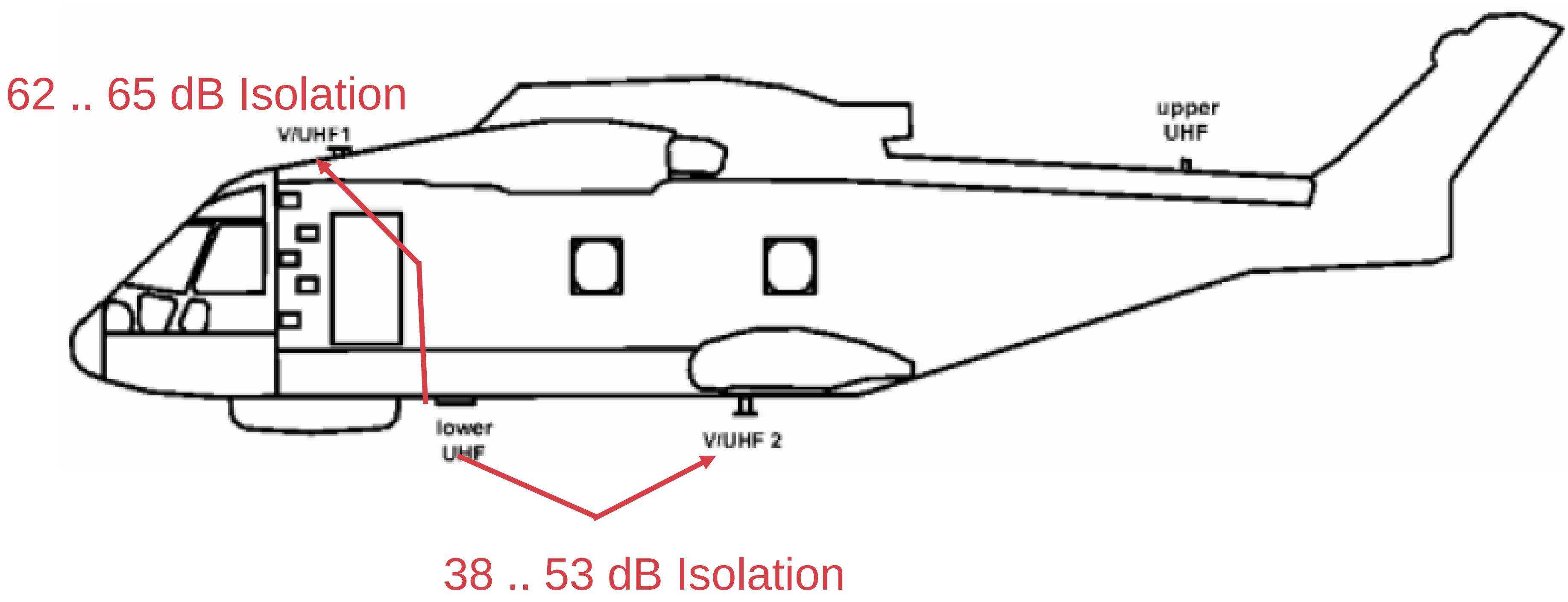
Example for a small installation V/UHF:	**2 V/UHF radio lines**	**2 V/UHF antennas**
Example for a large installation V/UHF:	**15 V/UHF radio lines**	**5 - 10 V/UHF antennas**

Cosite
Example Aircraft



Source:

Cosite
Example Helicopter



Cosite
Example ATC Radio Site

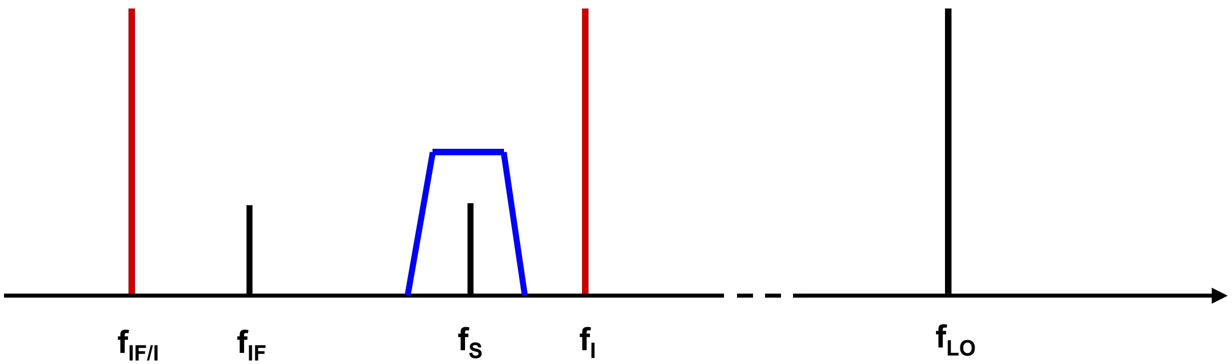
Limited Resources !

Cosite Issues
View of the Effects

Effect	Reason	Origin	
Rx Desensitization	Rx Blocking	Rx Frontend	Broadband
	Tx Noise	Tx Synthesizer	
	Rx Reciprocal Mixing	Rx Synthesizer	
„Ghost“ signals	Rx Intermodulation	Rx Frontend	Discrete frequencies
	Tx Backdoor intermodulation	Tx Power Amplifier	
There are more effects like cross modulation, spurious signals, „Rusty Bolt Effect“ but not discussed here			

Desensitization by Blocking

Nearby Transmitter



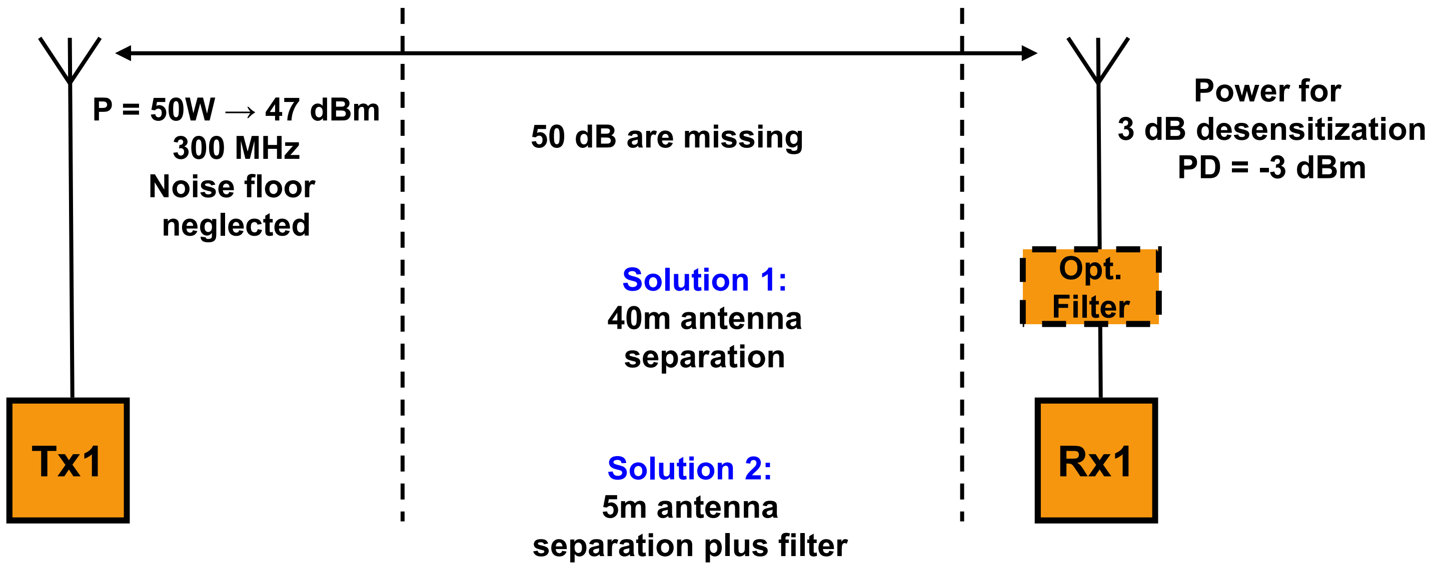
f_{LO}: Local oscillator
f_S: Useful signal
f_I: Interfering signal
f_{IF}: Intermediate frequency
$f_{IF/I}$: Downconverted interfering signal

Solution: Rx-Cosite-Filter (external or internal)

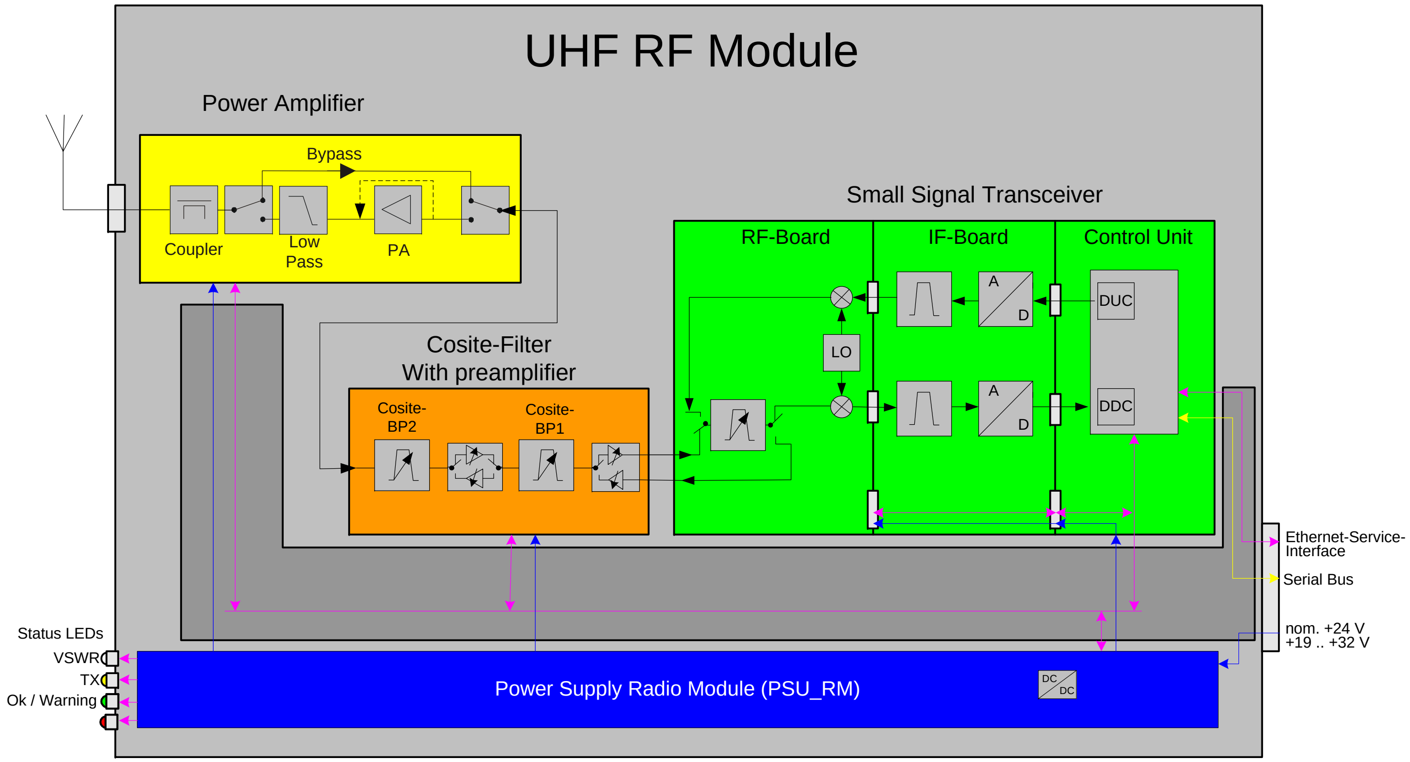
Due to the high interfering signal the AGC is ramping down the gain - this is decreasing significantly the useful signal

The interfering signal must be filtered out at the receiver‘s input (preselection)

Desensitization by Blocking
Practical Example

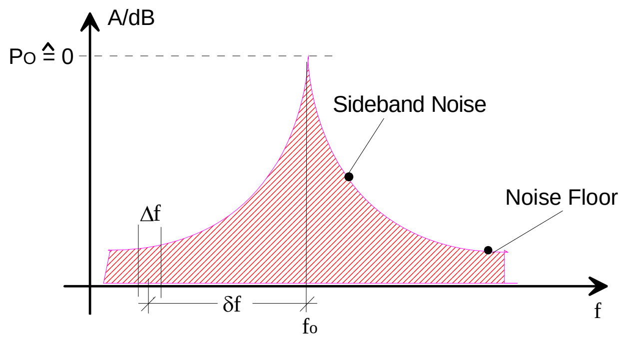


Transceiver RF Part
Example



Transmitter Noise

At the Tx output a spectrum analyzer may show the following picture



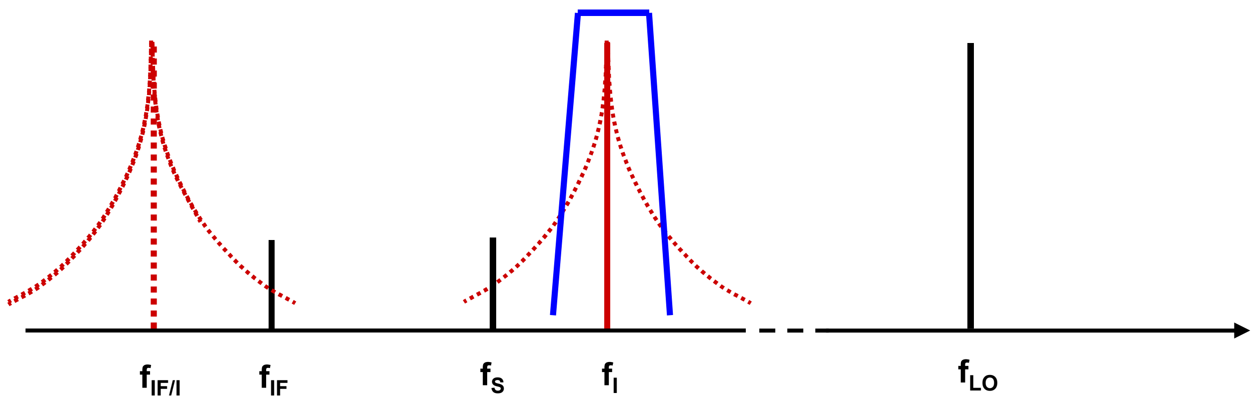
A specification of the effect might say e.g. "150 dBc/Hz @ 1% from carrier„ What does this mean?

- The „c" means, that the measured value is related to the carrier power (P_0)
- " /Hz " means, that the value is normalized to 1 Hertz
- 1% from carrier means the frequency, where the measurement took place (δf)

In practice this means:

- A transmitter is transmitting not only at the carrier frequency, but also at frequencies nearby
- The value depends on the frequency distance δf from the carrier; the higher the distance the lower the noise
- All values (including the measurement bandwidth Δf) should be converted into a logarithmic representation to be able to calculate the normalized measurement result

Desensitization by Transmitter Noise



f_{LO}: Local oscillator
f_S : Useful signal
f_I : Interfering signal
f_{IF} : Intermediate frequency
$f_{IF/I}$: Downconverted interfering signal

Solution: Tx-Cosite-Filter

Each transmitter is generating noise (phase noise) around the carrier

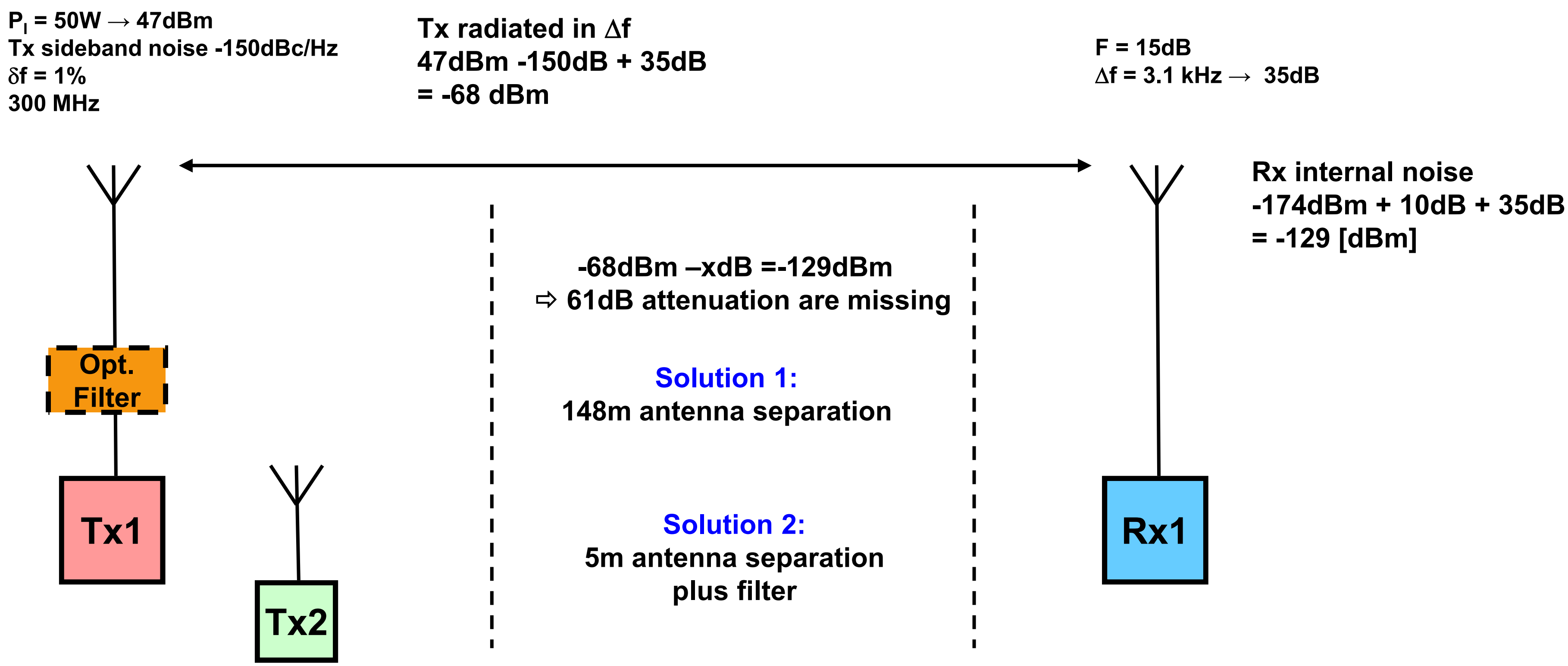
This noise cannot be filtered out at the receiver side but only at the transmitter side

What else could we do?

- Buy a better transmitter with lower phase noise
- Shift the interfering frequency away from the useful frequency
- Move the interfering transmitter away from the receiver

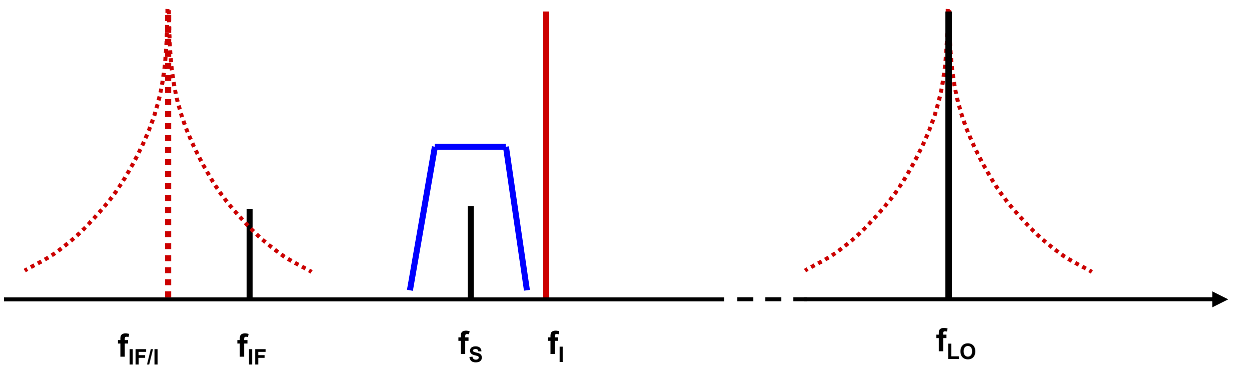
Desensitization by Transmitter Noise

Practical Example



Desensitization of 3 db happens, if Tx noise and Rx noise at Rx input are equal

Desensitization by Reciprocal Mixing



f_{LO}: Local oscillator
f_S : Useful signal
f_I : Interfering signal
f_{IF} : Intermediate frequency
$f_{IF/I}$: Downconverted interfering signal

Solution: Rx-Cosite-Filter (external or internal)

The useful signal f_S is downcoverted by the mixer to IF

Given a strong nearby interferer f_I is present; will usually be filtered out by the IF filter

Parts of the phase noise of the LO is mixing with the strong interfering carrier and fall inside the IF pass band

This can mask a weak useful signal

Potential Improvements

- Rx cosite filter
- Reduce phase noise of the local oscillator (buy better equipment)

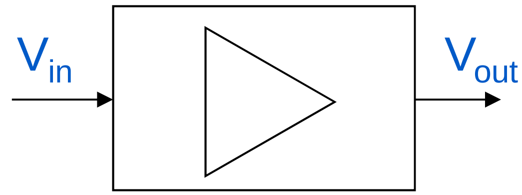
Representation of a Non-linear Transfer Function

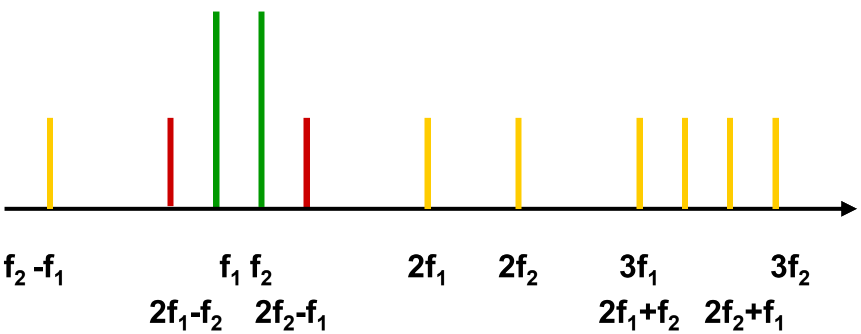
Intermodulation is coming from non-linearities, so how can we express it mathematically?

Power series:

$$V_{out} = K_1 * V_{in} + K_2 * V_{in}^2 + K_3 * V_{in}^3 + \dots .$$

$$V_{in} = A_1 * \sin(2*\pi*f_1+\phi_1) + A_2 * \sin(2*\pi*f_2+\phi_2)$$





Responsible Coefficient	Frequency	Product
K1	f_1; f_2	Useful signals
K2	$2f_1$; $2f_2$	Second harmonics (IM 2nd order)
	f_1+f_2; f_1-f_2	Intermodulation 2nd order
K3	$3f_1$; $3f_2$	Third harmonics (IM 3rd order)
	$2f_1-f_2$; $2f_2-f_1$	Intermodulation 3rd order
	$2f_2+f_1$; $2f_1+f_2$	Intermodulation 3rd order

Rx Intermodulation (3rd Order)

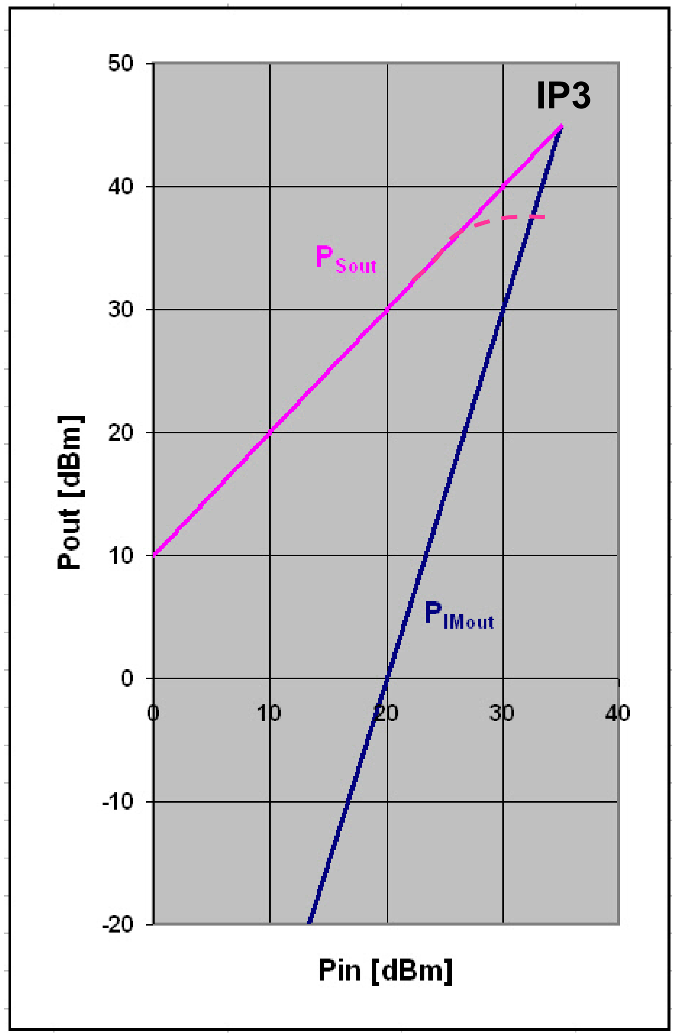
A helpful parameter:
Intercept point 3rd order (IP3); describes the growth of the intermodulation products of 3rd order P_{IM3}

$$P_{IM3} = 3 * P_S - 2 * IP3 \quad \text{(all in dBm)}$$

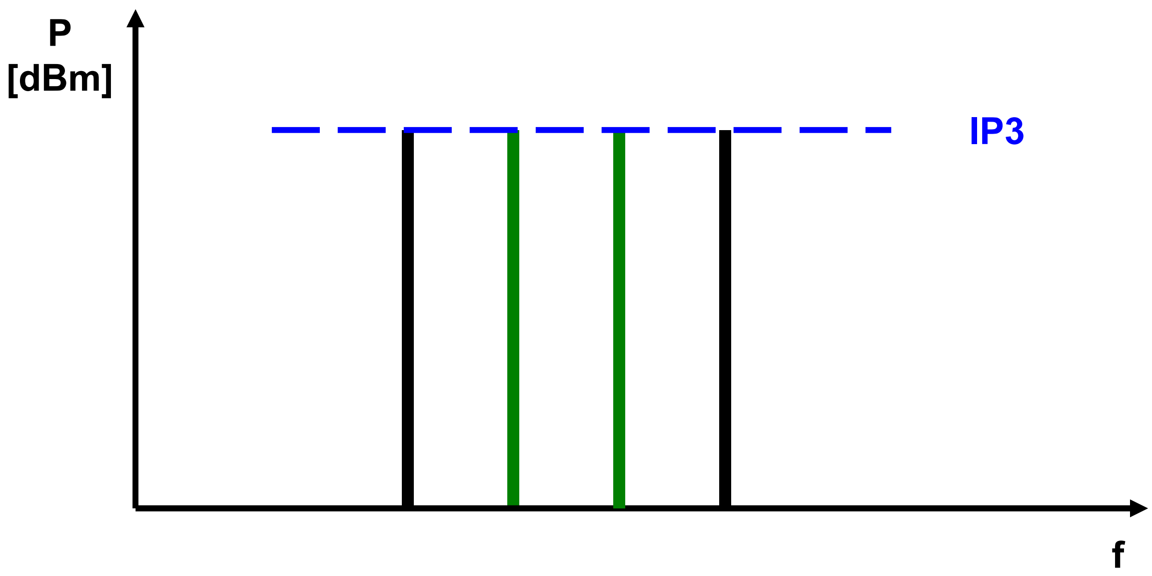
IP3 is nothing real - cannot be measured directly

Example to the right

- Amplifier with gain 10 dB
- IP3 +45 dBm

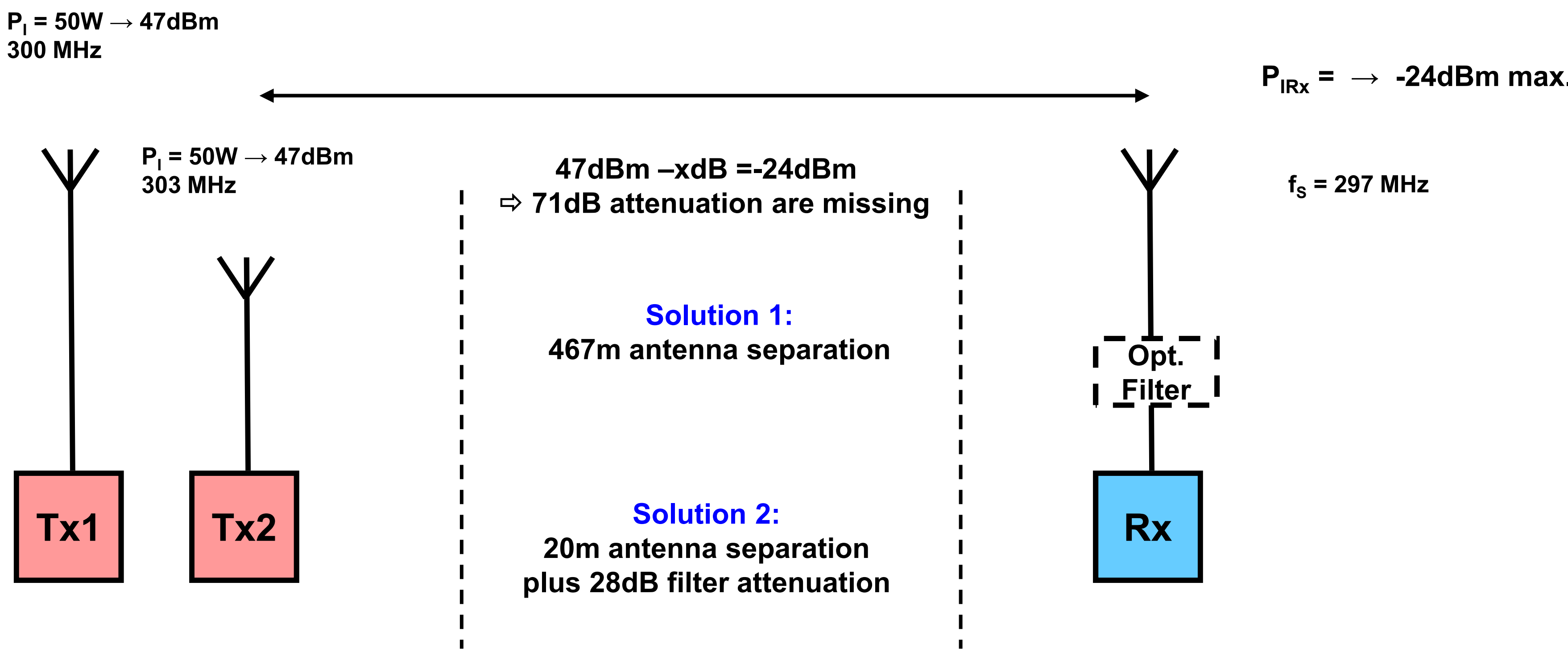


Intermodulation 3rd Order



Receiver Intermodulation
Practical Example

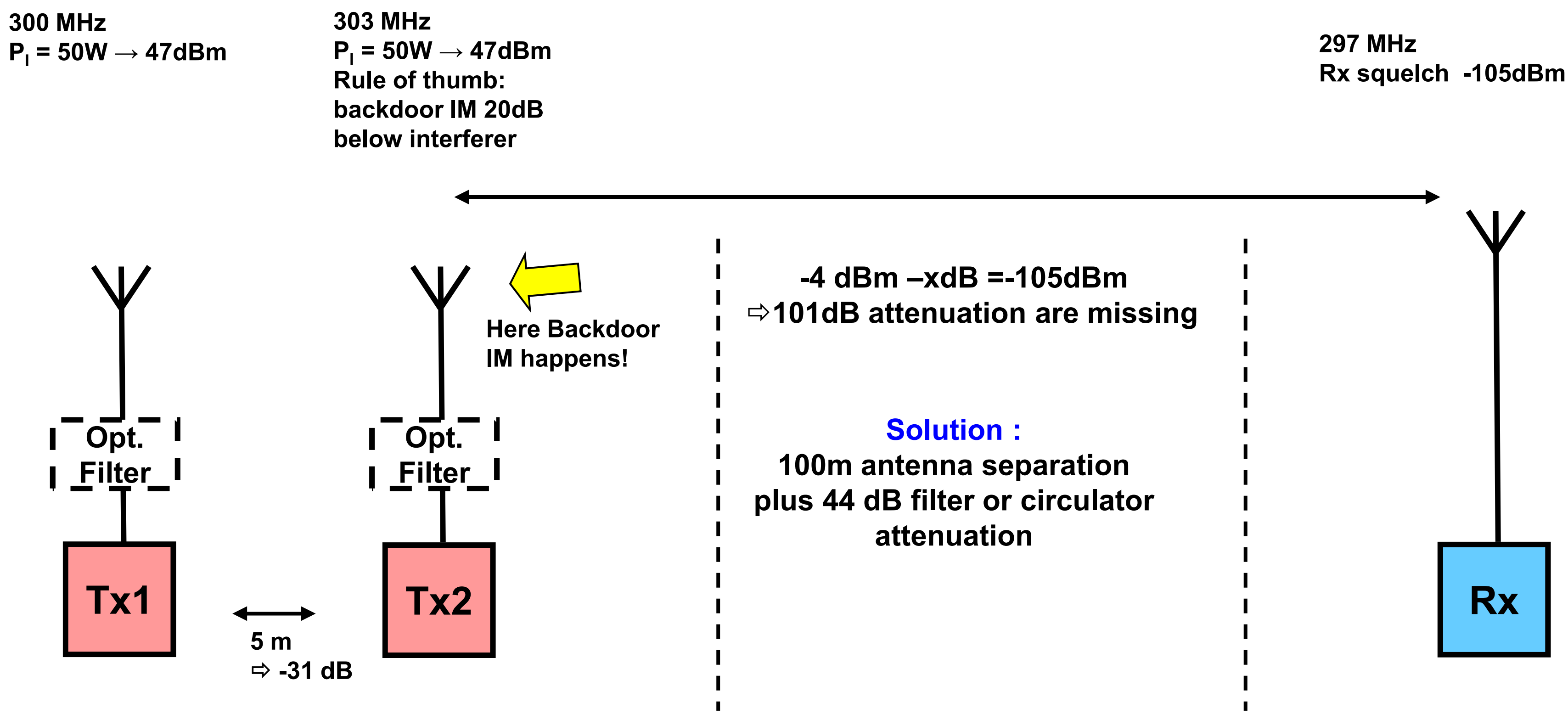
Assumed Rx characteristics
Rx squelch -105dBm
IP3 +16dBm



Intermodulation products must not open the receiver squelch!

Transmitter Backdoor Intermodulation

Practical Example



Rationale:

Intermodulation products must not open the receiver squelch (-105dBm)
Signal from Tx1 at Tx2 ⇨ 16dBm
Backdoor IM at Tx2 ⇨ -4dBm
Solution with antenna separation only is not feasible – filters or circulators required

Cosite Cook Book

A Few Recipes

- **Use high quality equipment**
  ⇨ care about technical data like intercept point, built-in cosite filters etc.

- **Avoid transmitters and receivers at the same site**
  ⇨ don‘t use transceiver solutions in difficult cosite situations

- **Try to decouple Tx and Rx antennas by at least 60 dB**
  ⇨ appr. 300m distance at VHF, 100m distance at UHF

- **Try to decouple Tx antennas by at least 25 dB**
  ⇨ appr. 5m distance at VHF

- **Don‘t forget frequency management**
  ⇨ Use software tools to configure IM-free operation

Many thanks for your attention!
Any questions?