S J Nightingale

14th October 2013

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The most important thing we build is trust


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- Aerospace Communications
- Antenna Systems
- Commercial Systems
- SATCOM
- Tactical Communications and Surveillance


DEFENCE SYSTEMS DIVISION
- Defence Electronics


MISSION SYSTEMS DIVISION
- Aviation Services
- Life Support
- Mission Equipment

A Workshop on RF Interference Suppression on Fixed and Mobile Platforms

by

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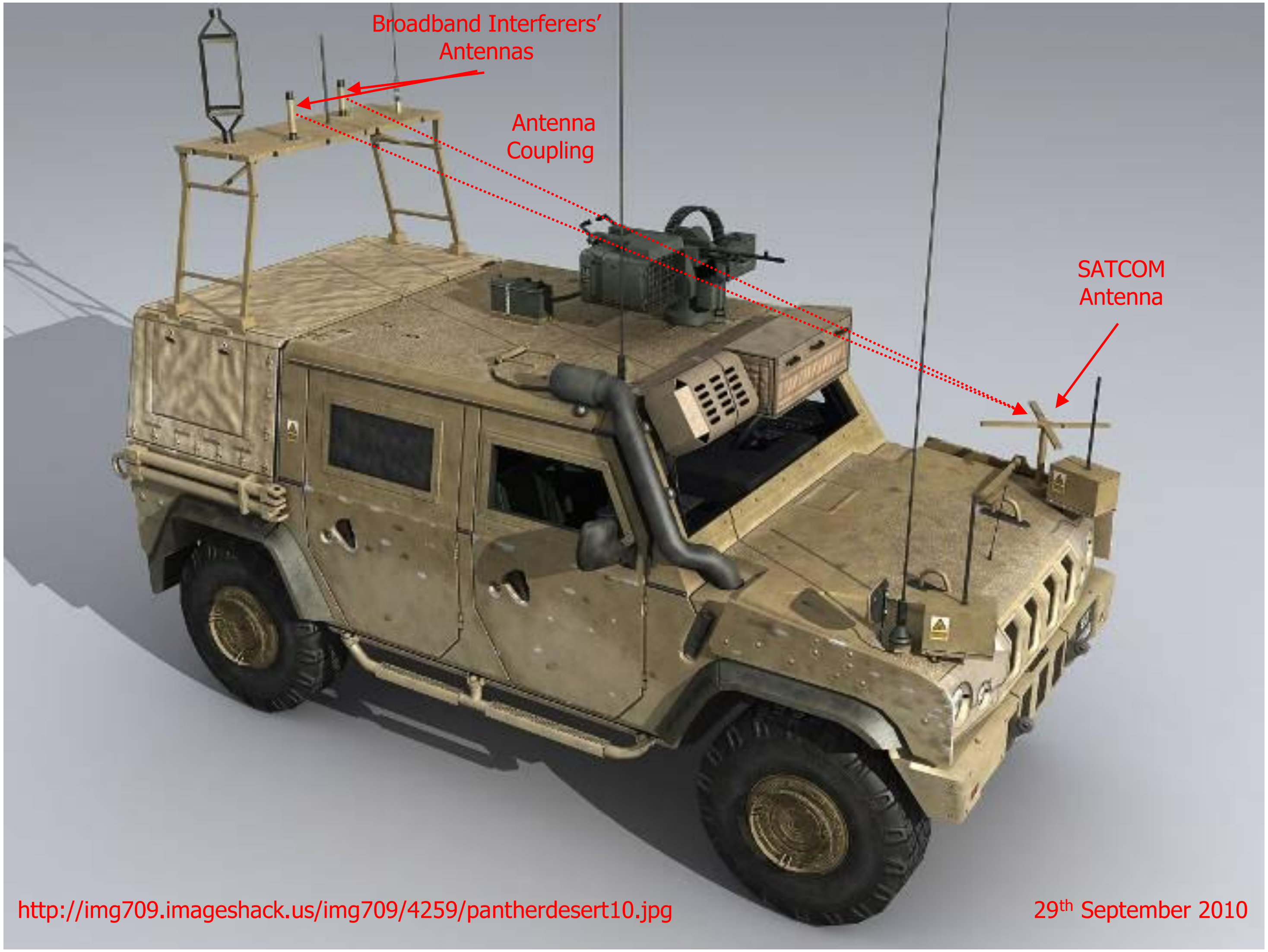
RF Interference Suppression on Fixed and Mobile Platforms – US LAVC2

RF Interference Suppression on Fixed and Mobile Platforms – UK Panther



RF Interference Suppression on Fixed and Mobile Platforms – Test Vehicle

RF Interference Suppression on Fixed and Mobile Platforms – Presentation Outline

- The Problem
- Potential Solutions
- Results from interference suppression systems
- Conclusions

RF Interference Suppression on Fixed and Mobile Platforms – The Problem

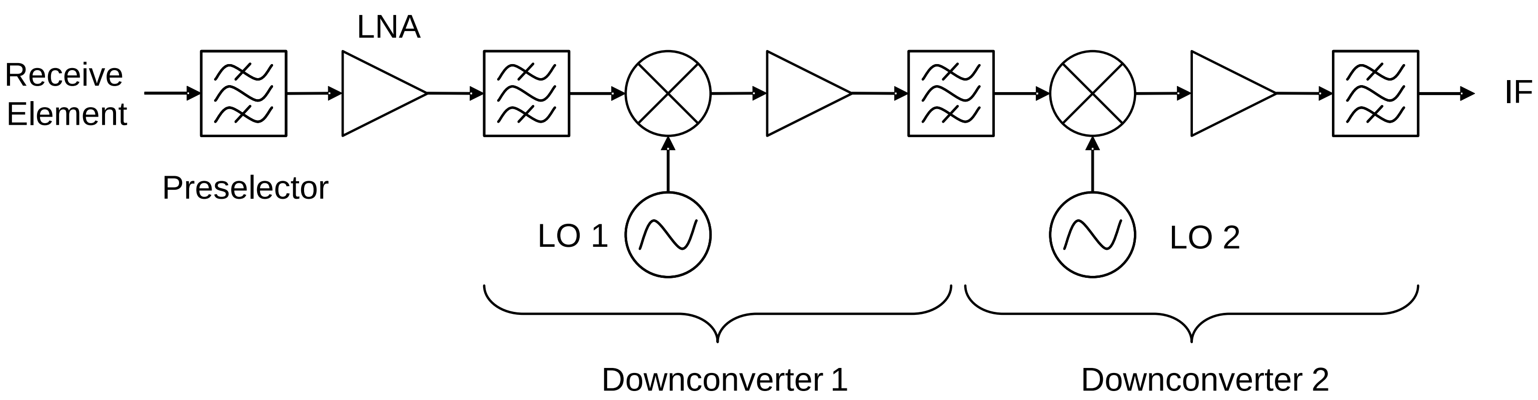
- Many transmitting and receiving devices in theatre
  - on- and off-board comms and data radios and jammers
- Close proximity of associated antennas on-board leads to high level of mutual coupling
  - highest at low frequencies (VHF), eg <15dB at 30MHz
- Typical frequency of operation (30 – 512MHz) and size of platform makes directional antennas large and impractical, therefore antennas are generally omnidirectional

RF Interference Suppression on Fixed and Mobile Platforms – On- and Off-channel Considerations

- The front end of most modern radios is relatively wideband and easily desensitised
- It is generally the total power captured by the front end that matters, eg from narrowband comms radios or wideband jammers
- The problem can be divided into on- and off-channel RF interference, which can be on- or off-board

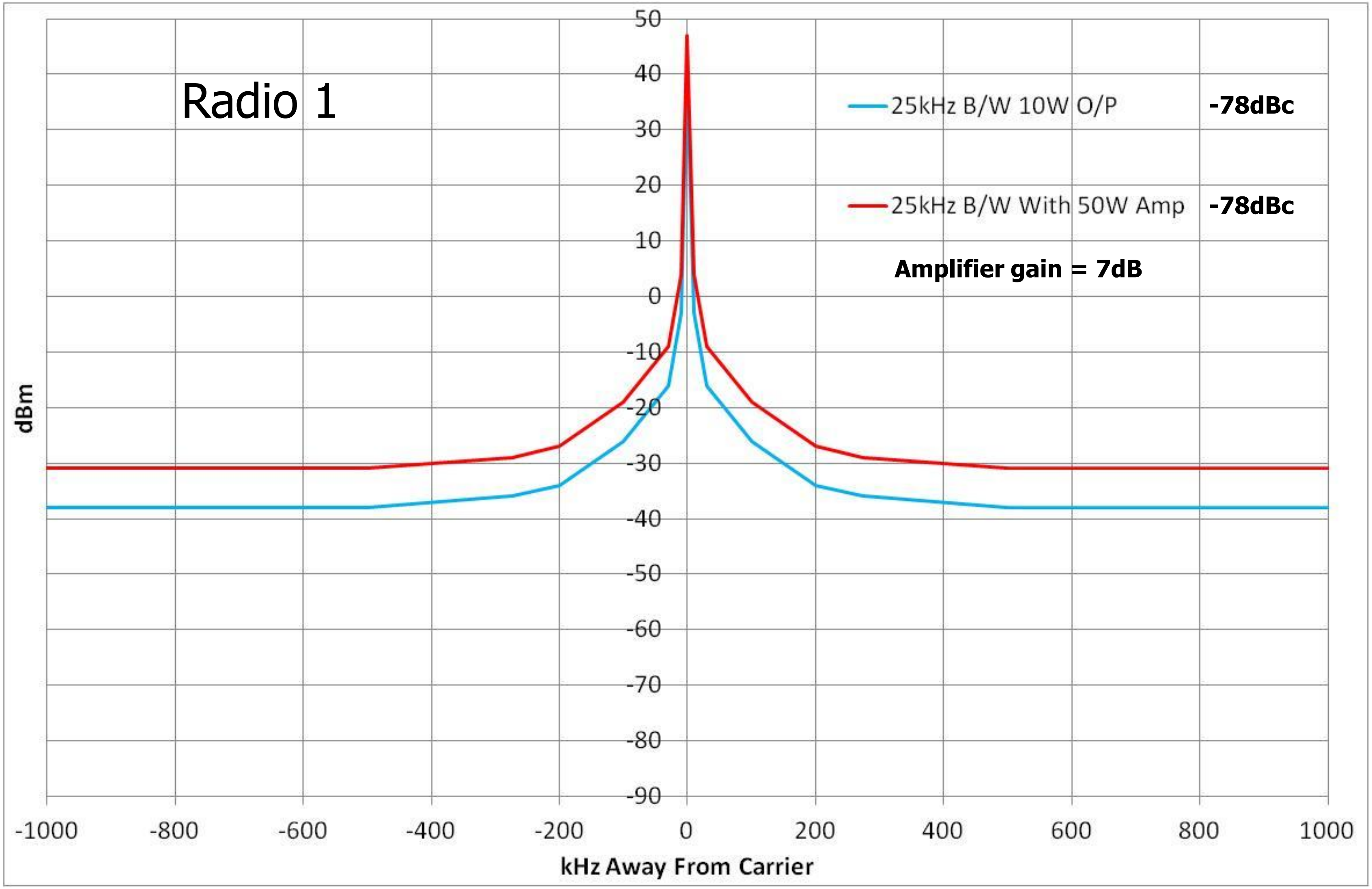
RF Interference Suppression on Fixed and Mobile Platforms – Front End Saturation

A typical receiver front end

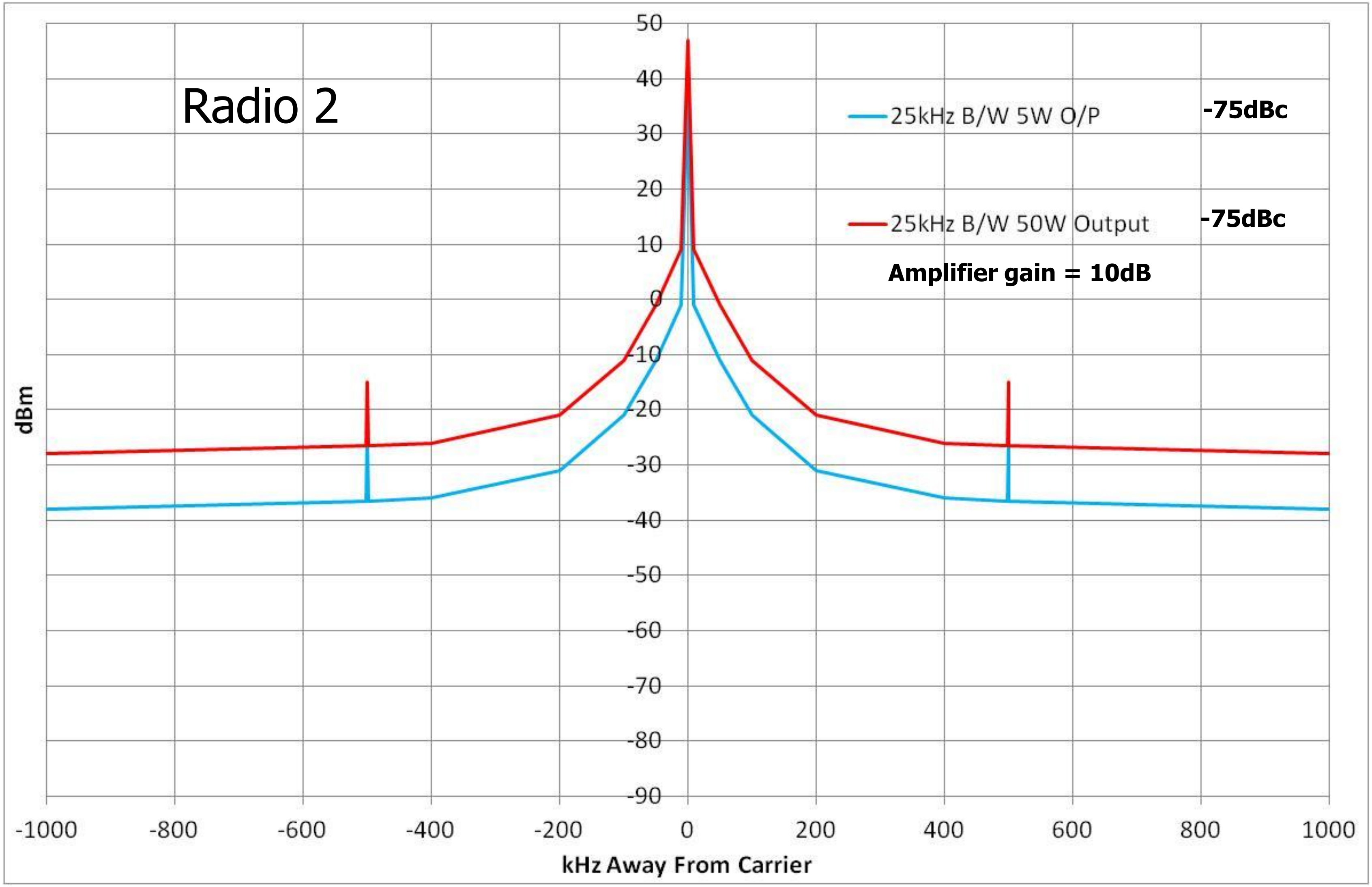


Therefore, if the interfering signal received from the antenna is large, it must be removed **before** the receiver input to avoid desensitisation (saturation or blocking)

RF Interference Suppression on Fixed and Mobile Platforms – Typical Comms Transmitter Spectrum



RF Interference Suppression on Fixed and Mobile Platforms – Typical Comms Transmitter Spectrum



RF Interference Suppression on Fixed and Mobile Platforms – Problem Summary 1

- Noise is -75 to -78dBc, take -75dBc as a working value
- When transmitting 50W (+47dBm), noise sidebands are at -28dBm
- Noise entering receiving radio is at – (antenna coupling (dB) + 28)dBm, eg 25dB coupling is -53dBm
- Therefore must remove main large signal, to prevent front end desensitisation by overdriving, and on-channel noise to restore radio sensitivity to an acceptable operational level

RF Interference Suppression on Fixed and Mobile Platforms – Problem Summary 2

- On-board RF Interference
  - Comms and data radios: high power main comms signal (off-channel interference) with low power broadband noise (on-channel interference)
  - Jammers: high power broadband (off- and on-channel interference

    (sample of interference only is available)

- Off-board RF Interference
  - Same as above, but generally signals will be of significantly lower power than on-board interference

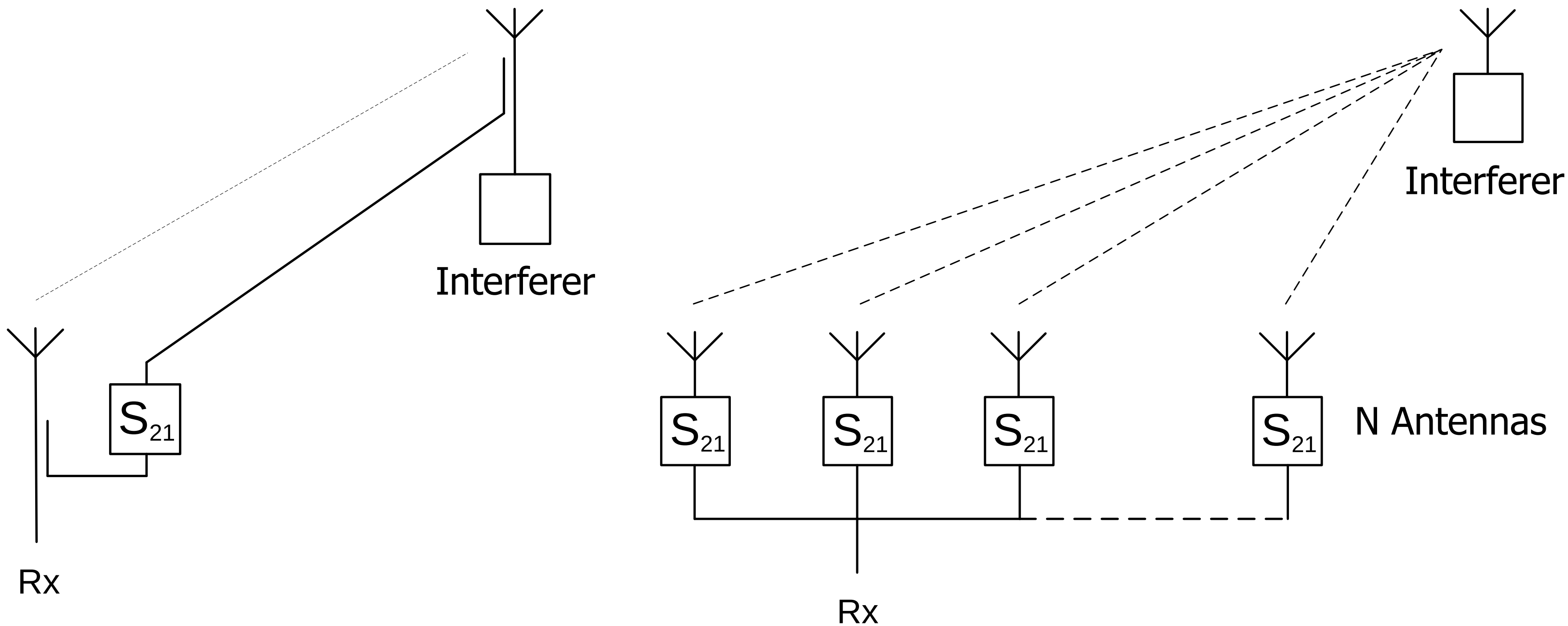
    (sample of interference only is not available)

RF Interference Suppression on Fixed and Mobile Platforms – Potential Solutions

- RF interference cancellation (on-board only)
- RF interference suppression using time division multiplexing (on- and off-board)
- Antenna polarisation techniques (off-board)
- Adaptive antenna nulling (off-board) – applied to anti-jam GPS

RF Interference Cancellation
(on-board only)

RF Interference Cancellation
Cancelling Interfering Signals



2 Samples

On-board

N Samples

Off-board

Number of Nulls from N samples is (N – 1)

NB They are the same type of mathematical problem

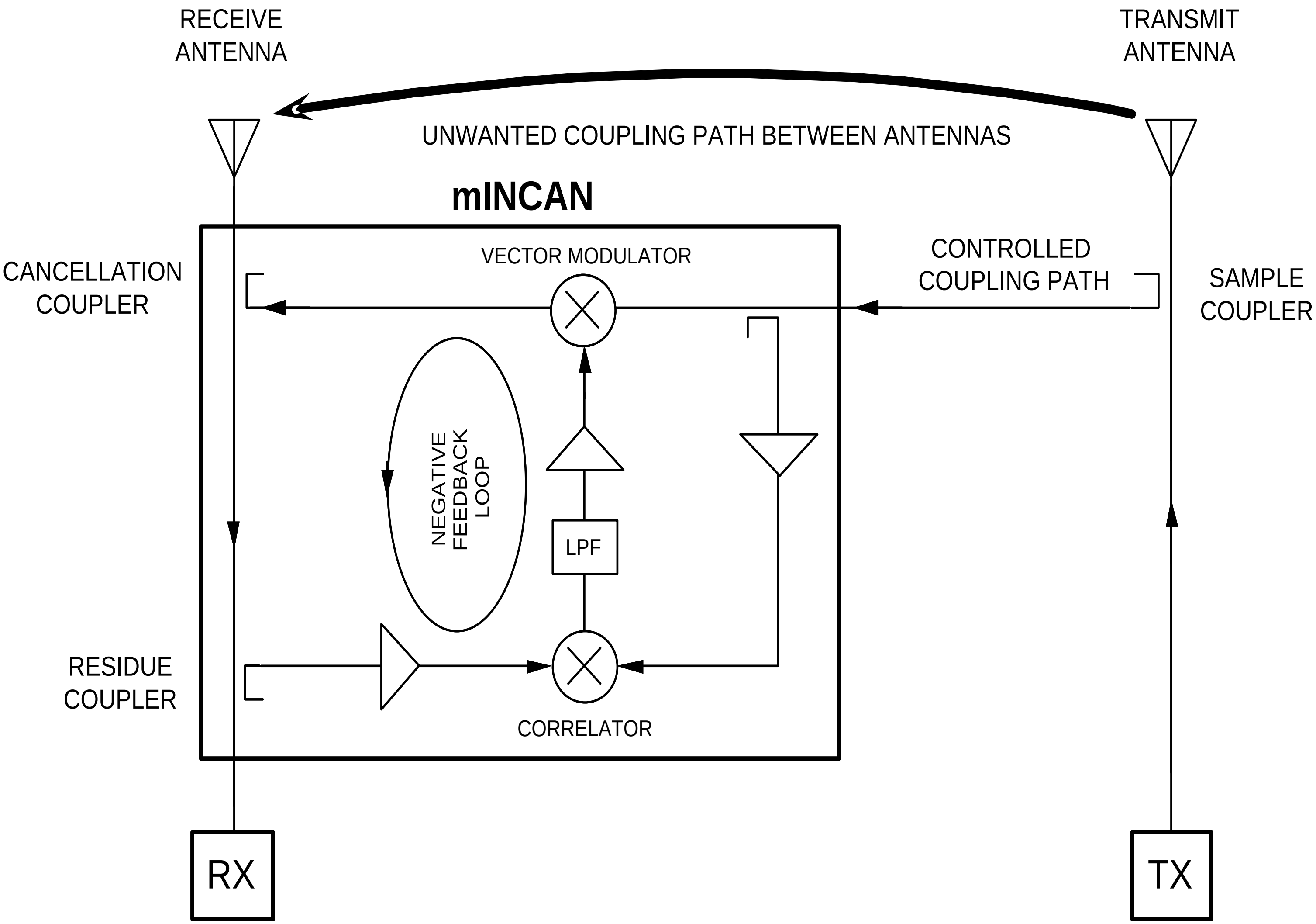
RF Cancellation of Narrowband On-board Interference

RF Interference Cancellation
Basic Principle

The removal of interference by injecting an accurately scaled anti-phase version of the interfering signal into the receive path

The basic system is analogue (no computer or digital hardware and no associated firmware or software is required for its operation)

Basic Block Diagram of RF Interference Cancellation System



RF Interference Cancellation
System Considerations

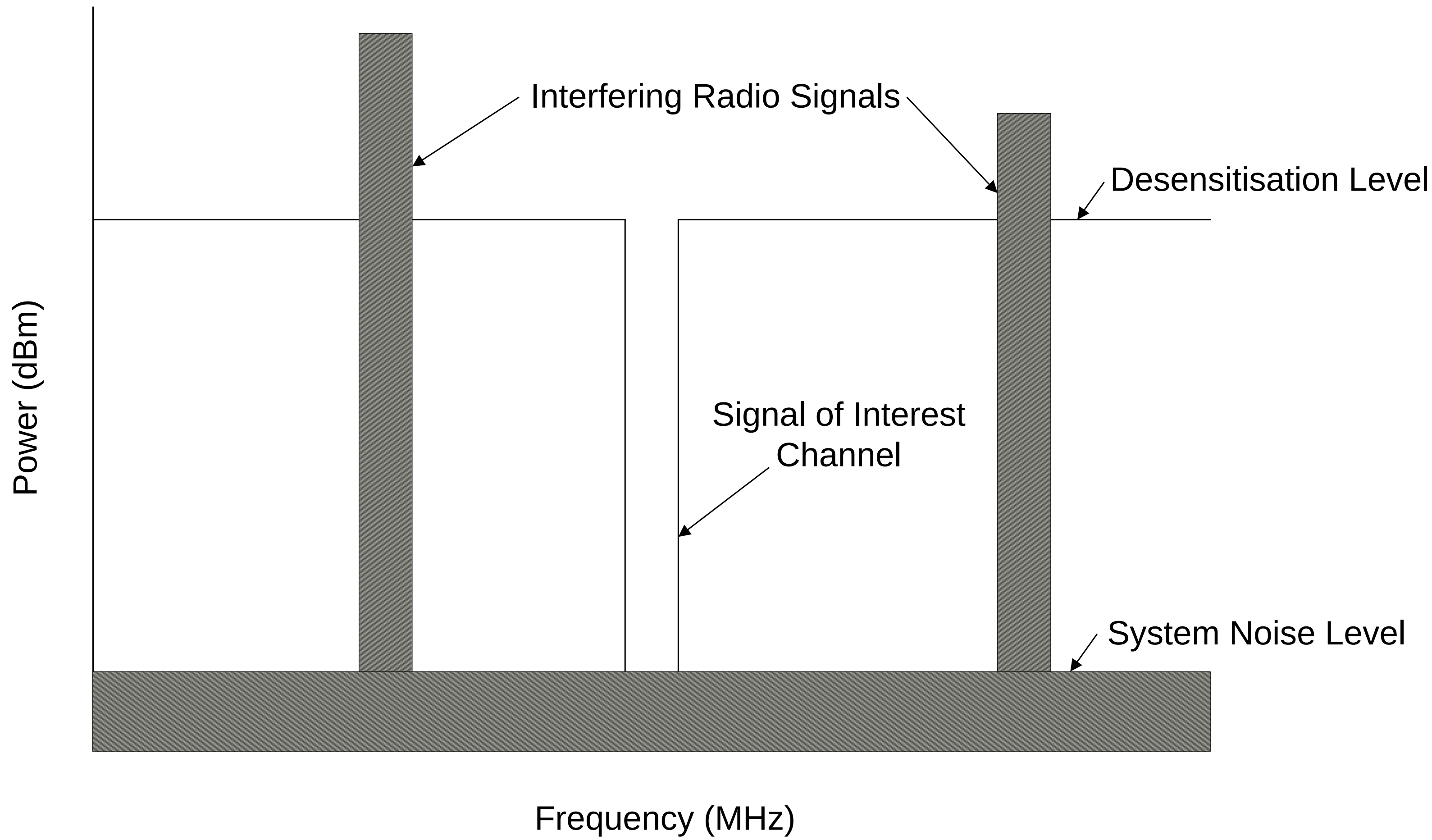
Interfering signal level received at antenna is high

- significant or total desensitisation of radio front end
- receive chain is nonlinear and generates harmonics and intermodulation products causing desensitisation
- occurs when interferer antenna is very close to receive antenna, eg co-located on the same platform
- must reduce signal level before it enters the receive chain

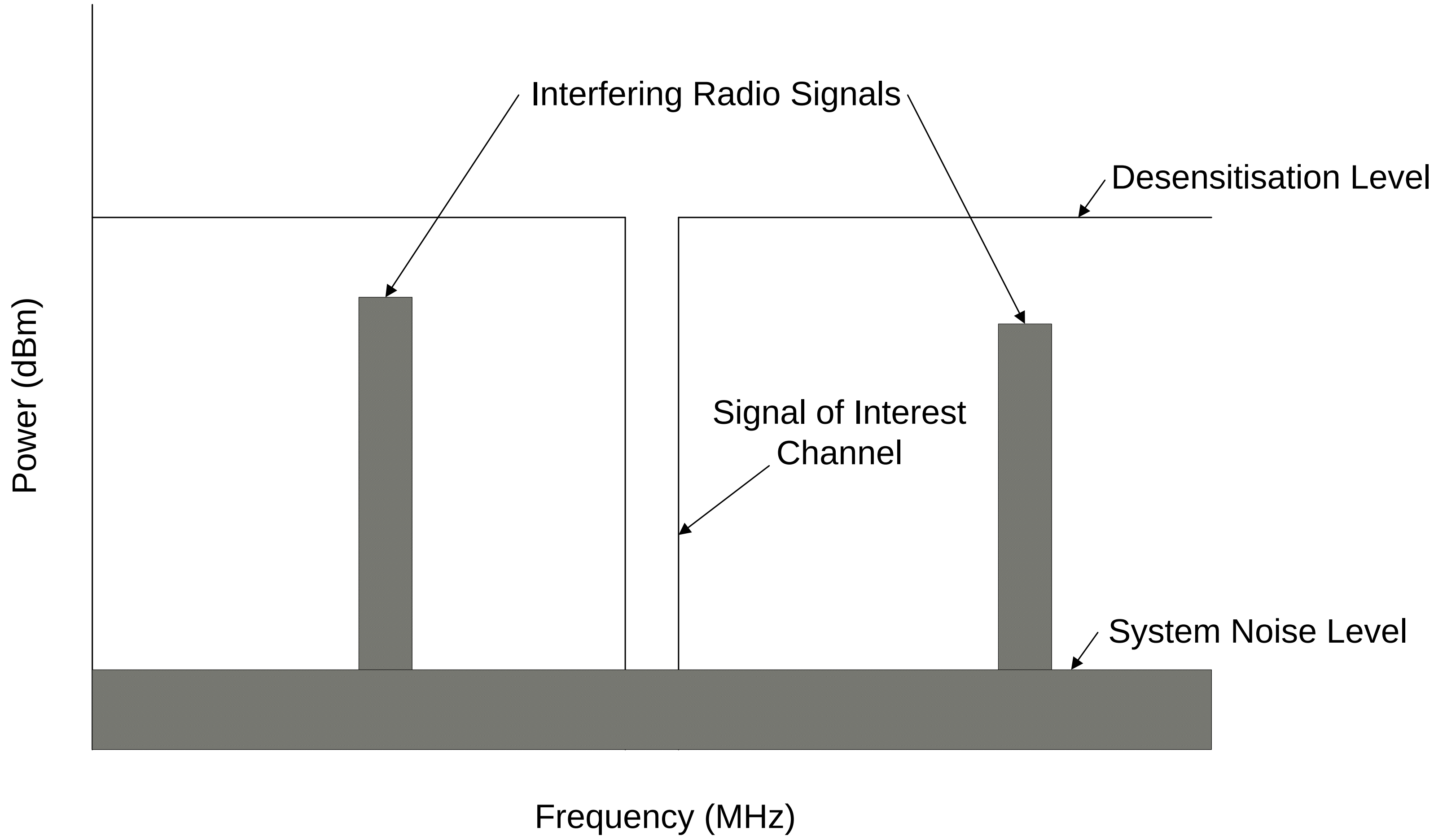
Interfering signal level received at antenna is low

- no desensitisation of radio front end
- receiver chain is linear
- occurs when interferer is remote from platform or some distance away
- off-channel interference can be removed by radio selectivity
- can cancel signal at any point in the receive chain

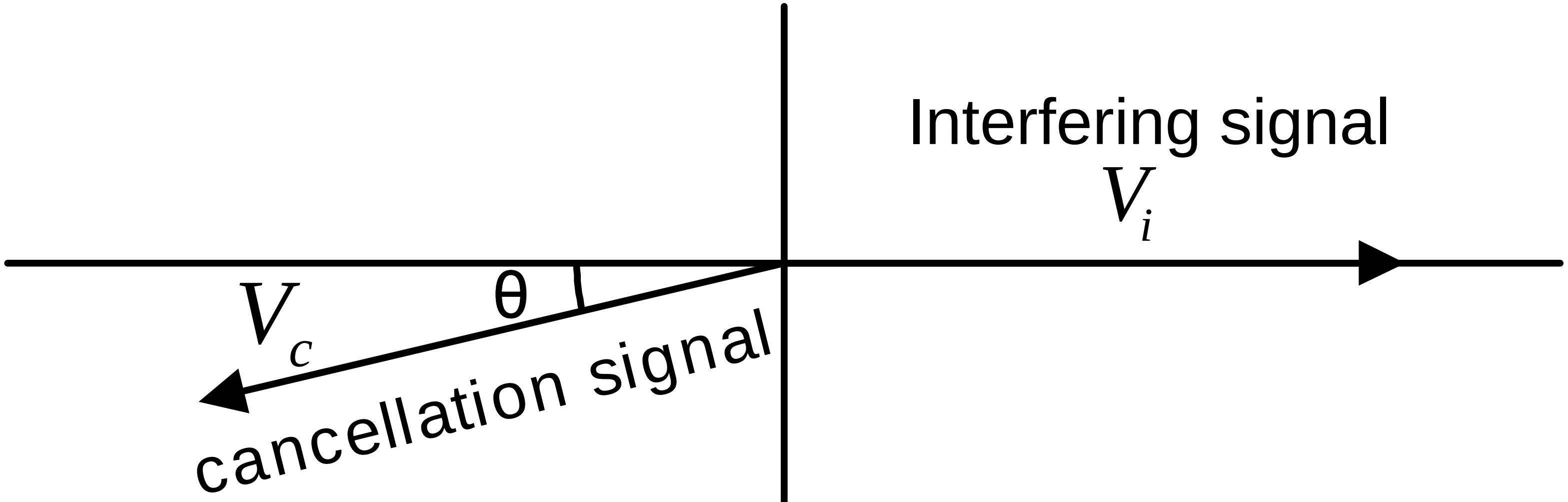
Cancellation of Interference from Co-located Radios - 1



Cancellation of Interference from Co-located Radios - 2



Principles of Interference Cancellation Vector Diagram



$$\theta = \pi B \tau$$

Principles of Interference Cancellation
Cancellation Equations - 1

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General Expression

$$c = -10Log_{10}\left[\left(1+(1-\delta)^2\right)-2(1-\delta)Cos(\pi B\tau)\right] \text{ dB}$$

where $\delta = 1 - \dfrac{V_c}{V_i}$

Approximate Expression

$$c \approx -10Log_{10}\left[\delta^2 + (\pi B\tau)^2(1-\delta)\right] \text{ dB}$$

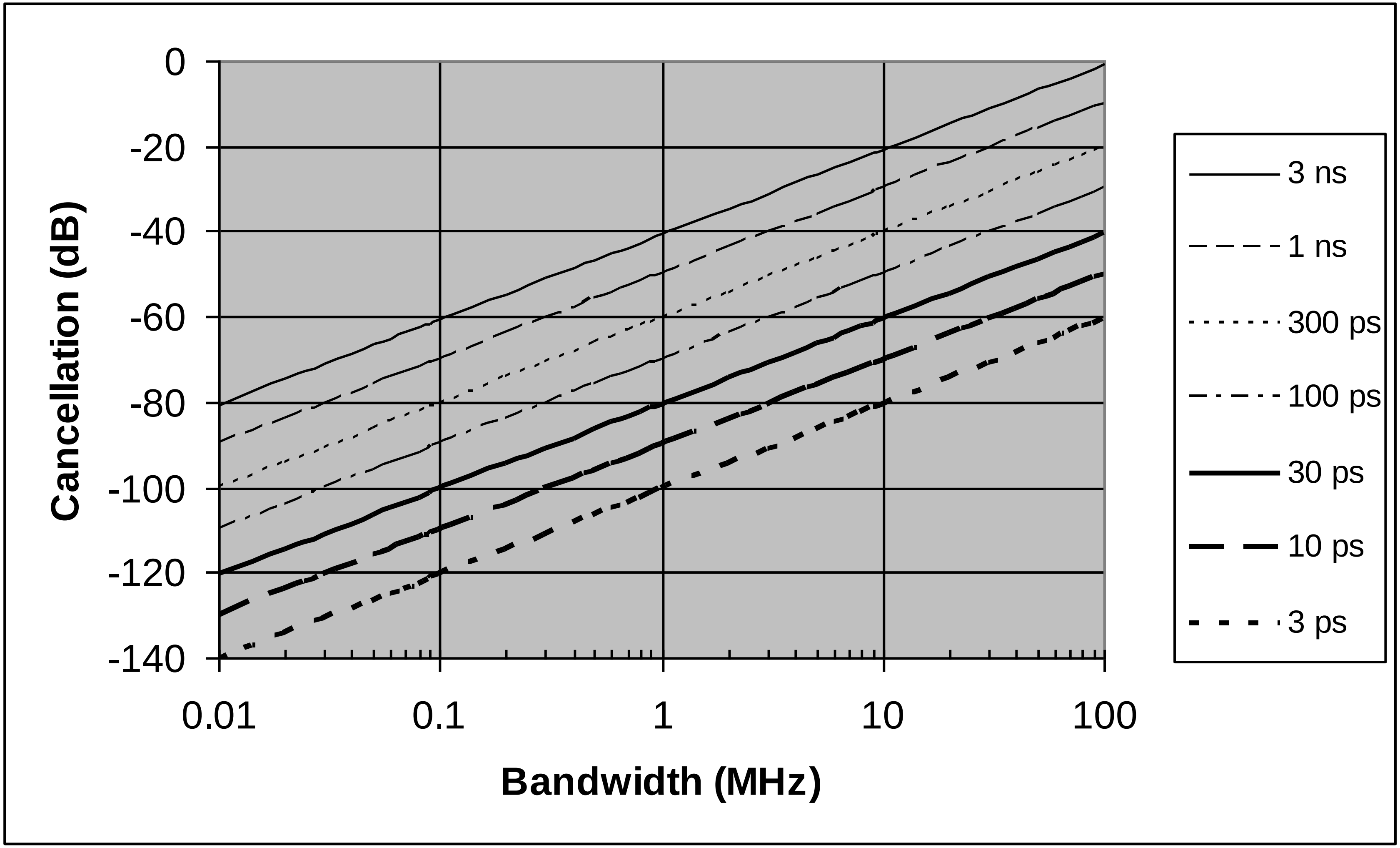
Principles of Interference Cancellation
Cancellation Equations - 2

when $\delta = 0$

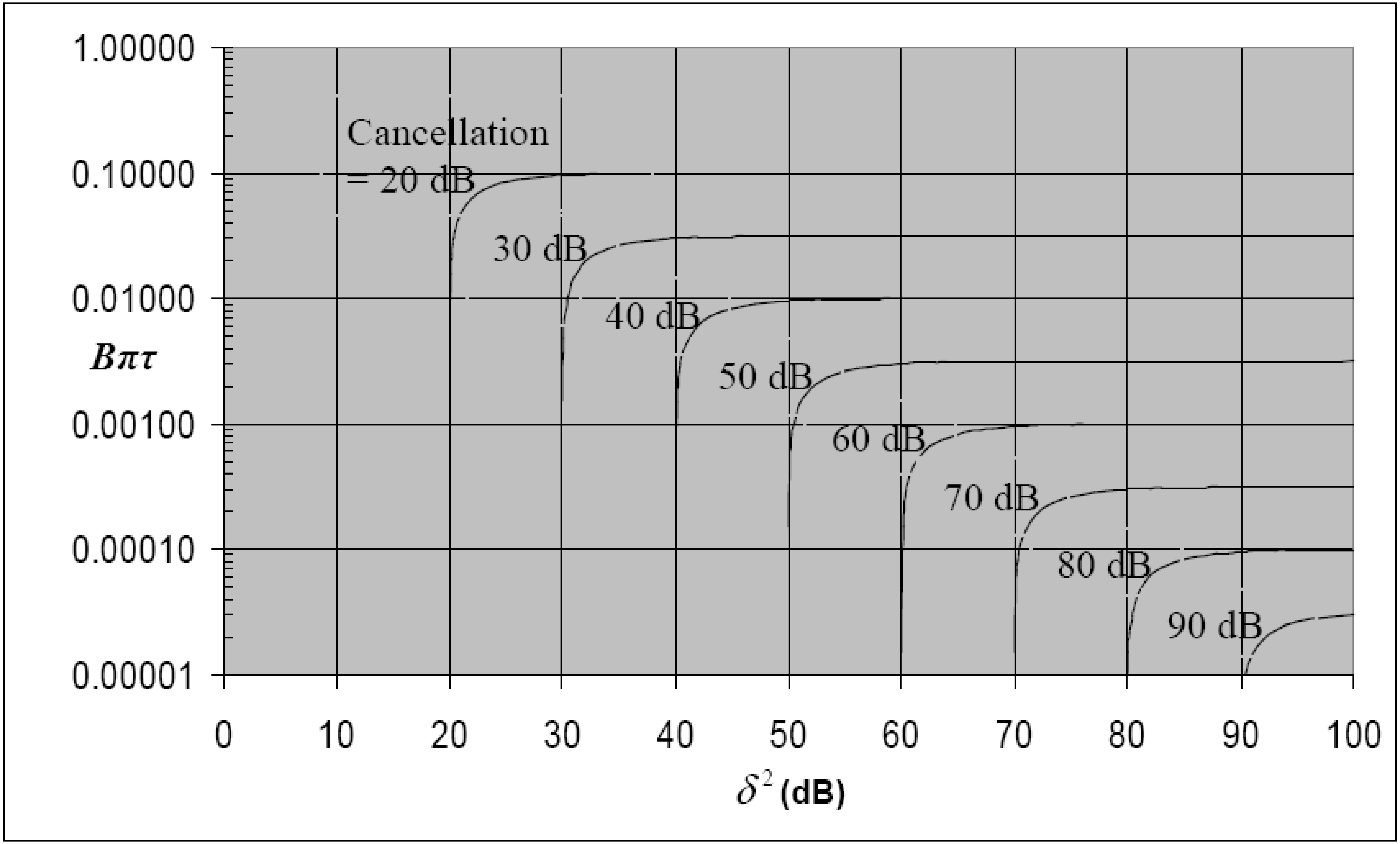
$$c \approx -20Log_{10}(\pi B\tau) \text{ dB}$$

$$\approx -9.9430 - 20Log_{10}B - 20Log_{10}\tau \text{ dB}$$

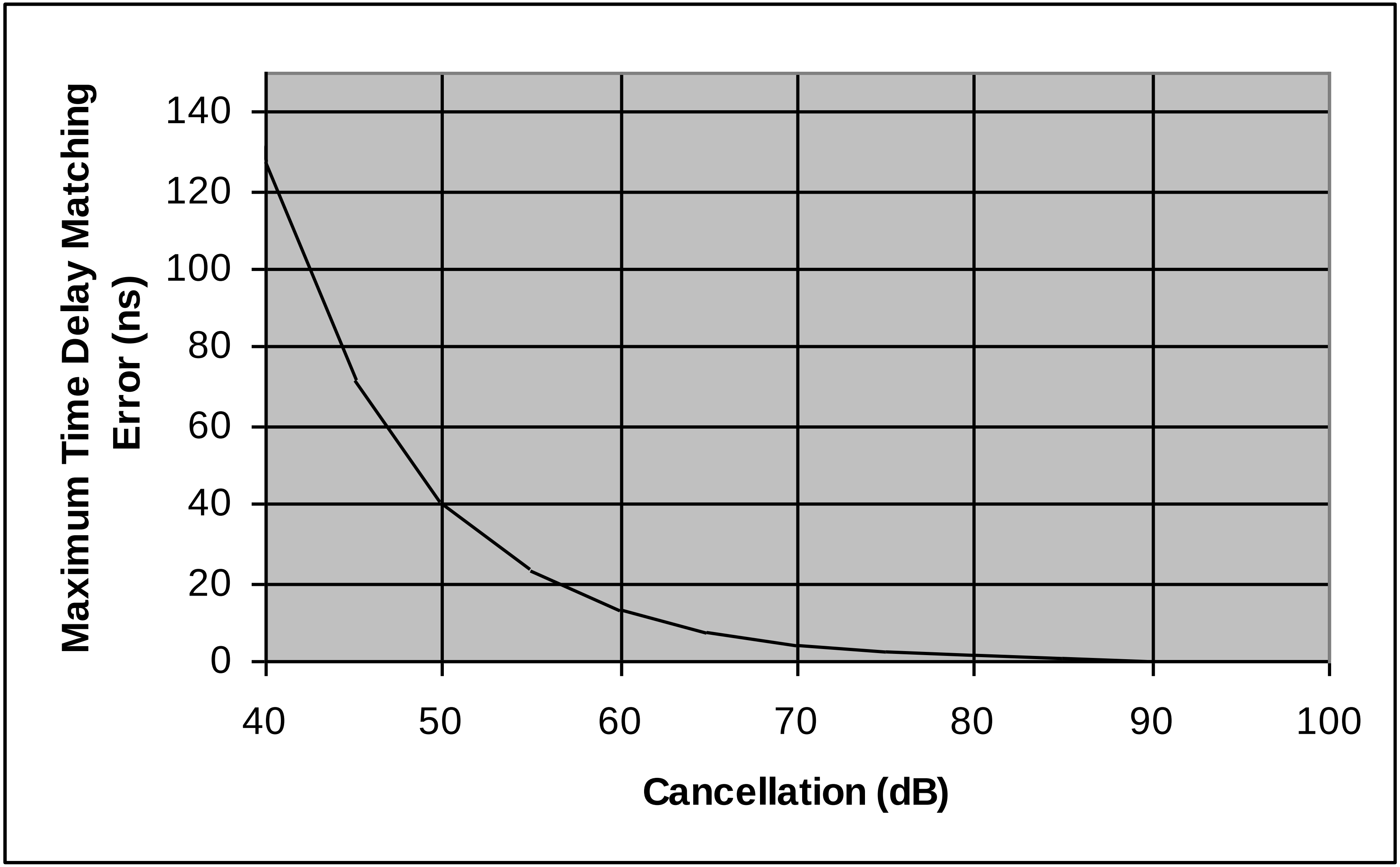
Principles of Interference Cancellation
Lines of Constant Cancellation



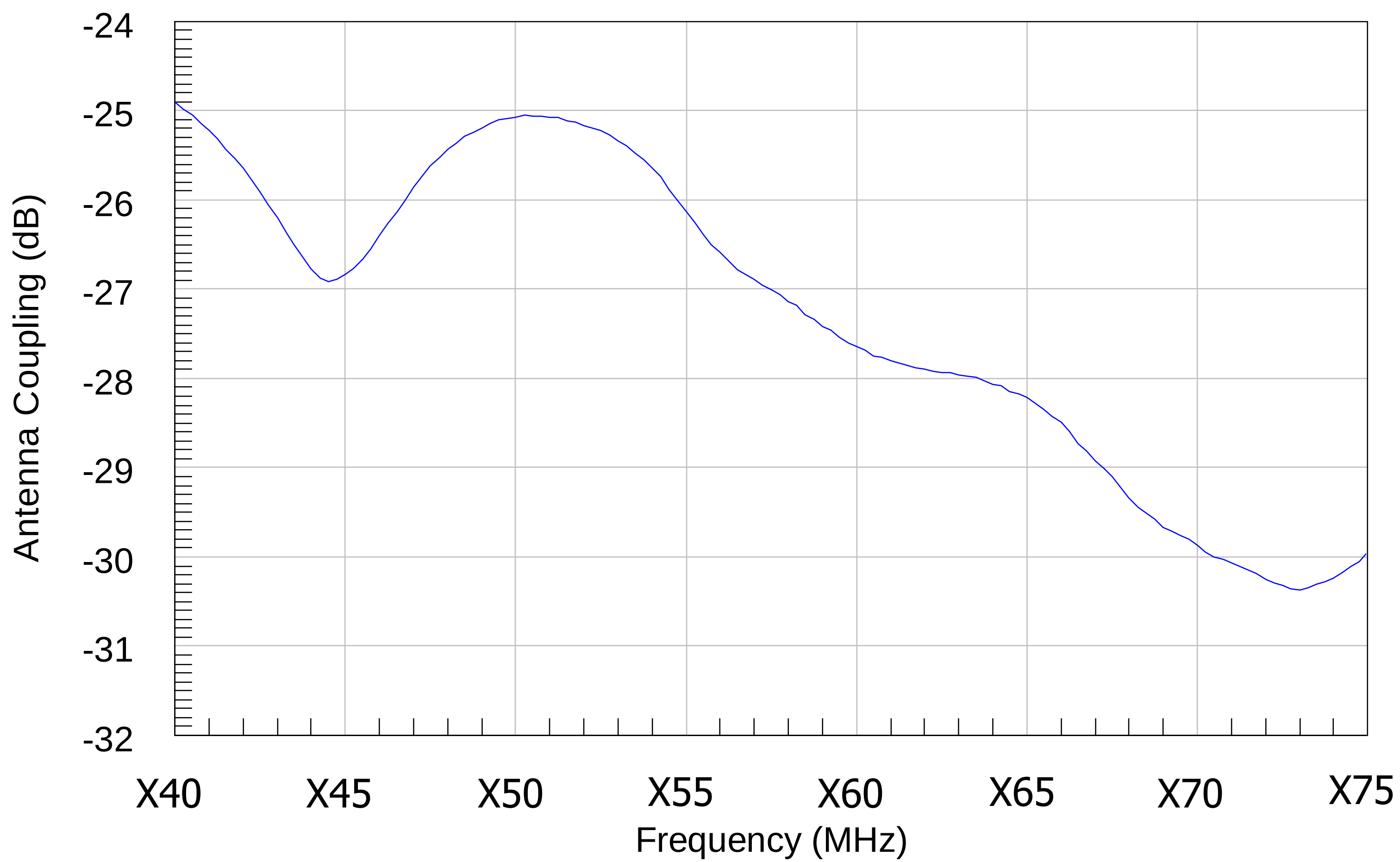
Principles of Interference Cancellation
Constant Cancellation Contours



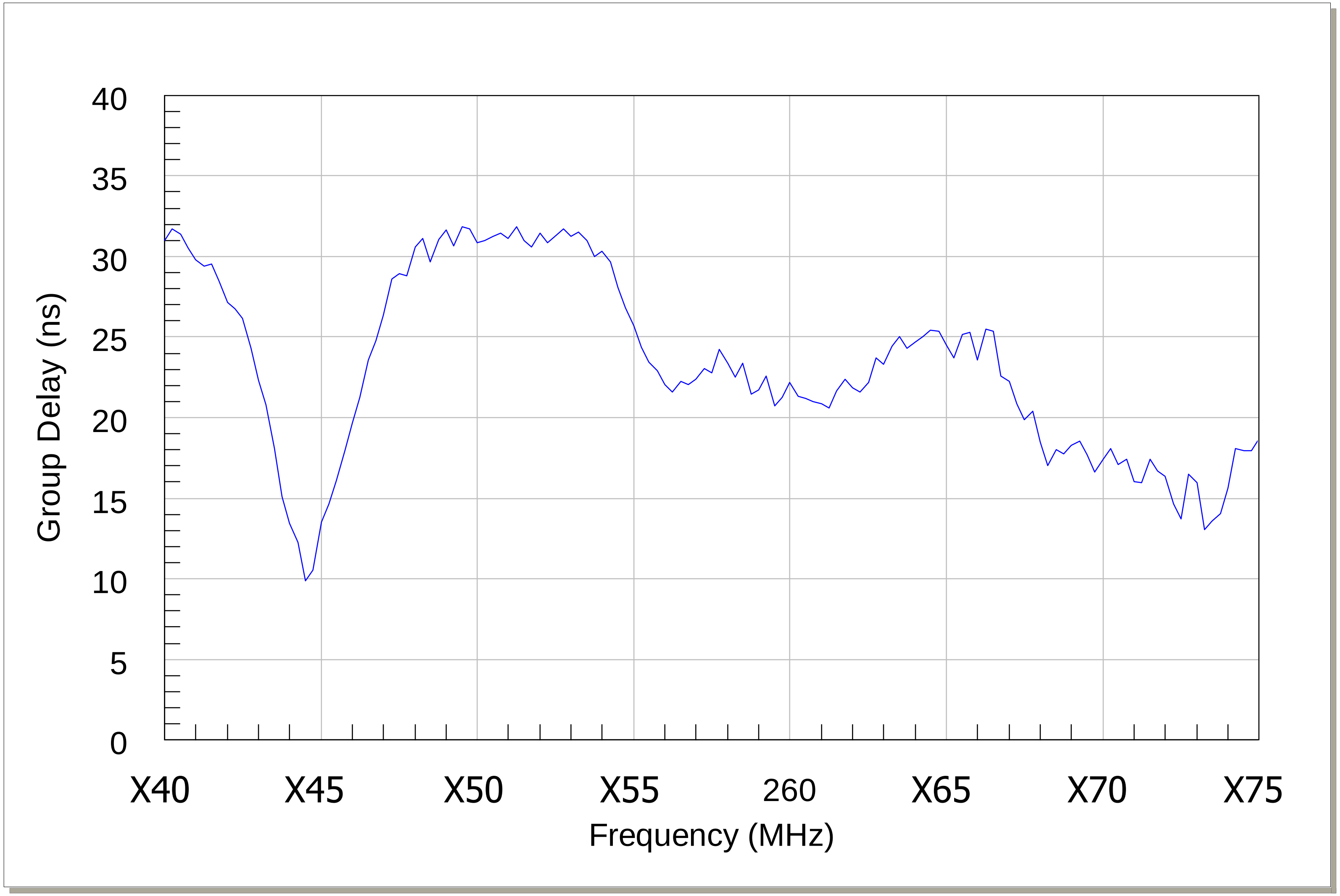
Cancellation over a 25kHz Receive Channel



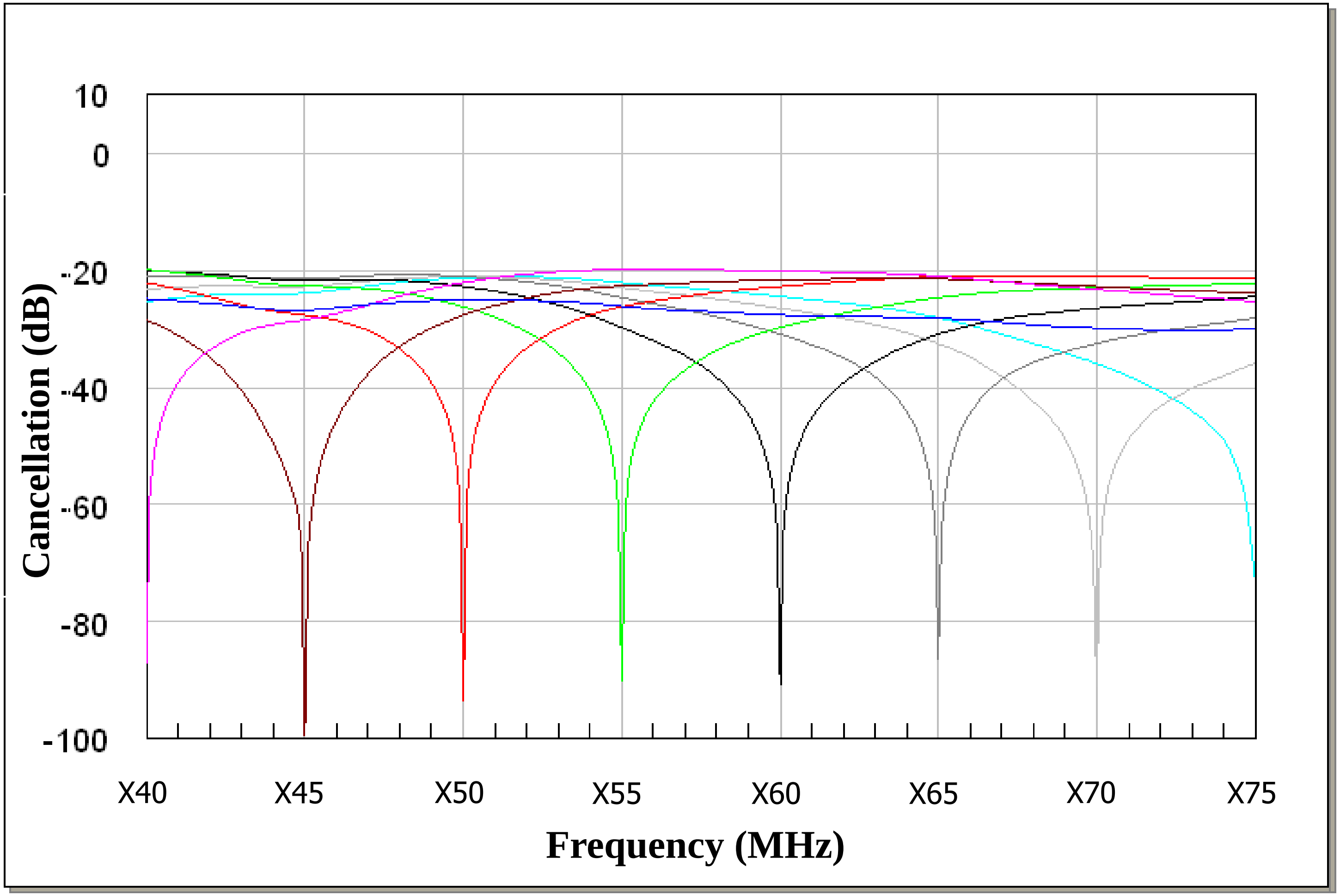
Principles of Interference Cancellation
Antenna Coupling v Frequency



Principles of Interference Cancellation
Group Delay v Frequency



Principles of Interference Cancellation
Cancellation (dB) v Frequency



Principles of Interference Cancellation
Cancellation Parameters

L_{f_0} = attenuation (dB) – not important

$\dfrac{dL}{df}_{f_0}$ = rate of change of attenuation (dB/MHz)

$\tau(f_0)$ = group delay (ns)

$\dfrac{d\tau(f_0)}{df}$ = rate of change of group delay (ns/MHz)

NB The above parameters are based on the difference between the antenna coupling and cancellation paths

Principles of Interference Cancellation
Cancellation Equations - 3

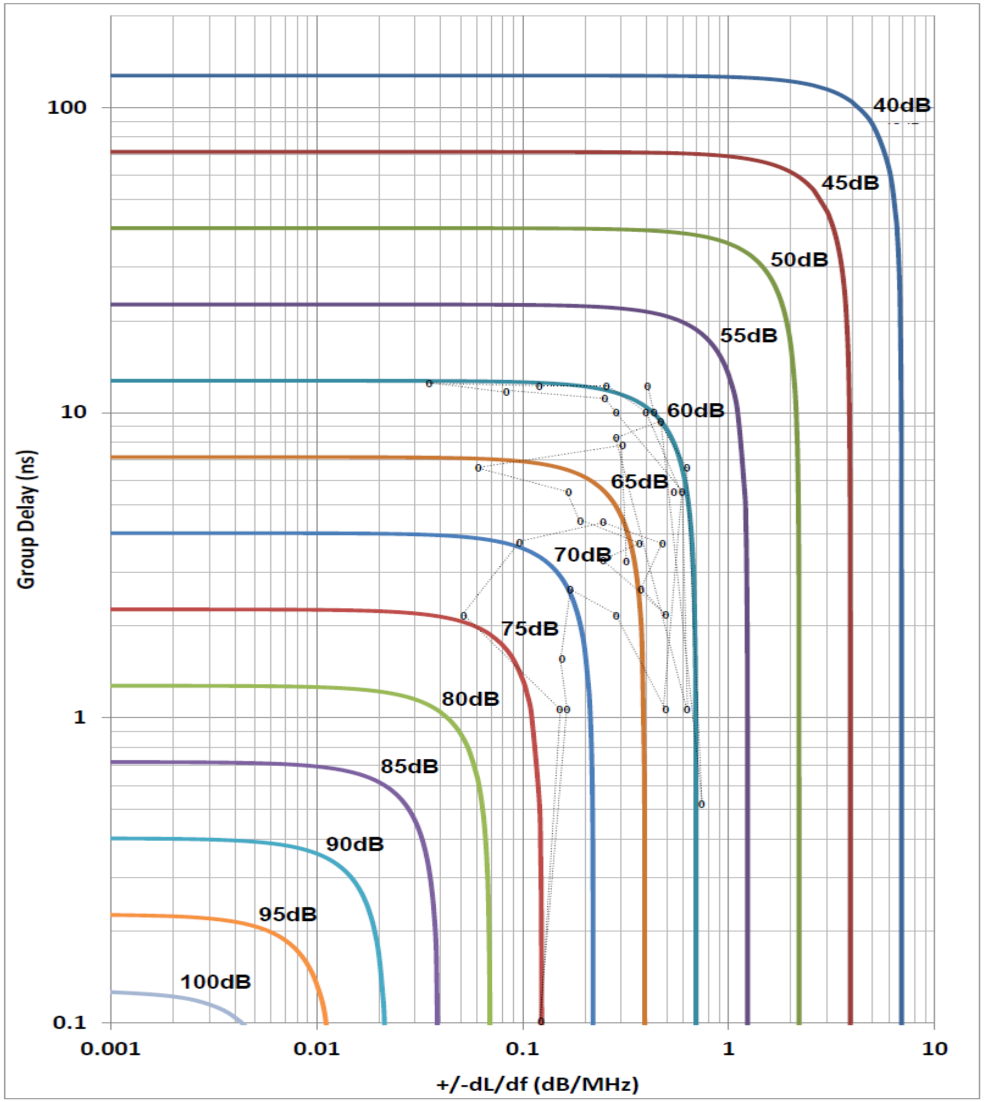
In practice, the rate of change of group delay, $\frac{d\tau(f_0)}{df}$, is not very significant unless one is looking to achieve cancellation levels greater than 70dB.

Hence one can use the approximation for cancellation, c,:

$$c \approx -10Log\left[\left(1-10^{2.5\times10^{-5}B\frac{dL(f_0)}{df}}\right)^2 + \left(\pi B\times10^{-6}\tau(f_0)\right)^2\right] \text{ dB}$$

Where B = receive bandwidth in kHz

Principles of Interference Cancellation
Curves of Constant Cancellation



Interference Cancellation Systems

Multi-channel 30 – 512MHz system in 3/8 ATR box supplied to UK & overseas customers

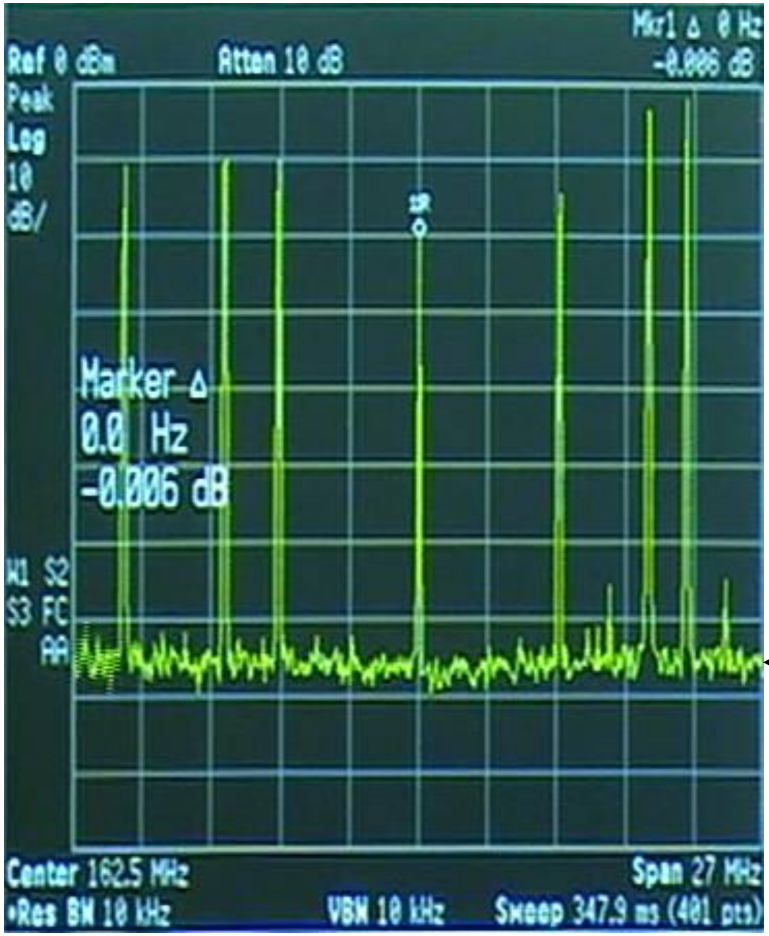
Rescue 21 150 – 175MHz system for US coastguard

Single channel tactical 30 – 512MHz system supplied to UK customers

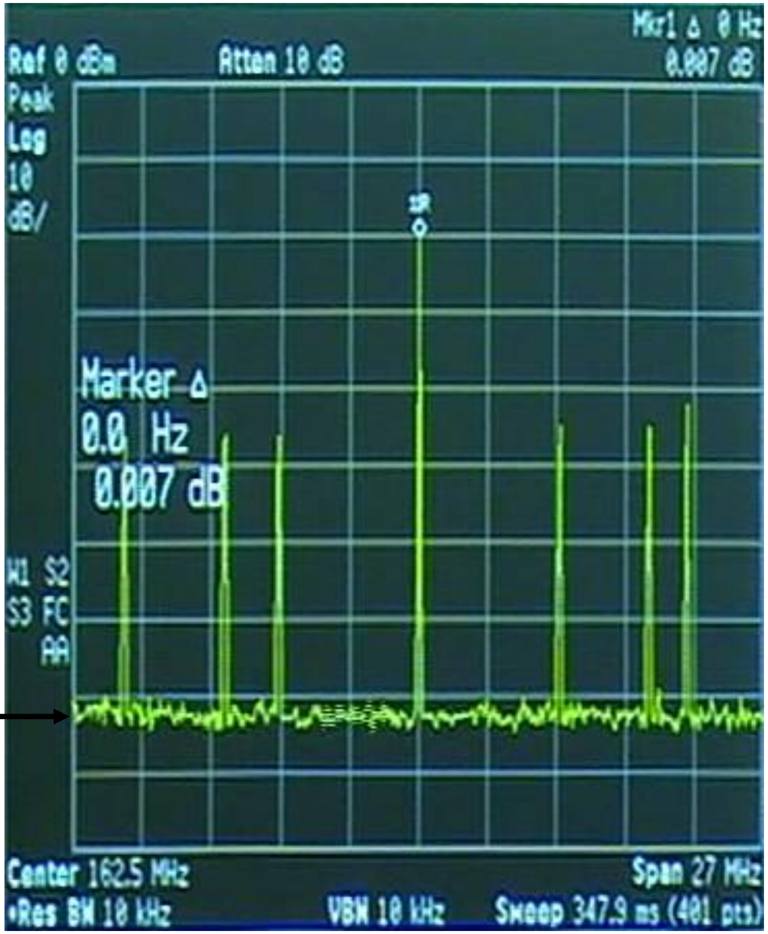
4-channel 30 – 512MHz system for LAVC2

RF Cancellation System with One SoI and 6 Interferers

RF canceller off

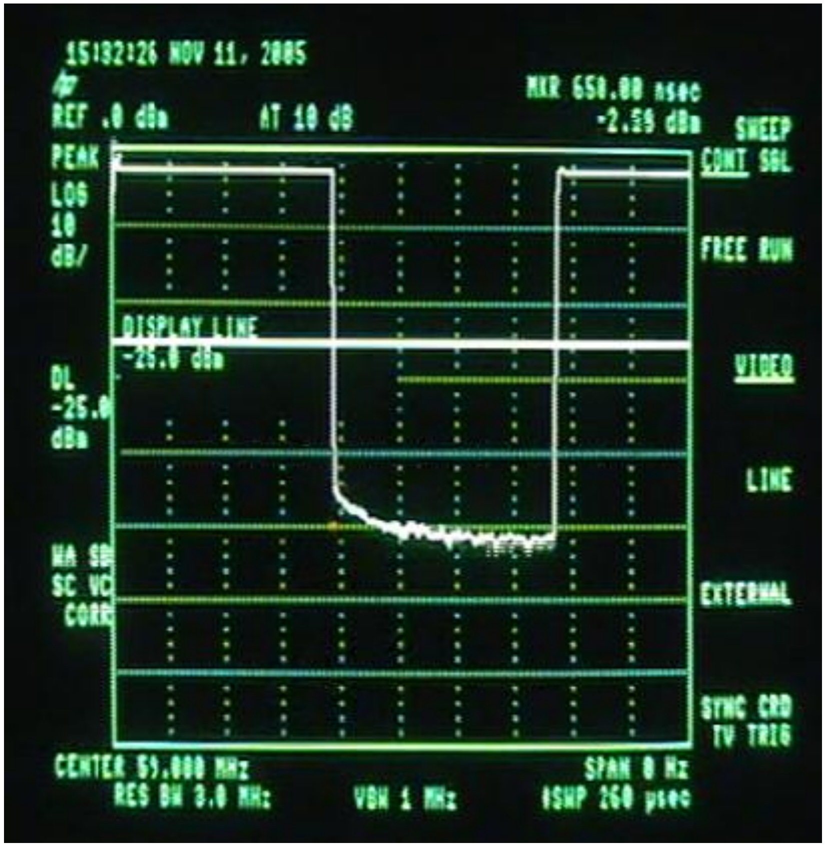


RF canceller on

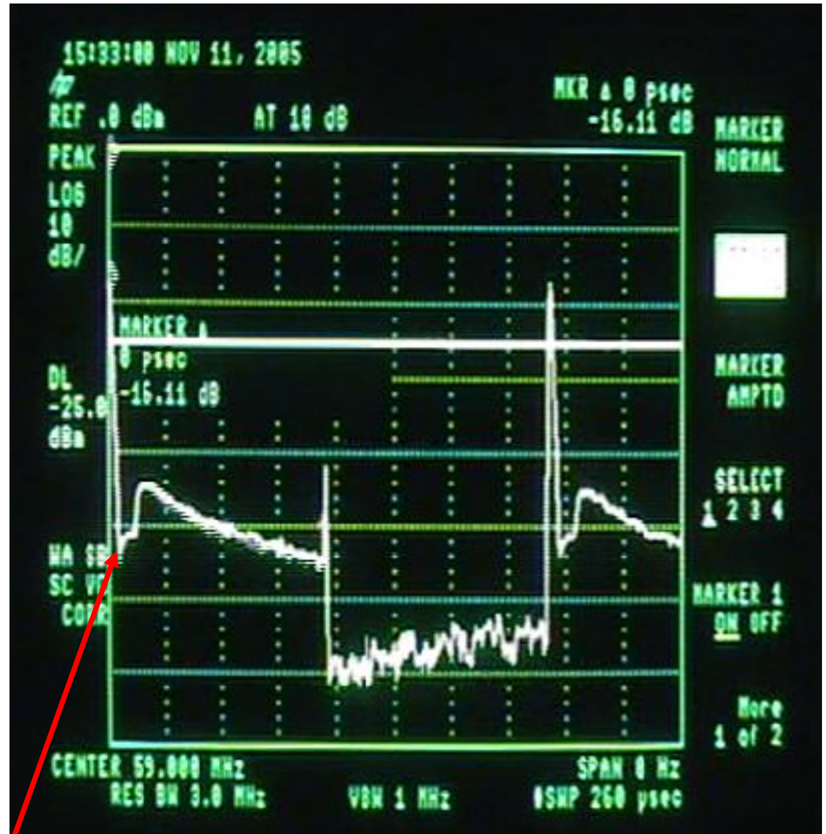


Speed of Cancellation

mINCAN off



mINCAN on



>50dB in <5µs

LAV Command and Control Platform employing RF Interference Cancellation

Summary for RF Cancellation of Large Narrowband Signals

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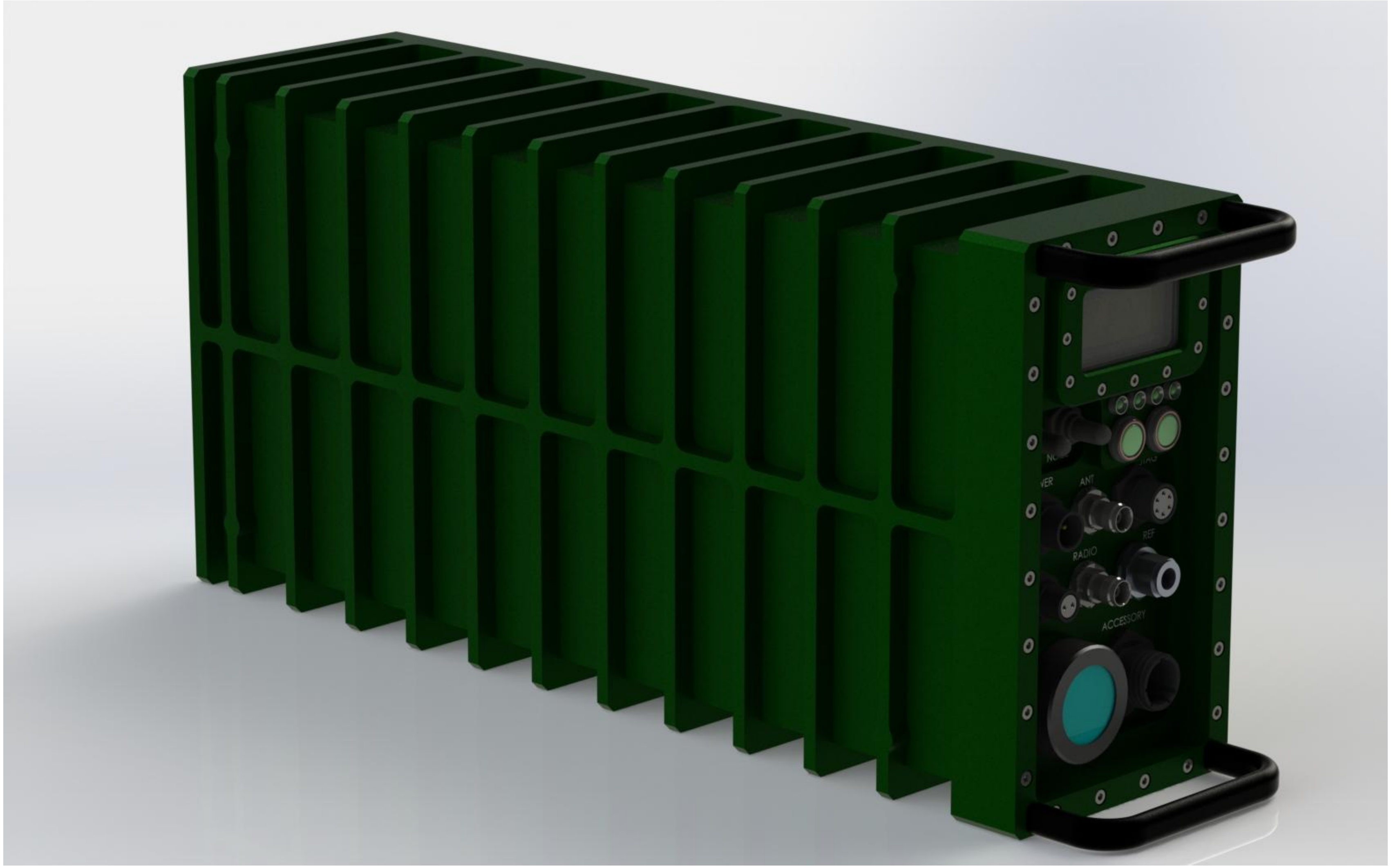
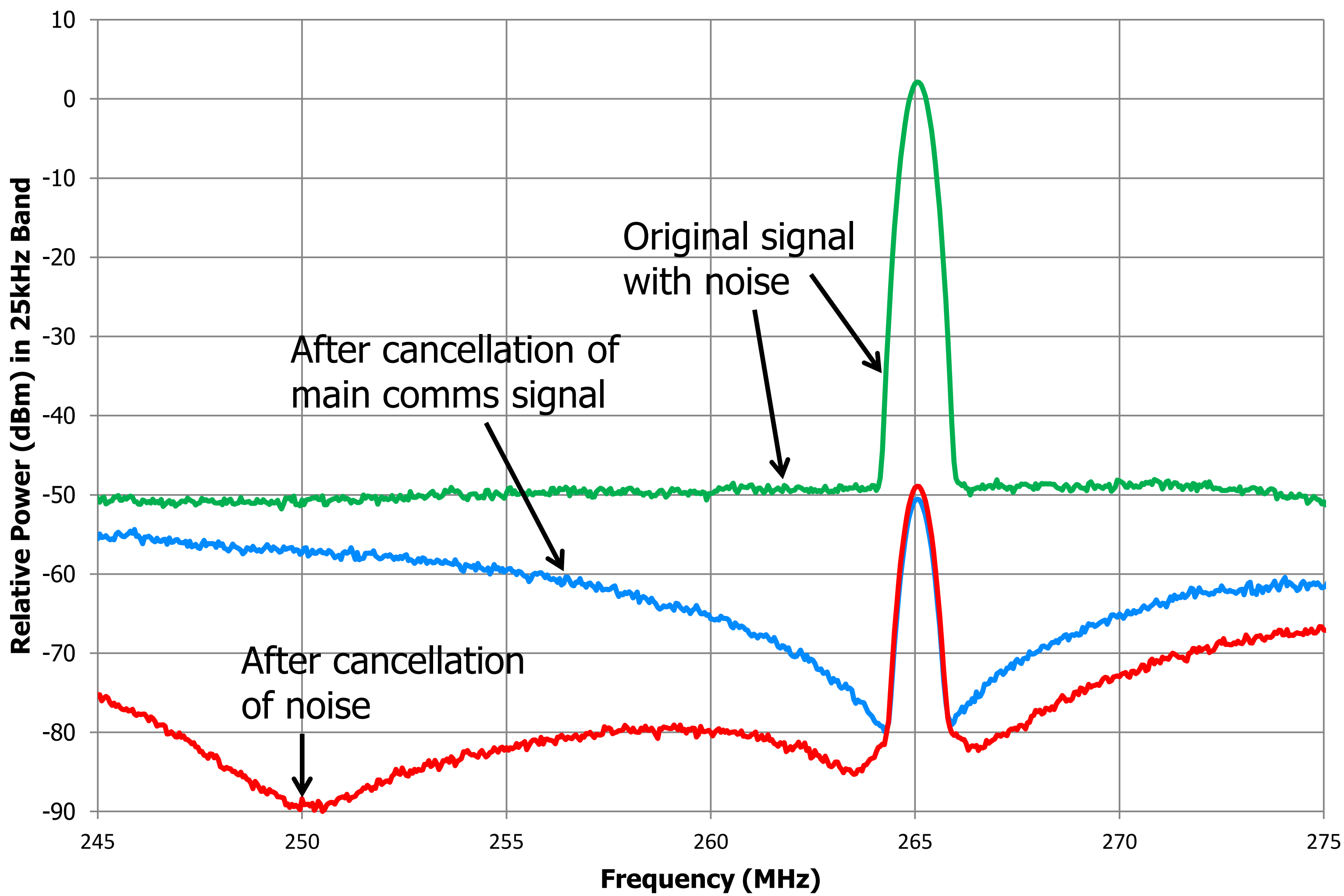
- A range of interference cancellation systems have been developed in the 30 – 512 MHz band, which remove the main large signal
- Inherently broadband if time delays and coupling in antenna and cancellation paths are matched
- Up to 30 channels cancelling simultaneously demonstrated
- 40 – 70 dB cancellation realized in practice depending on configuration
- Cancellation speeds of 50 dB in 5 μs
- Equivalent Q factors of 0.5 million (Rescue 21)
- SINAD of 22 dB @ -110 dBm in 8 channel system (Rescue 21)
- Mature technology
- Systems in production and deployed in the field
- The RF cancellation technique can be applied at any frequency
- The principle can be extended to cover wider instantaneous bandwidths by using multi-tap delay lines

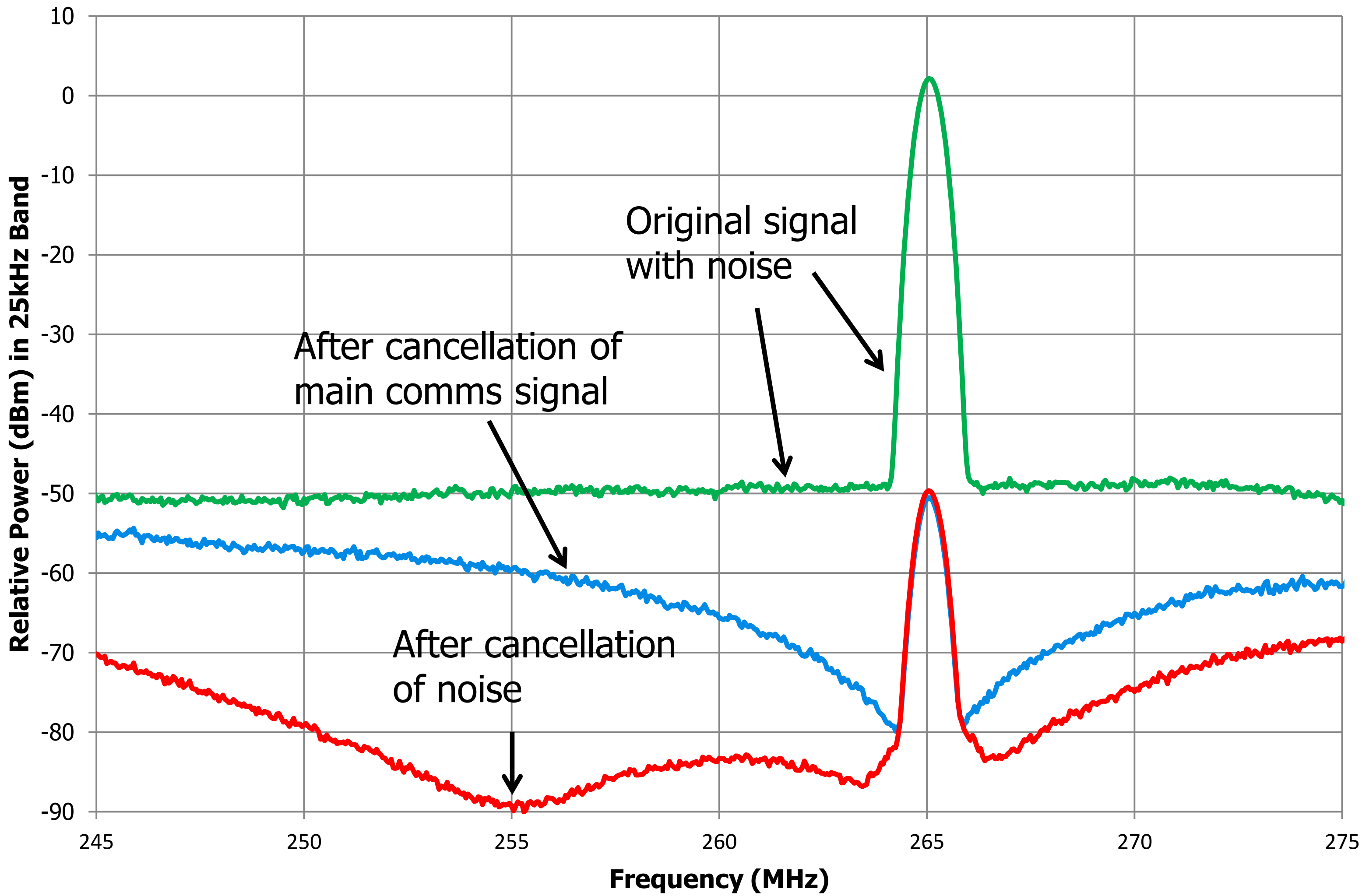
RF Interference Cancellation System to Remove Main Large Comms Signal and Noise



RF Cancellation of Main Large Signal at 265MHz and On-channel Noise at 250MHz



RF Cancellation of Main Large Signal at 265MHz and On-channel Noise at 255MHz



Cancellation of Main Off-channel Large Signal Interference and On-Channel Noise - Video

- Span on spectrum analyser is 245 – 275MHz
- Main large signal comms radio interference is at 265MHz
- We wish to receive a signal at 250MHz
- The main signal is produced by a signal generator and noise is added to represent the transmitter sideband noise
- The main large off-channel interference at 265MHz is reduced by 50dB
- The on-channel noise at 250MHz is reduced by 50dB (cancellation is instantaneous, but appears slow due to averaging)

(mINCAN = miniature Interference CANcellation system)

Cancellation of Main Off-channel Large Signal Interference and On-Channel Noise - Summary

- Cancellation of main large off-channel signal = 50dB
- Cancellation of on-channel noise = 50dB

SINAD in the Presence of RF Interference with Noise and Distortion

Question:

What is the relationship between SINAD, interfering transmitter sideband noise, antenna coupling and RF cancellation?

SINAD in the Presence of RF Interference with Noise and Distortion - 1

Definition of SINAD:

$$SINAD_1 = \frac{P_{signal} + P_{noise} + P_{distortion}}{P_{noise1} + P_{distortion1}} = 1 + \frac{P_{signal}}{P_{noise1} + P_{distortion1}}$$

SINAD in the Presence of RF Interference with Noise and Distortion - 2

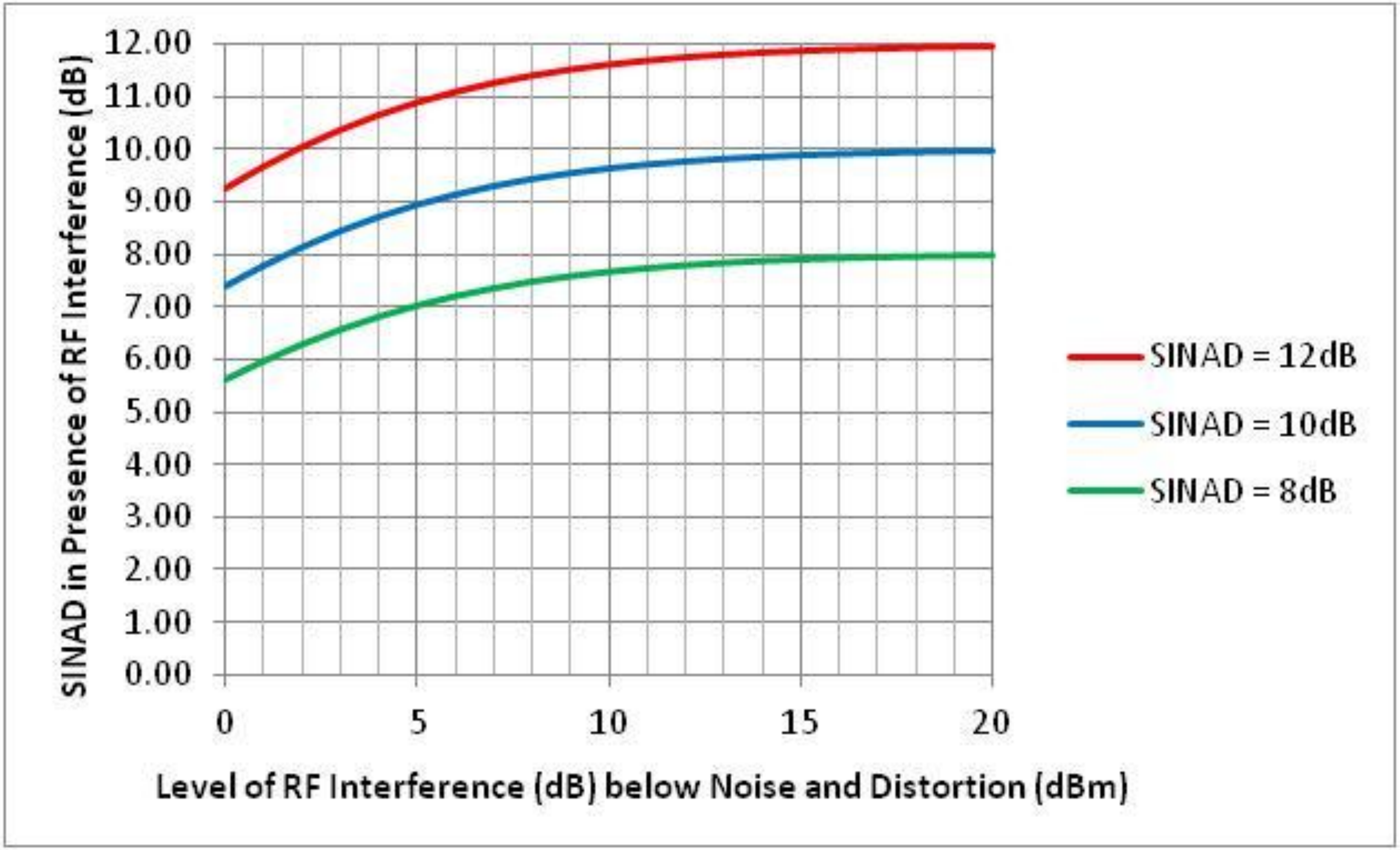
$$SINAD_2 = 1 + \frac{P_{signal}}{\left(P_{noise1} + P_{distortion1}\right) + \left(P_{noise2} + P_{distortion2}\right)}$$

$$= 1 + \frac{P_{signal}}{\left(P_{noise1} + P_{distortion1}\right)\left(1 + X\right)}$$

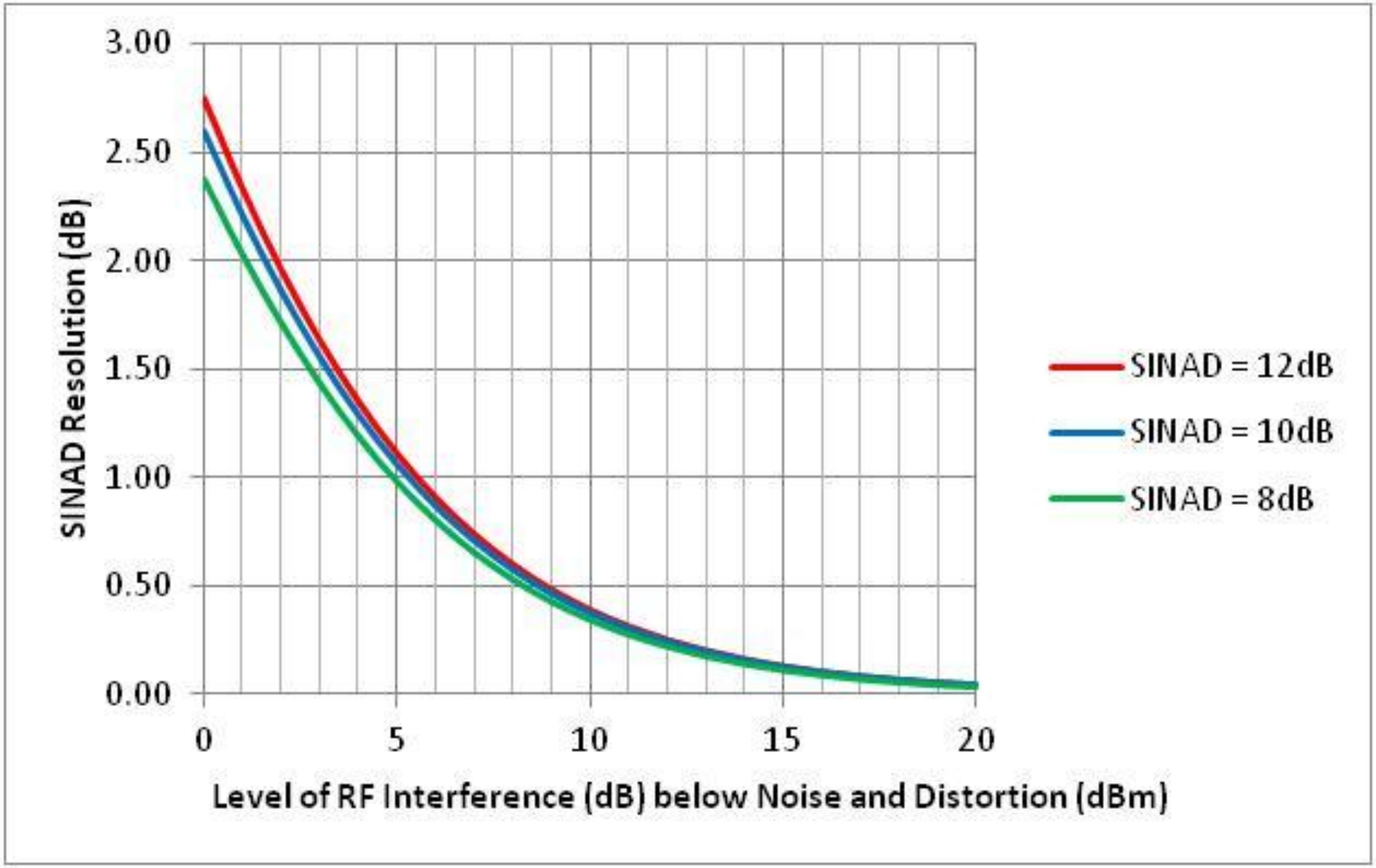
$$X = \frac{P_{noise2} + P_{distortion2}}{P_{noise1} + P_{distortion1}}$$

$$SINAD_2 = 1 + \frac{\left(SINAD_1 - 1\right)}{\left(1 + X\right)}$$

SINAD in the Presence of RF Interference with Noise and Distortion



SINAD Resolution versus Level of RF Interference below Noise and Distortion



Radio Sensitivity in the Presence of RF Interference from On-channel Noise

Radio Sensitivity (dBm)

~ Interfering Noise Level (dBm) (from transmitter)

– Antenna Coupling (dB)

– Cancellation (dB)

+ SINAD (dB)

+10

Radio Sensitivity in the Presence of RF Interference from On-channel Noise - Example

For a radio transmitting +47dBm (50W) the noise is at -28dBm (-75dBc/25kHz = -119dBc/Hz)

If we assume that the antenna coupling is 25dB, the noise into the radio is -53dBm (-28dBm -25dB)

Therefore the sensitivity of the radio for 10dB SINAD is -33dBm (-53dBm +20dB)

If we cancel the received on-channel noise by 60dB, the sensitivity is now -93dBm

RF Interference Cancellation applied to 2 On-board Broadband Interferers (Jammers) to Restore Radio Sensitivity in the Satellite Communications Band

Extraction of Signal buried in Noise

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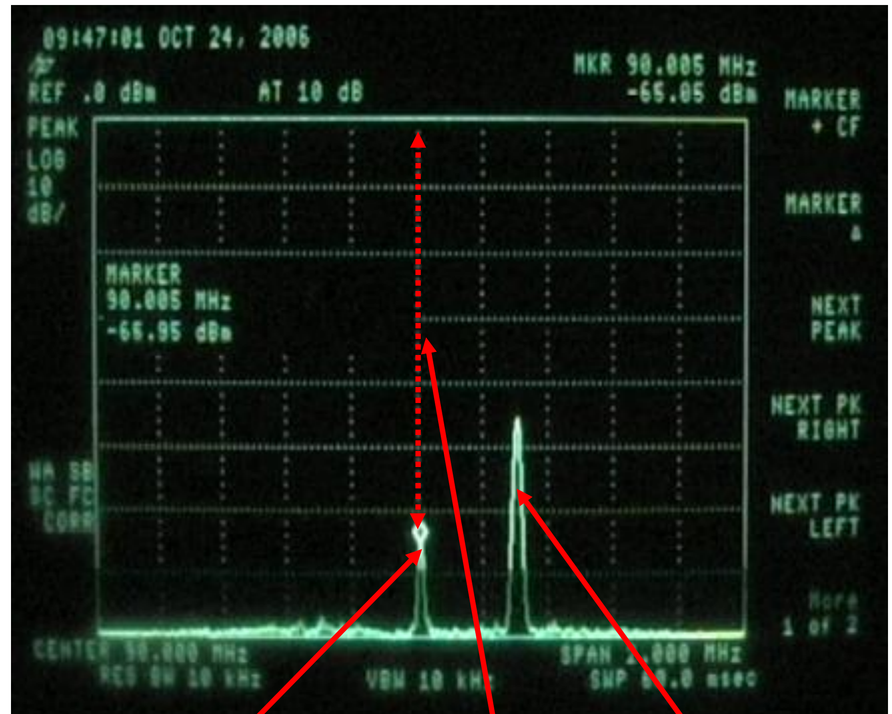
mINCAN off

Interference

mINCAN on

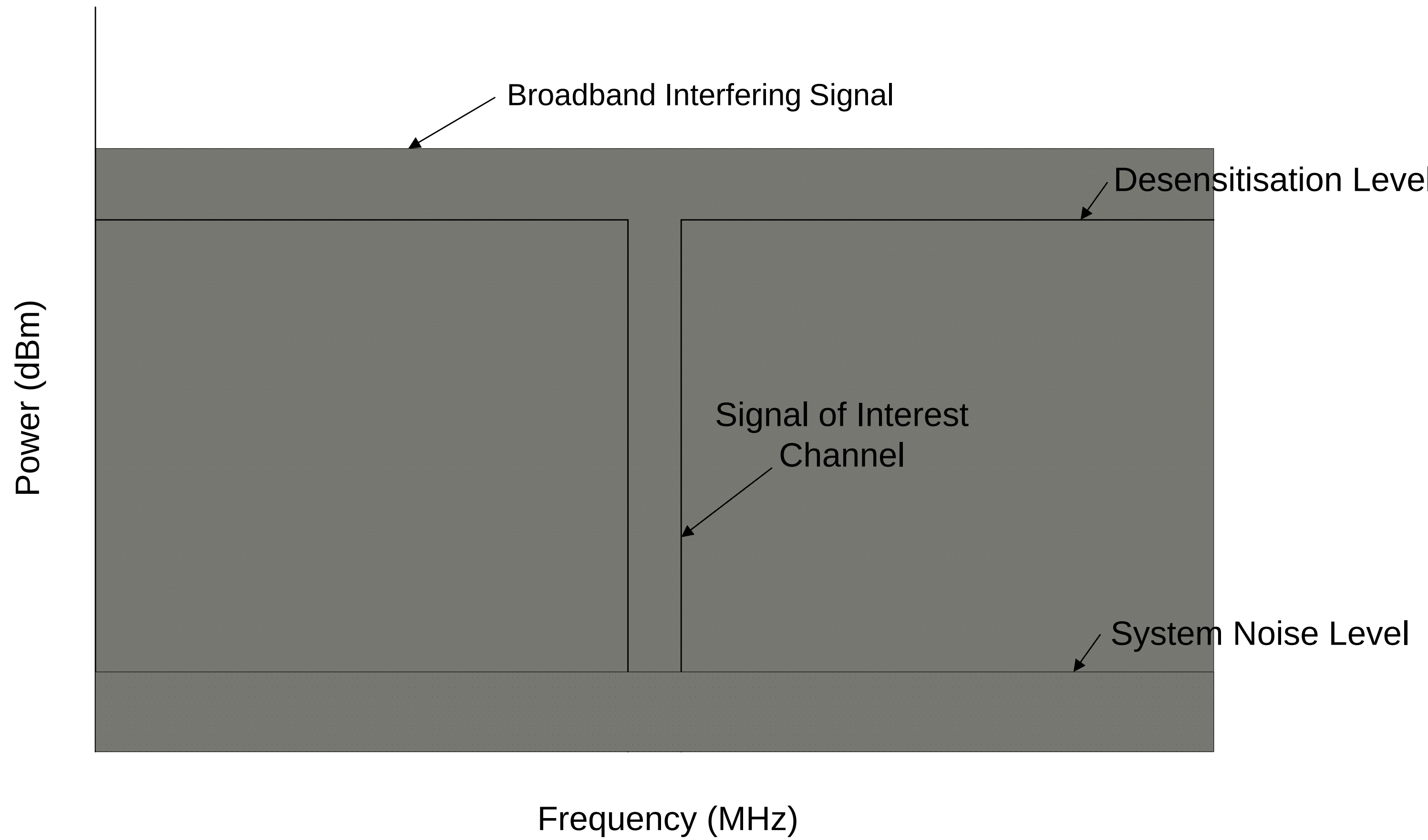


Cancelled Interference

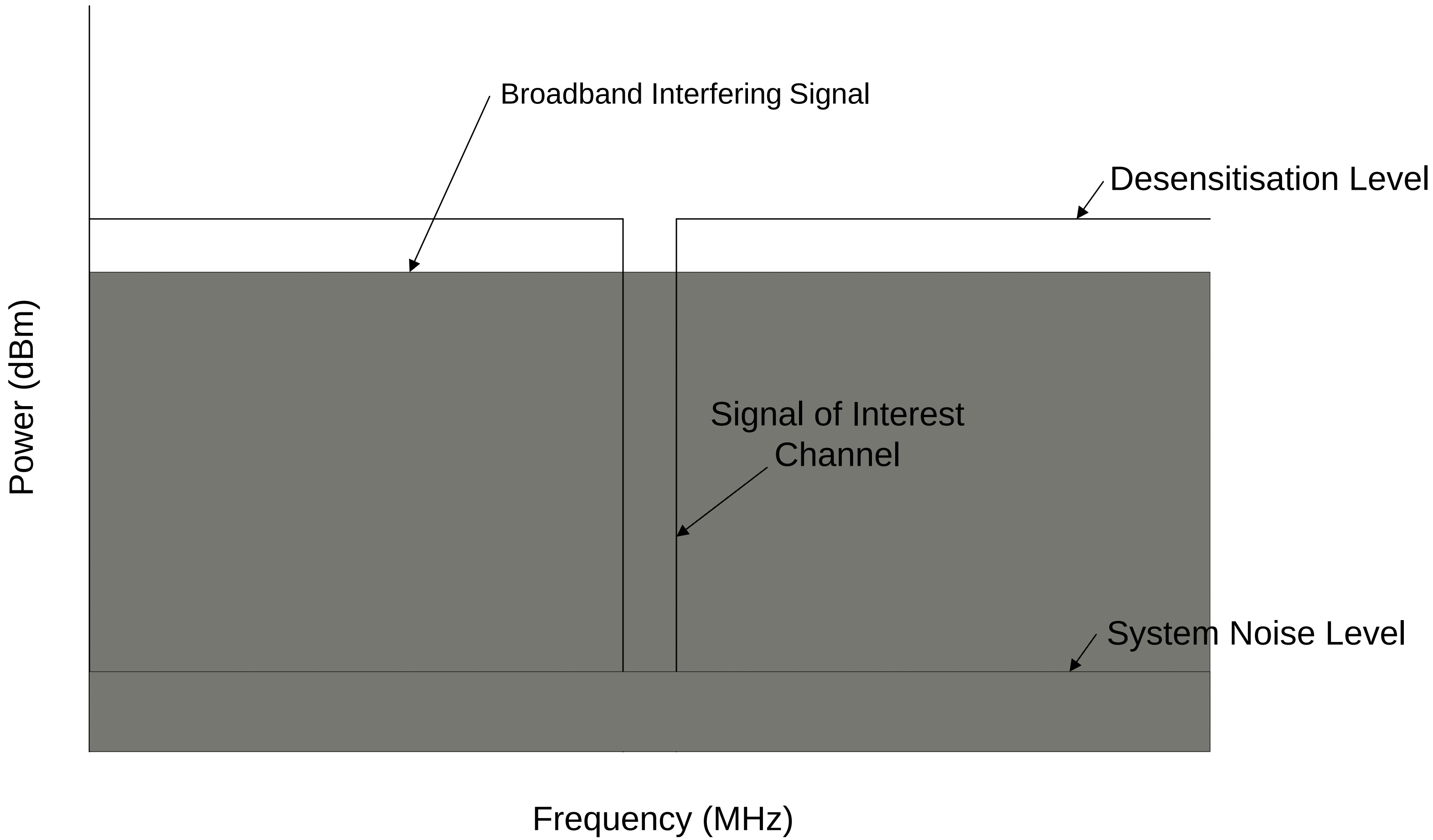
Signal of interest

Cancellation >60dB

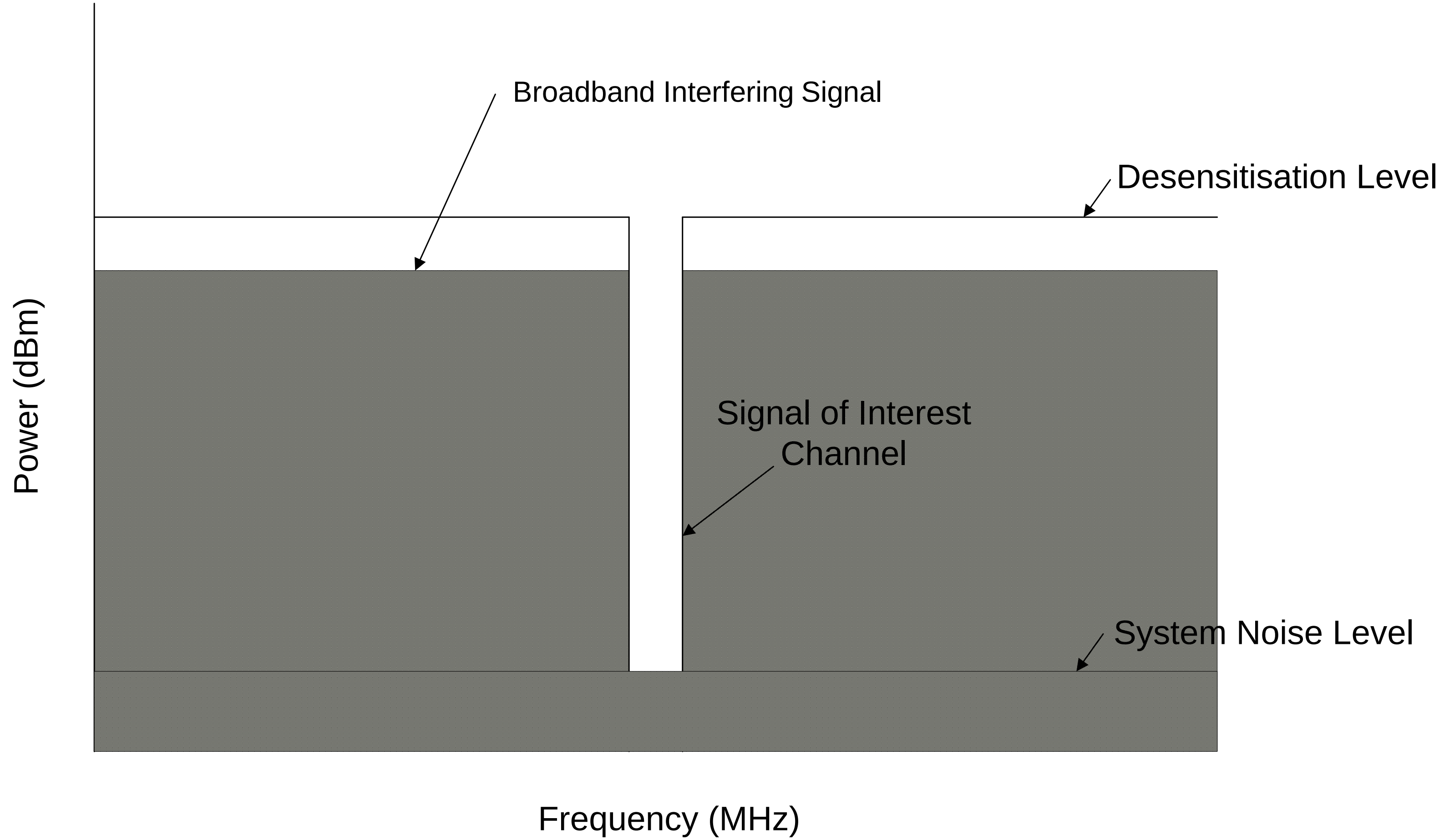
Cancellation of Interference from Co-located Broadband Interferers - 1



Cancellation of Interference from Co-located Broadband Interferers - 2



Cancellation of Interference from Co-located Broadband Interferers - 3



Interference from Co-located Broadband Interfering Signals

Characteristics of Interfering Signals

- One or more very wideband interfering signal waveforms
- Overlap with the Signal of Interest (SoI) channel

Requirements from Cancellation System

- One or more weight modules to cancel broadband the interference to below the large signal desensitisation level of the co-sited radios
- One or more weight modules to cancel 'on channel' interference to the maximum possible, ideally to the noise floor of the radio

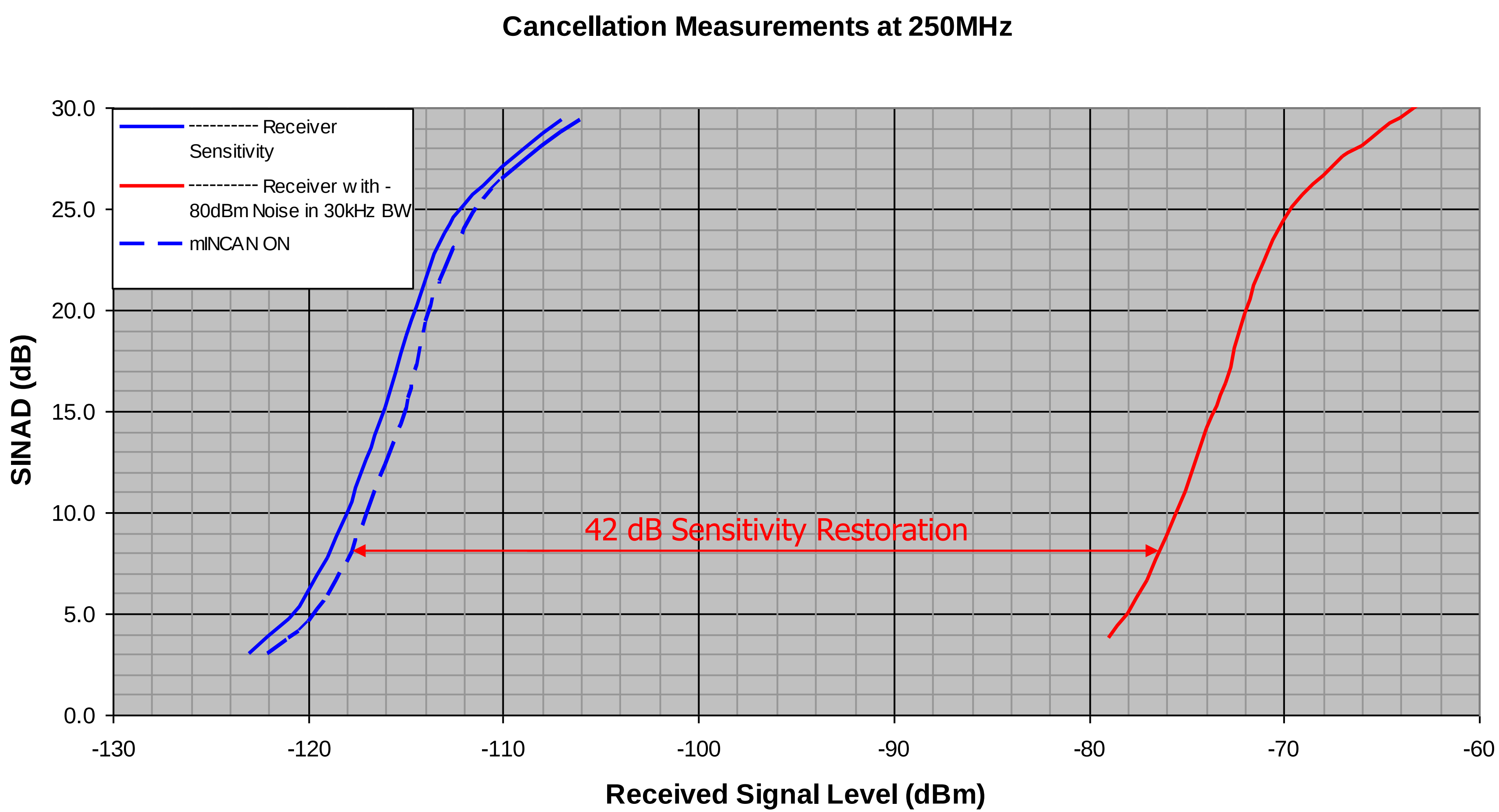
Note: Unlike the interference associated with co-sited radios, no benefit is gained from the selectivity of the IF filter as the interference is 'on channel'

Unit for Demonstration of Communications in the Presence of Co-located Broadband Interference

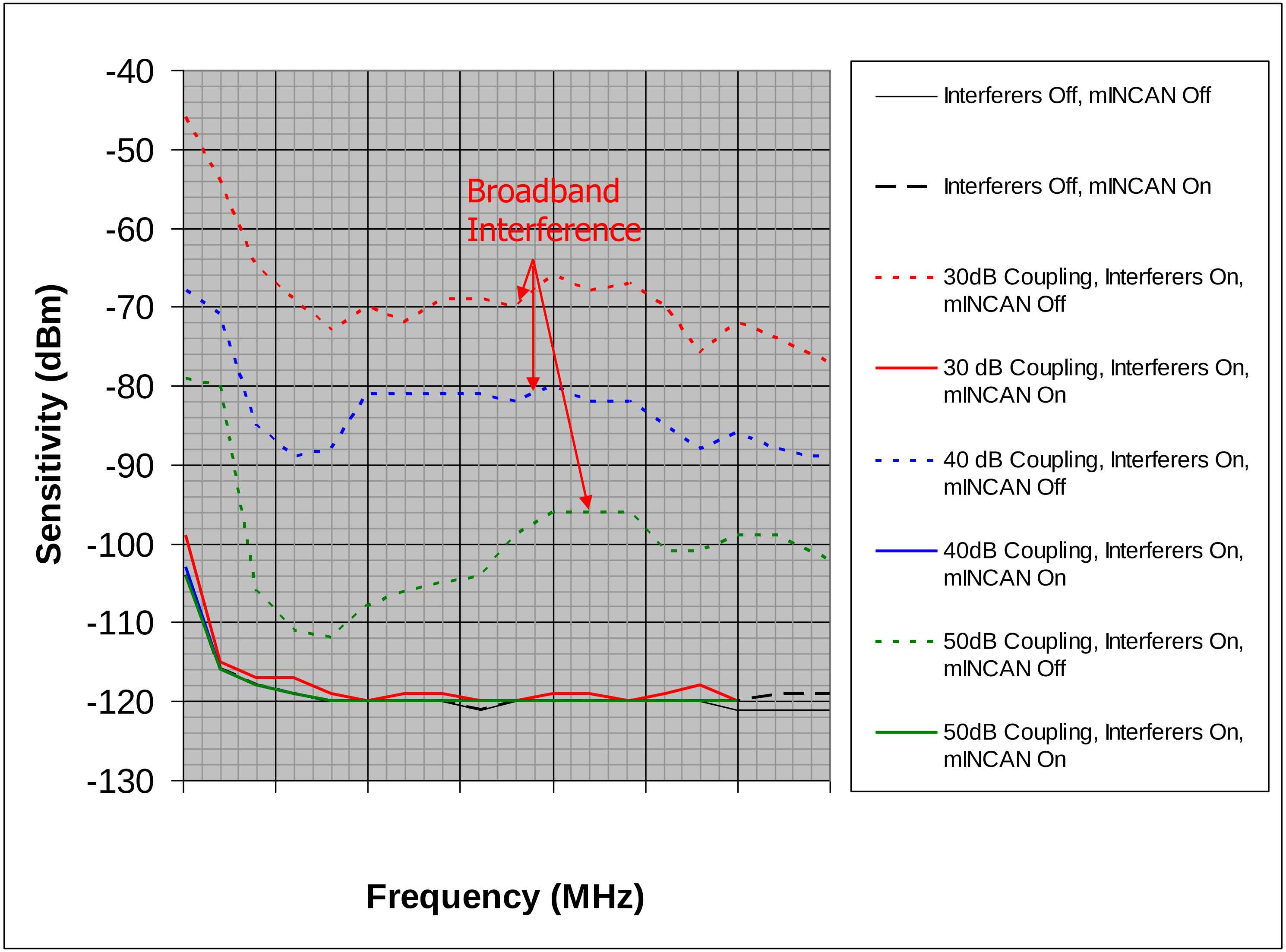
Lab and Field Measurements

- Lab and field measurements all made with the same equipment that is used in the field on the Panther vehicle, ie radio and broadband interferers
- All lab and field measurements witnessed by representatives from UK MoD and QinetiQ
- Radio sensitivity -120dBm for 8dB SINAD in unsecure mode

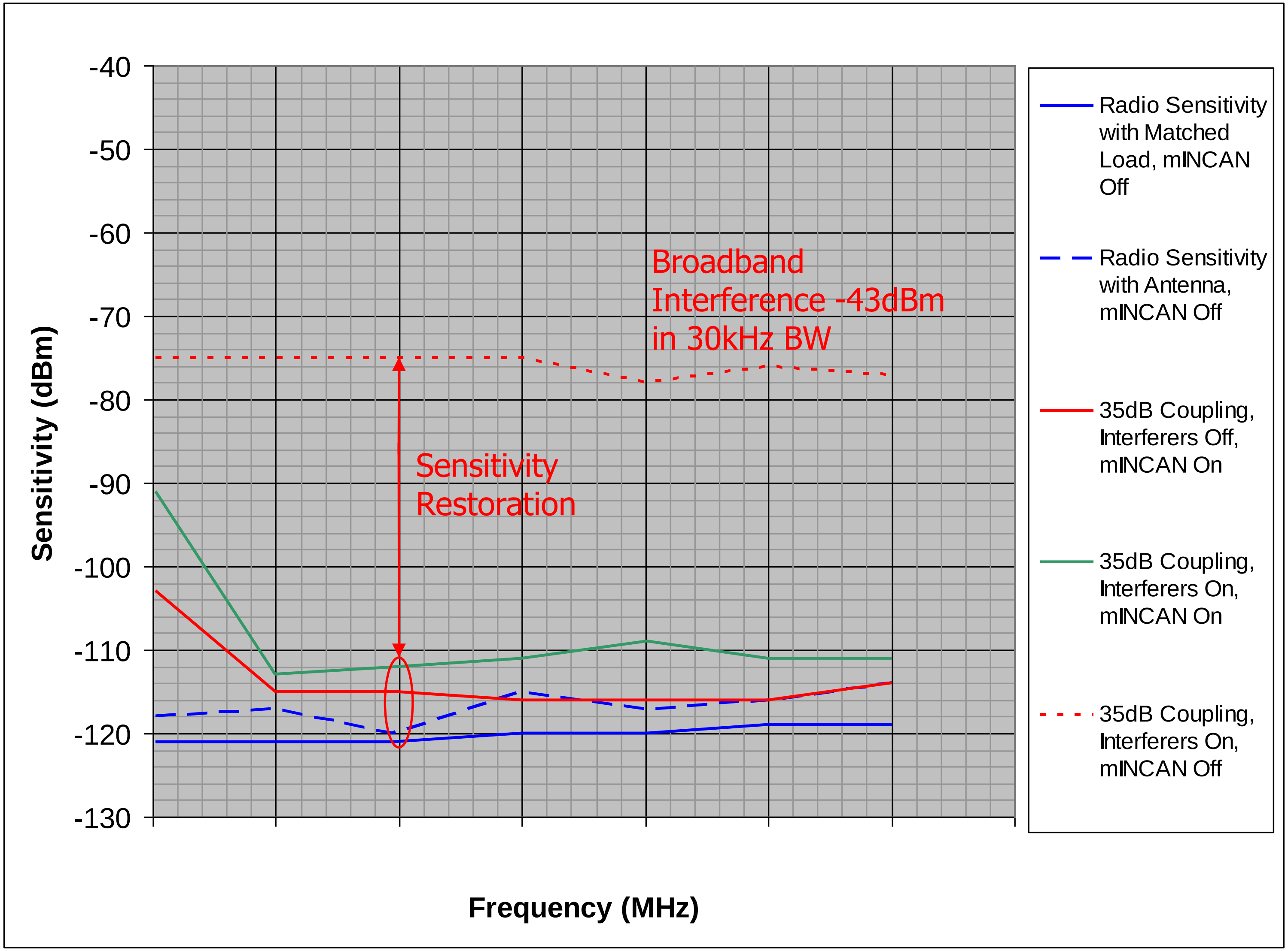
Radio Sensitivity Plots for Non-Secure Mode for Different Antenna Coupling Values (Lab Result)



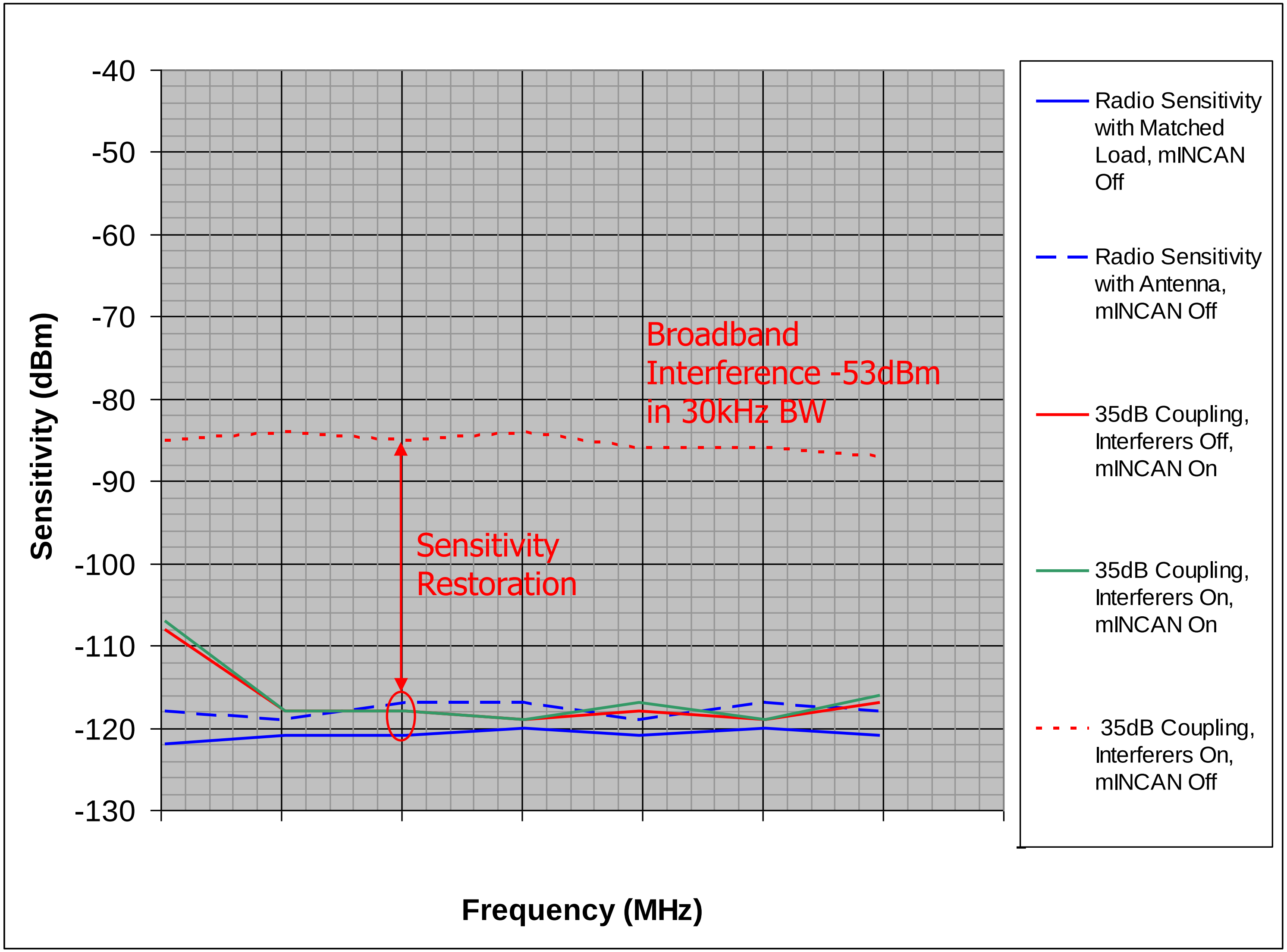
Radio Sensitivity Plots for Non-Secure Mode for Different Antenna Coupling Values (Lab Result)



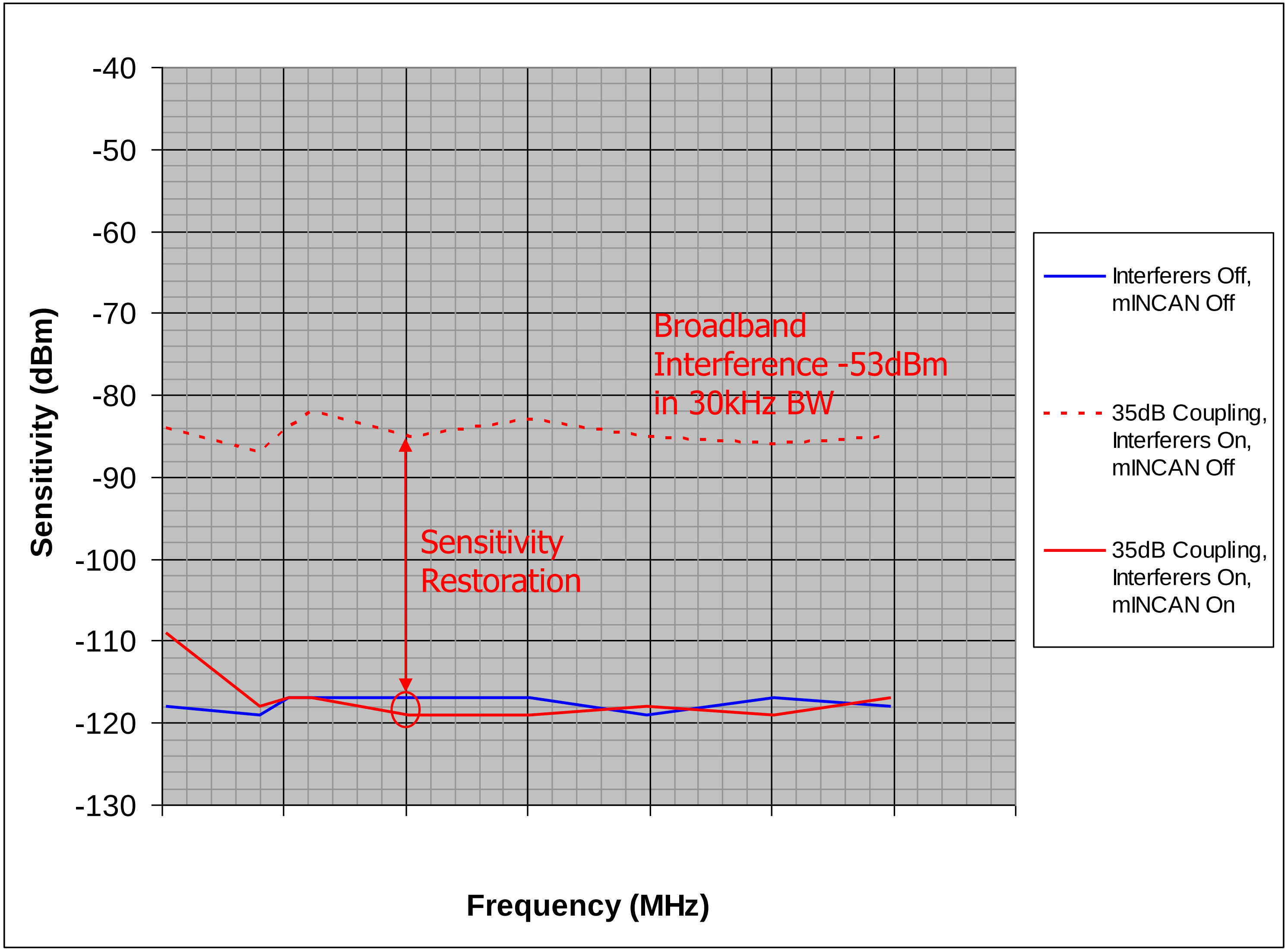
Snatch Results for 35dB Antenna Coupling with no Correction for Filter Loss at Band Edge – Local Signal (Field Result)



Snatch Results for 35dB Antenna Coupling with no Correction for Filter Loss – Local Signal (Field Result)

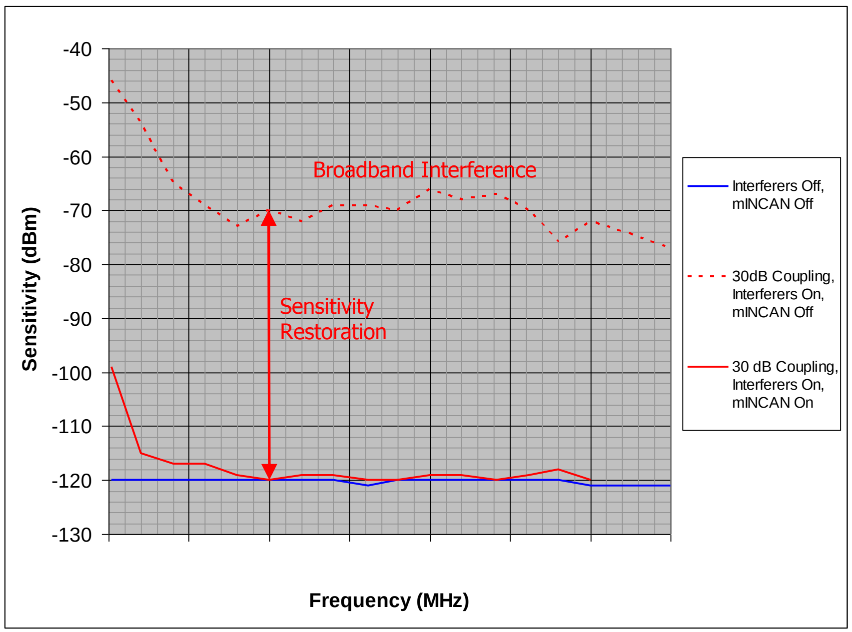


Snatch Results for 35dB Antenna Coupling with no Correction for Filter Loss – Remote Radiated Signal (Field Result)

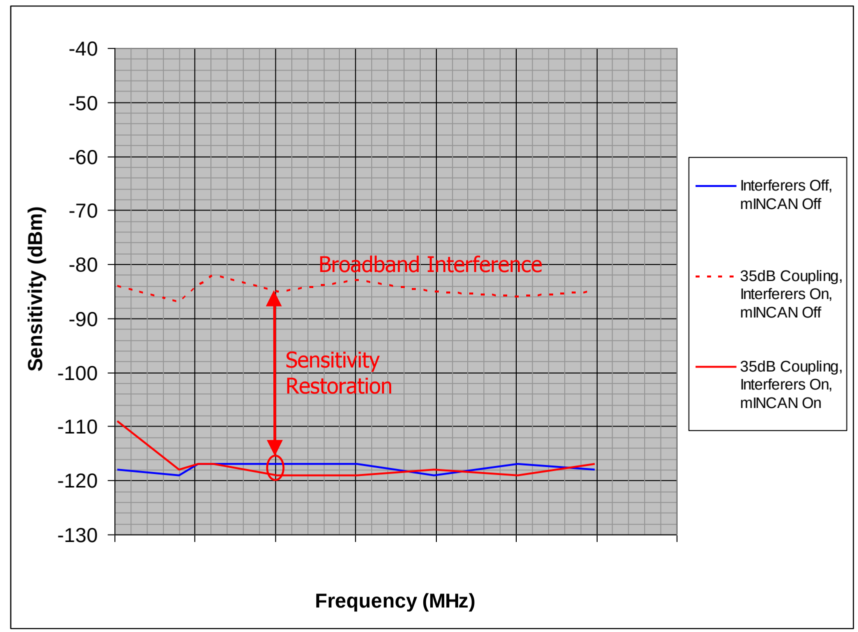


Comparison of Laboratory and Field Results

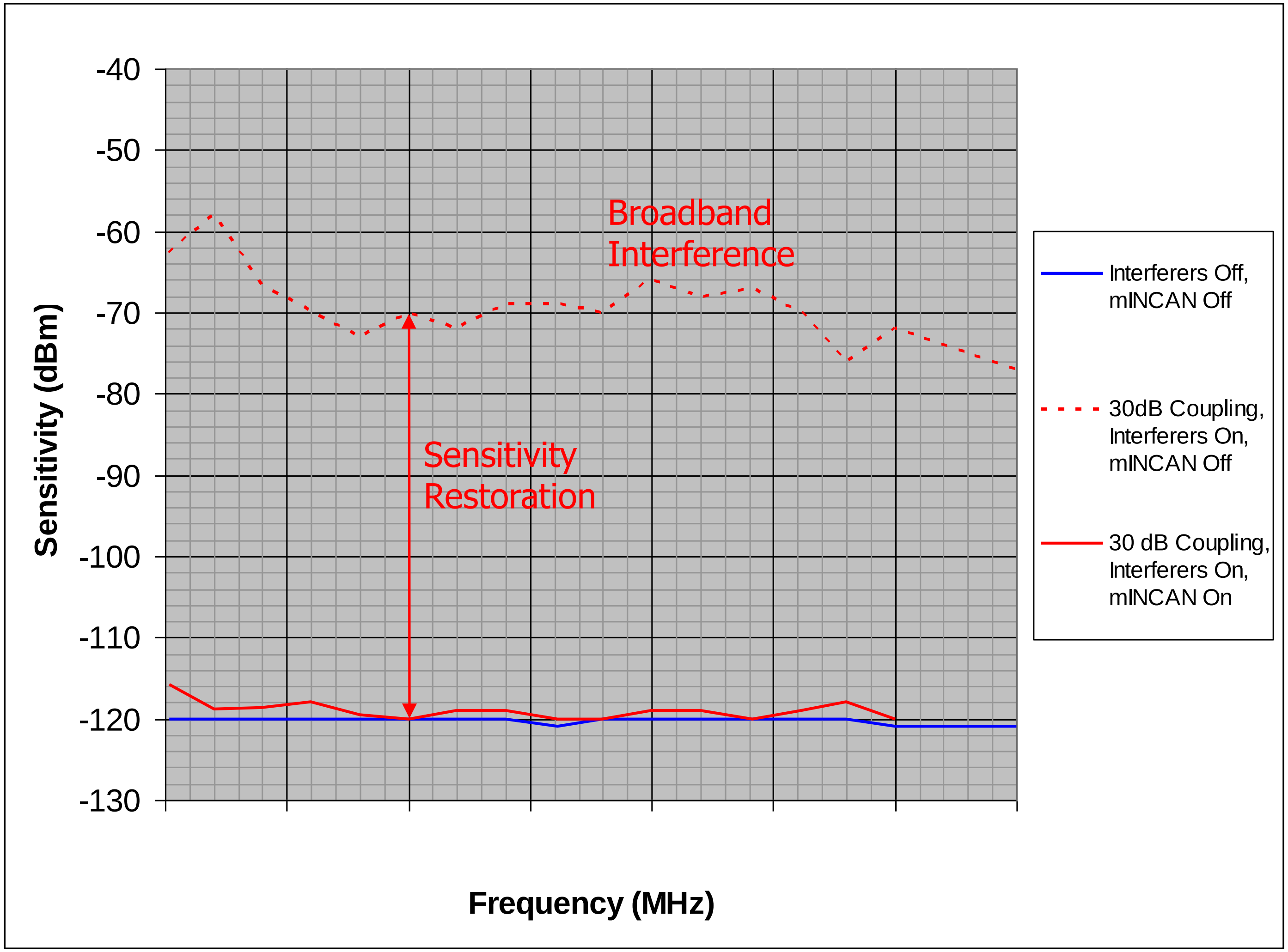
Lab Result



Field Result



Summary Results for 30dB Antenna Coupling with Correction for Filter Loss (Lab Result)



RF Interference Cancellation applied to 2 Jammers to Restore Radio Sensitivity in the Satellite Communications Band

- The size could be reduced to that of a car radio or similar volume
- The weight could be reduced to less than 2kg
- The system consumes about 10W (could be reduced further)

RF Interference Cancellation applied to 2 Jammers to Restore Radio Sensitivity in the Satellite Communications Band - Conclusions

- Using RF interference Cancellation techniques, radio sensitivity can be restored providing a suitable technique is used to steer the vector modulator.

- Lab Results
  - Radio sensitivity, in the presence of 2 broadband interferers, restored to within 1dB of the -120dBm for 8dB SINAD achieved without broadband interference
  - Worst case of 30dB antenna coupling showed cancellation levels to be in the region of 68dB (50dB difference + 8dB for SINAD + 10dB margin)
  - Radio sensitivity restoration identical for non-secure and secure modes

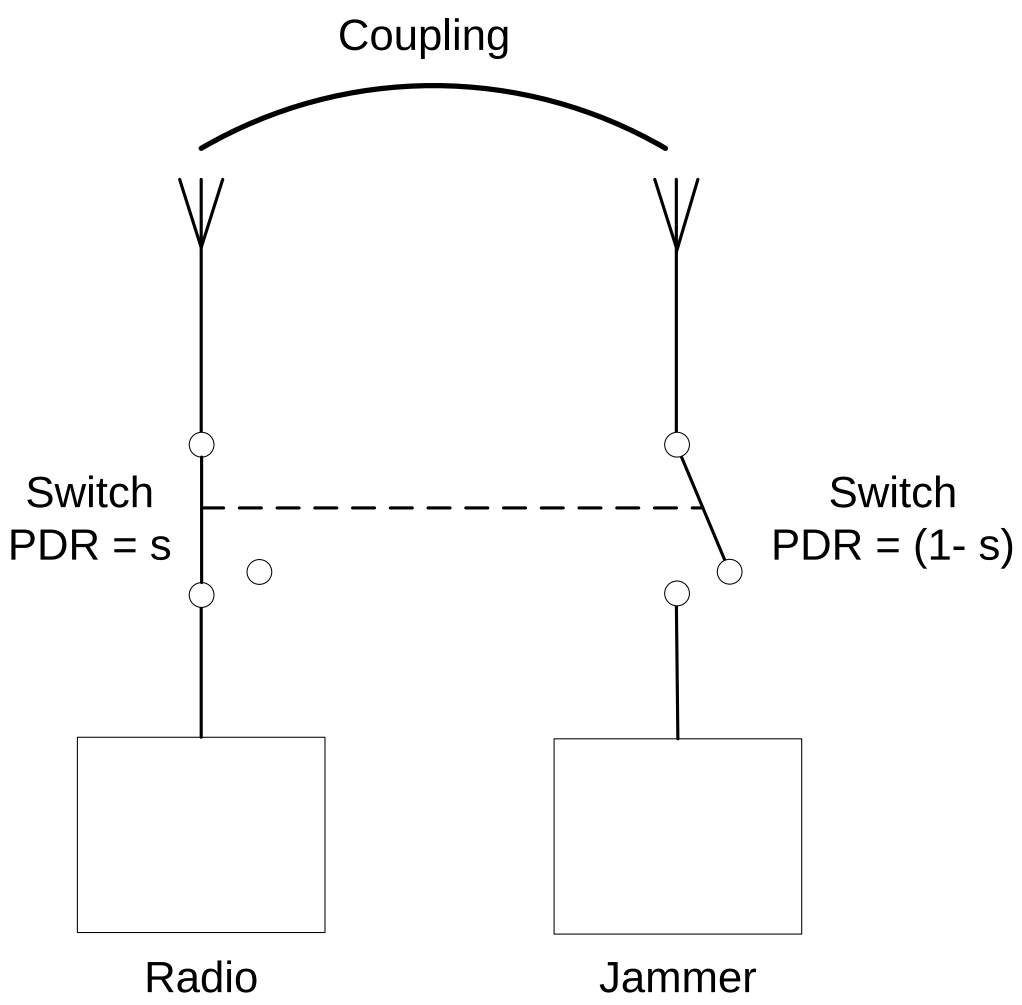
- Field Results
  - Radio sensitivity, in the presence of 2 broadband interferers, restored to within 1 – 3dB of the -120dBm for 8dB SINAD without broadband interference
  - Results with 35dB antenna coupling were consistent with a cancellation of 53dB
  - Measurements show consistent and similar results to those in the lab

RF Interference Cancellation applied to a Jammer to Restore Radio Sensitivity in the Satellite Communications Band - Video

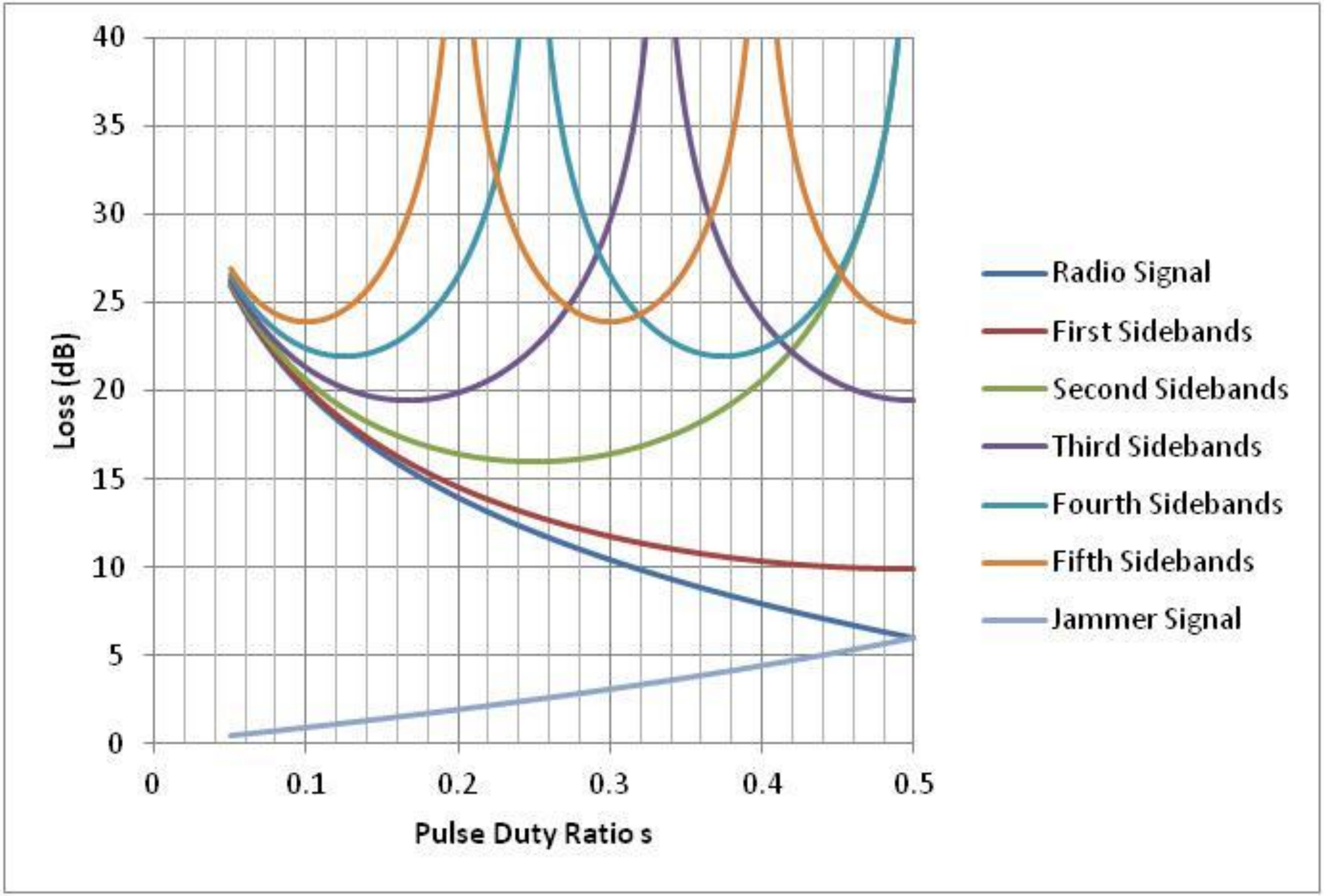
- Electronic Surveillance in the presence of on-board Jamming
- Span on spectrum analyser is 245 – 275MHz
- A broadband noise source and power amplifier is used to simulate a typical jammer operating over 240 – 280MHz
- A radio is preprogrammed to scan a number of channels over 240 – 280MHz in an arbitrary sequence
- Radio continues to scan until it finds an occupied channel and it then locks onto the channel
- Radio resumes scanning when channel is not being used
- Radio interface provides frequency of receive channel to drive the interference canceller

RF Interference Suppression using Time Division Multiplexing to suppress No- and Off-board Signals

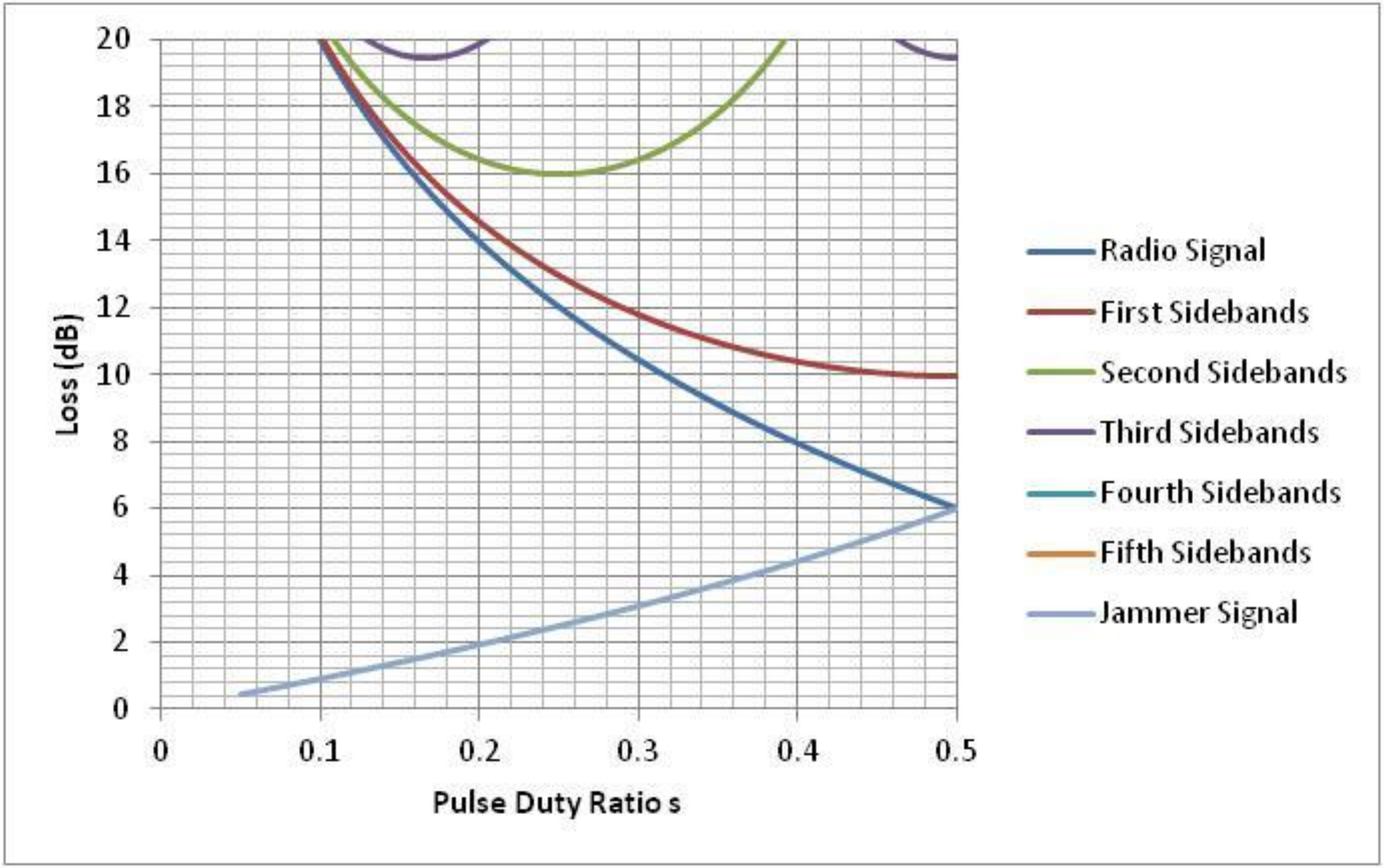
RF Interference Suppression on Fixed and Mobile Platforms - TDM



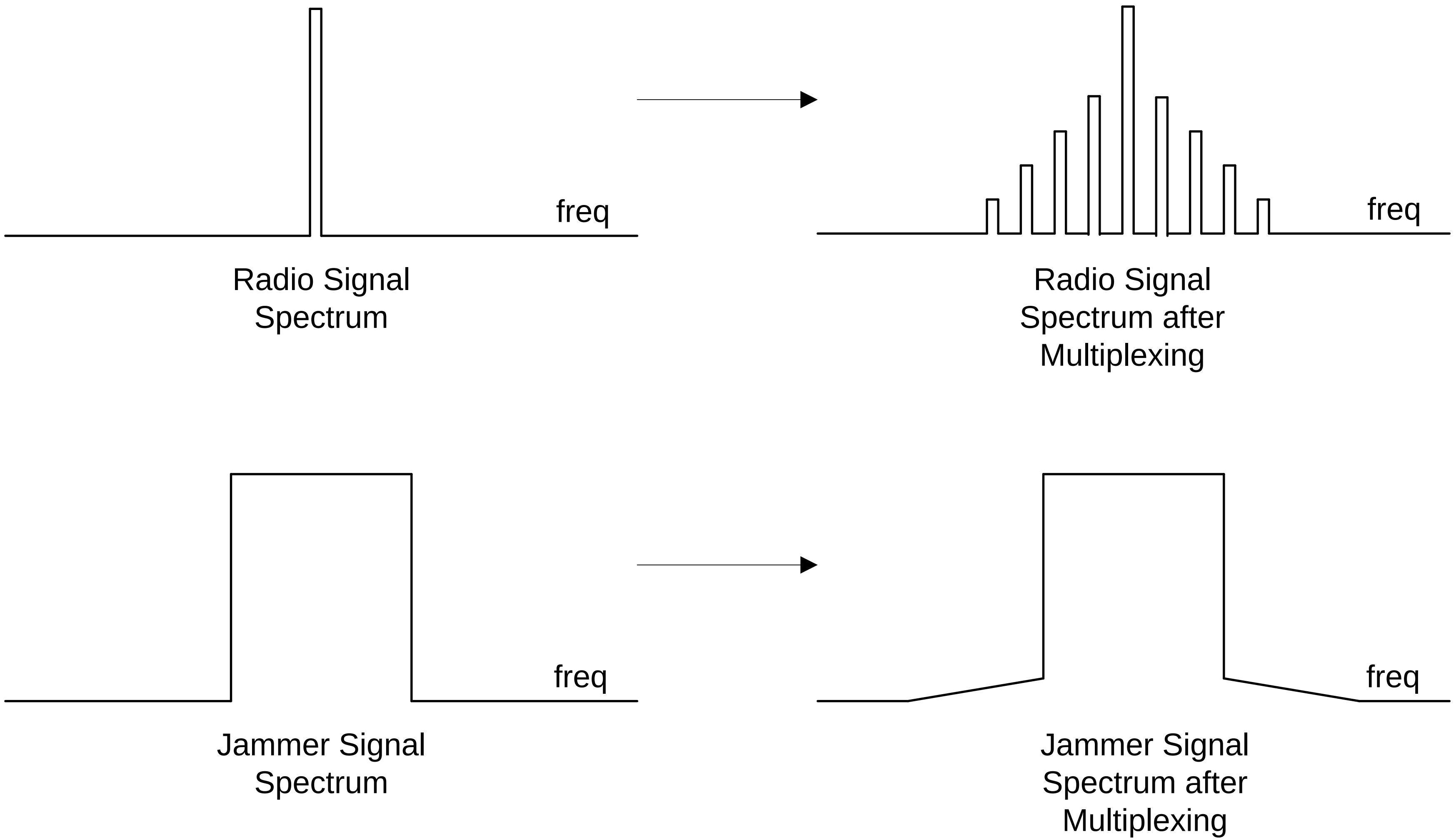
RF Interference Suppression on Fixed and Mobile Platforms - TDM



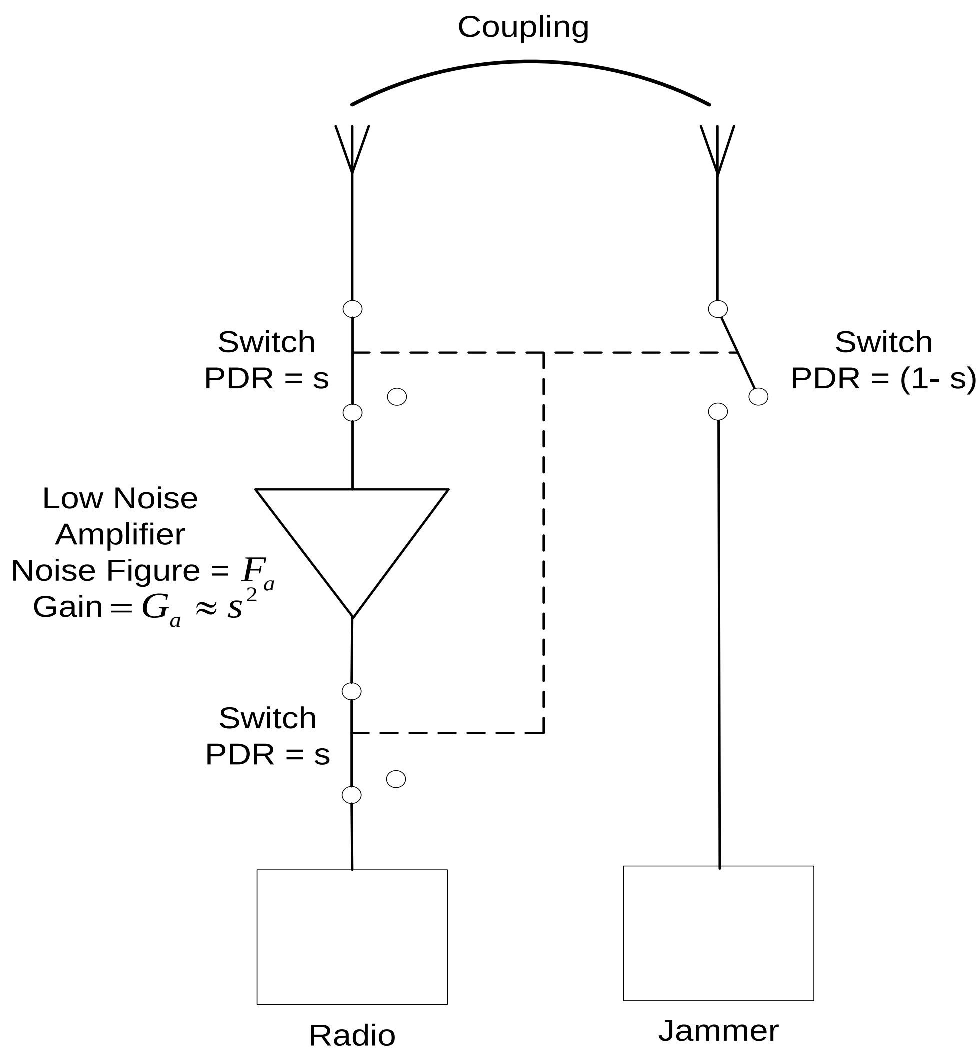
RF Interference Suppression on Fixed and Mobile Platforms - TDM



RF Interference Suppression on Fixed and Mobile Platforms – TDM – Switching Artifacts



RF Interference Suppression on Fixed and Mobile Platforms – TDM – a Practical Architecture



RF Interference Suppression on Fixed and Mobile Platforms – TDM - Gain

We now define the amplifier gain, G_a , as comprising two parts as follows:

$$G_a = G_1 G_2$$

Where

$$G_2 = \frac{1}{s^2}$$

RF Interference Suppression on Fixed and Mobile Platforms – TDM – Noise Figure

Hence

$$F_t = \frac{\left(F_a L_{son} + \left(1 - \frac{1}{L_{son}}\right) \frac{L_{son}^{\ 2}}{G_1} s^2 + F_a \frac{L_{son}^{\ 2}}{L_{soff}} \frac{\left(1 - s^2\right)}{s^2} + \left(1 - \frac{1}{L_{soff}}\right) \frac{L_{son}^{\ 2}}{G_1} \left(1 - s^2\right) \right)}{\left(1 + \frac{(1-s)}{s} \frac{L_{son}}{L_{soff}}\right)}$$

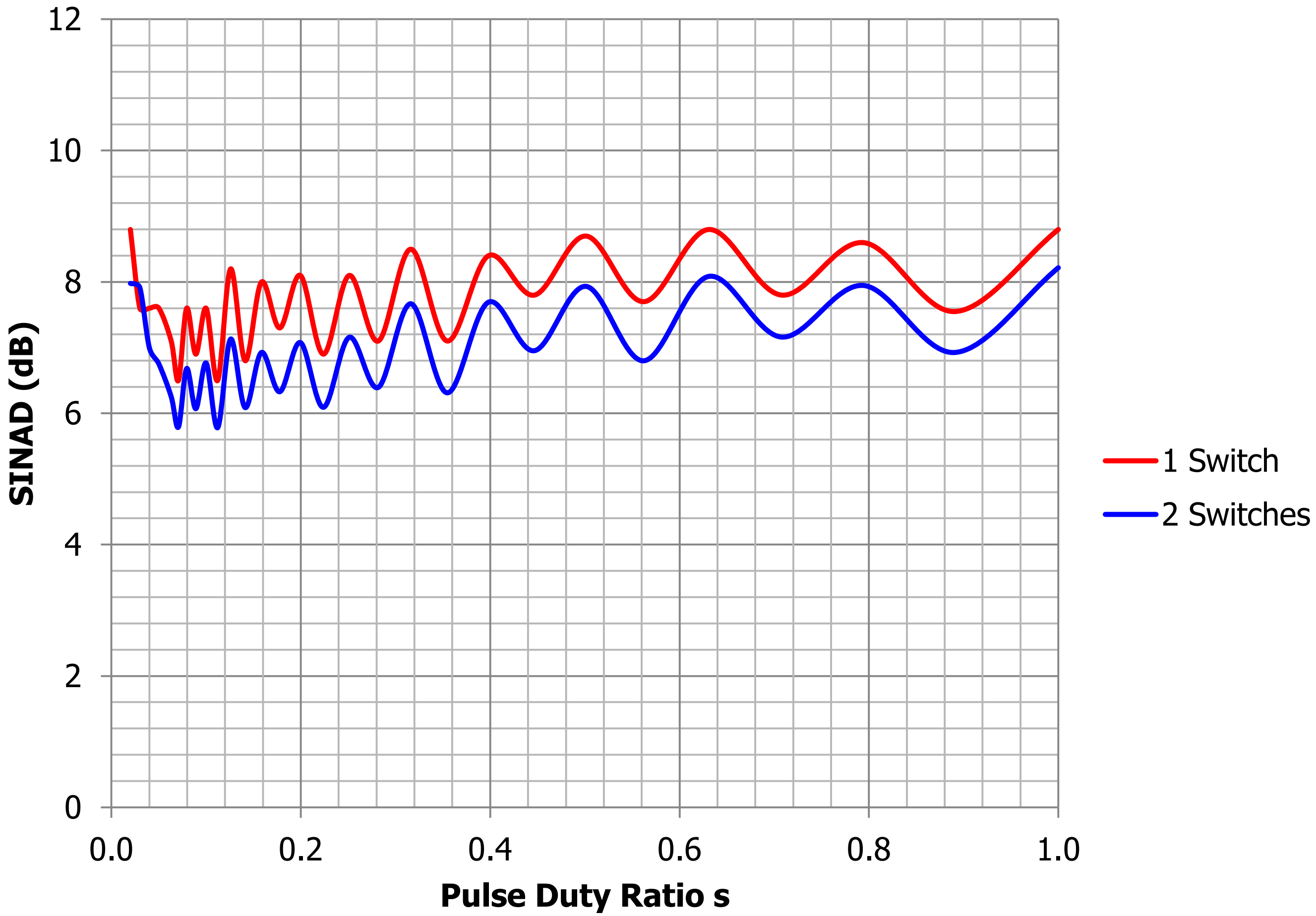
as $L_{off} \rightarrow \infty$

$$F_t \rightarrow \left(F_a + \frac{\left(L_{son} - s^2\right)}{G_1} \right) L_{son}$$

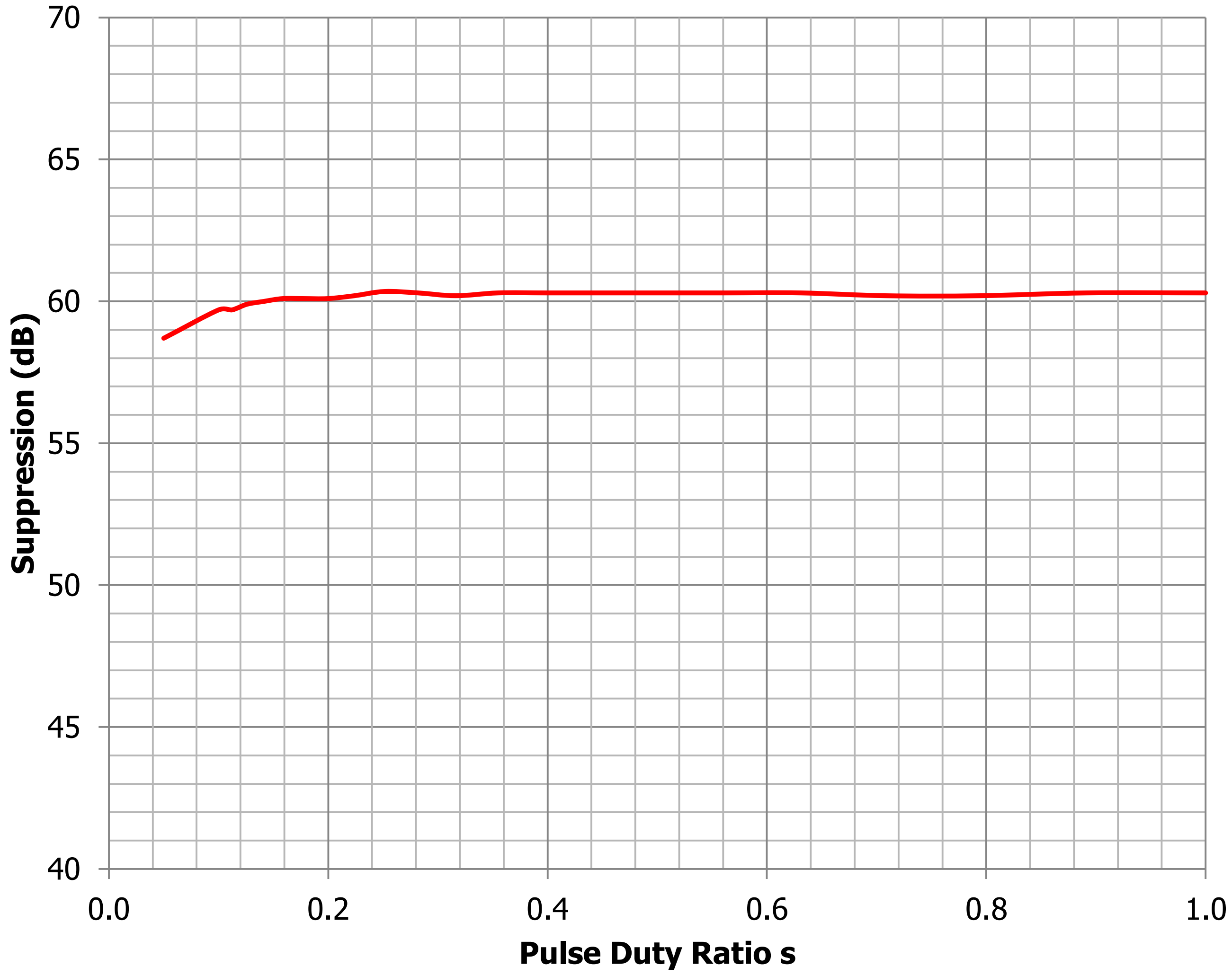
as $L_{on} \rightarrow 1$

$$F_t \rightarrow F_a + \frac{\left(1 - s^2\right)}{G_1}$$

RF Interference Suppression on Fixed and Mobile Platforms – TDM – SINAD v PDR



RF Interference Suppression on Fixed and Mobile Platforms - TDM



RF Interference Suppression on Fixed and Mobile Platforms – TDM Summary

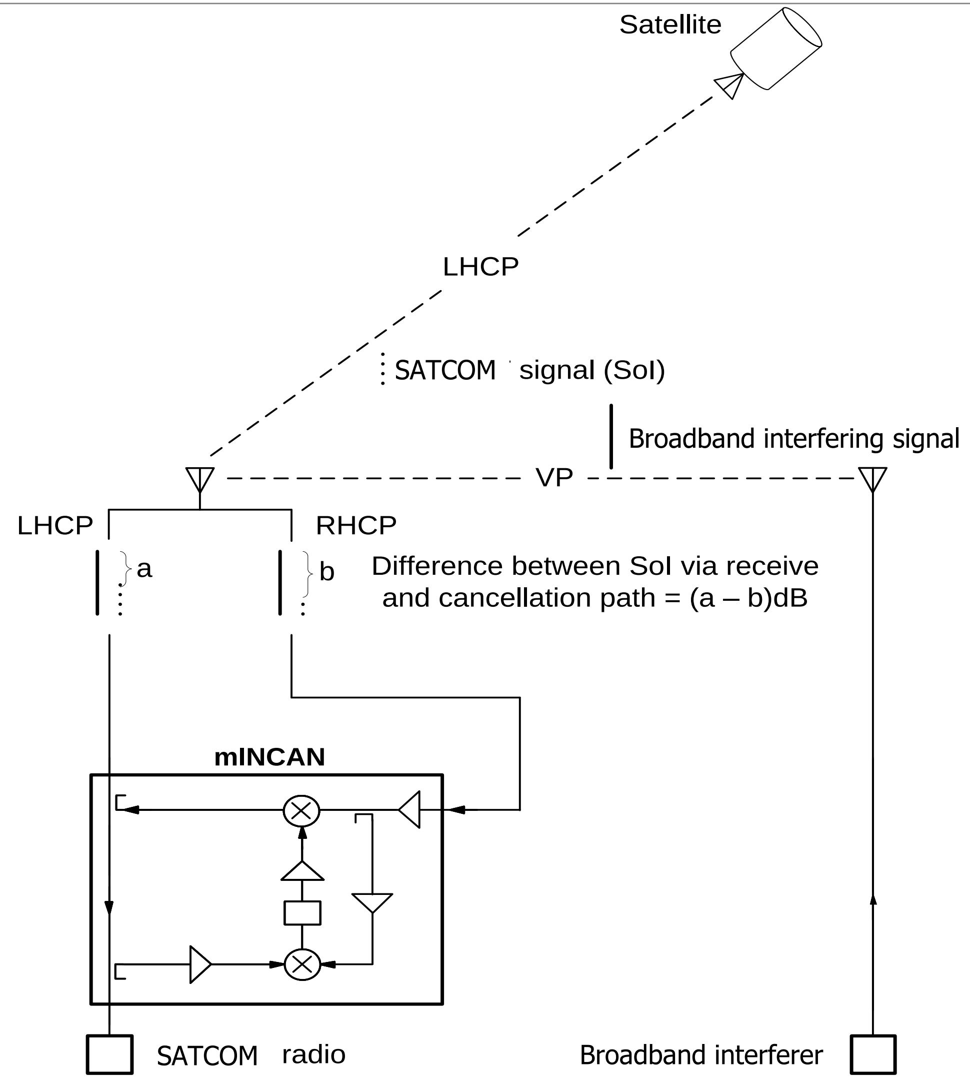
- Over 100dB (116dB measured) suppression of broadband interference achieved by cascading 2 switches with 60dB isolation
- Probably best suited for suppression of on-and off-board jamming signals rather than comms due to generation of sidebands
- Mixing-in of other remote signals into the required receive channel may be an issue unless steps are taken to mitigate this effect

Suppression of Off-Board Narrowband and Broadband Interfering Signals using RF Interference Cancellation

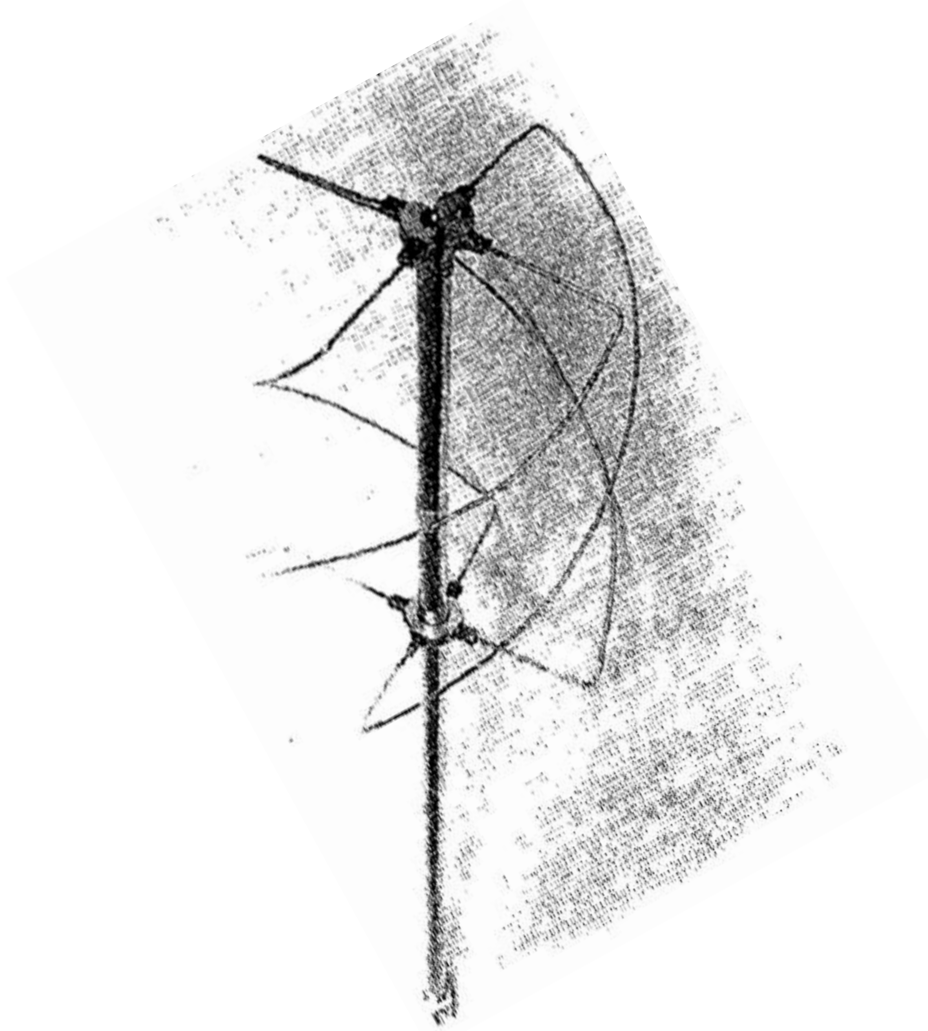
Suppression of Off-Board Narrowband and Broadband Interfering Signals – Key Points

- Sample of off-board interference must be taken off-air
- Sample includes interfering signal(s) and SATCOM (SoI) signal
- SATCOM signal is LHCP
- Interfering signal(s) is/are vertically polarised
- Use Quadrifilar Helical Antennas to receive LHCP and RHCP
- Interfering signal(s) are at same level in LHCP and RHCP antennas
- SATCOM signal level is at a higher level in the LHCP antenna

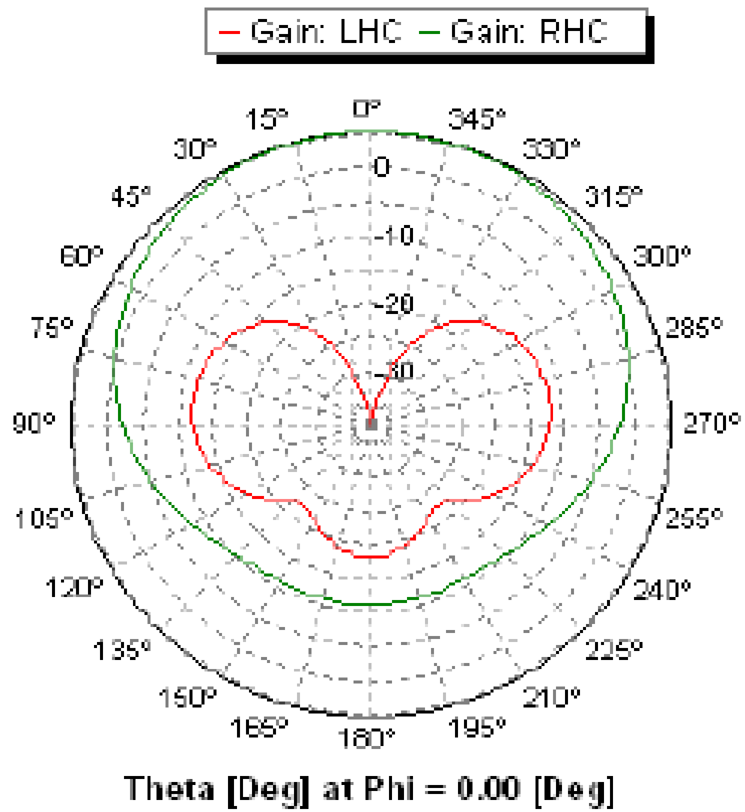
Cancellation of Off-board Broadband Interfering Signal

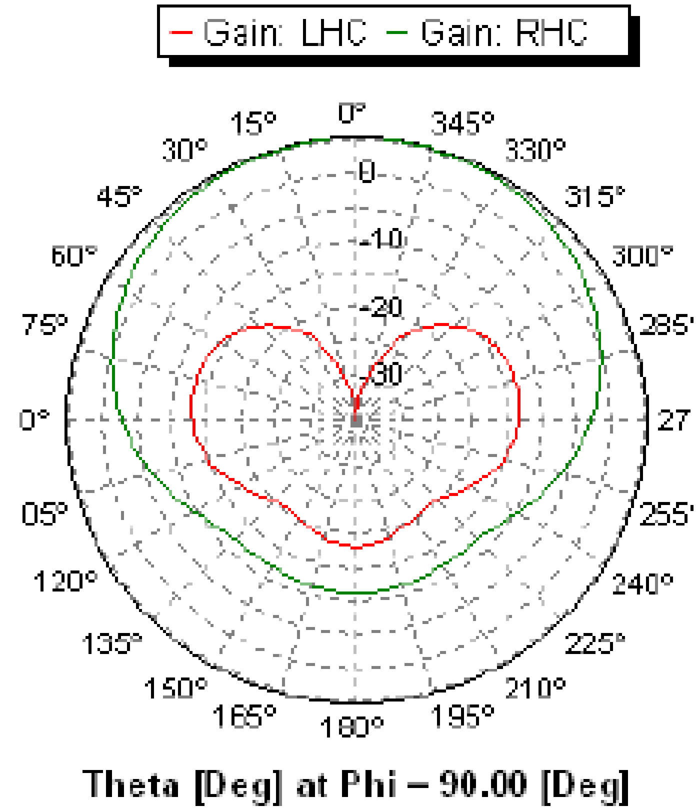


Quadrifilar Helical Antenna – C C Kilgus

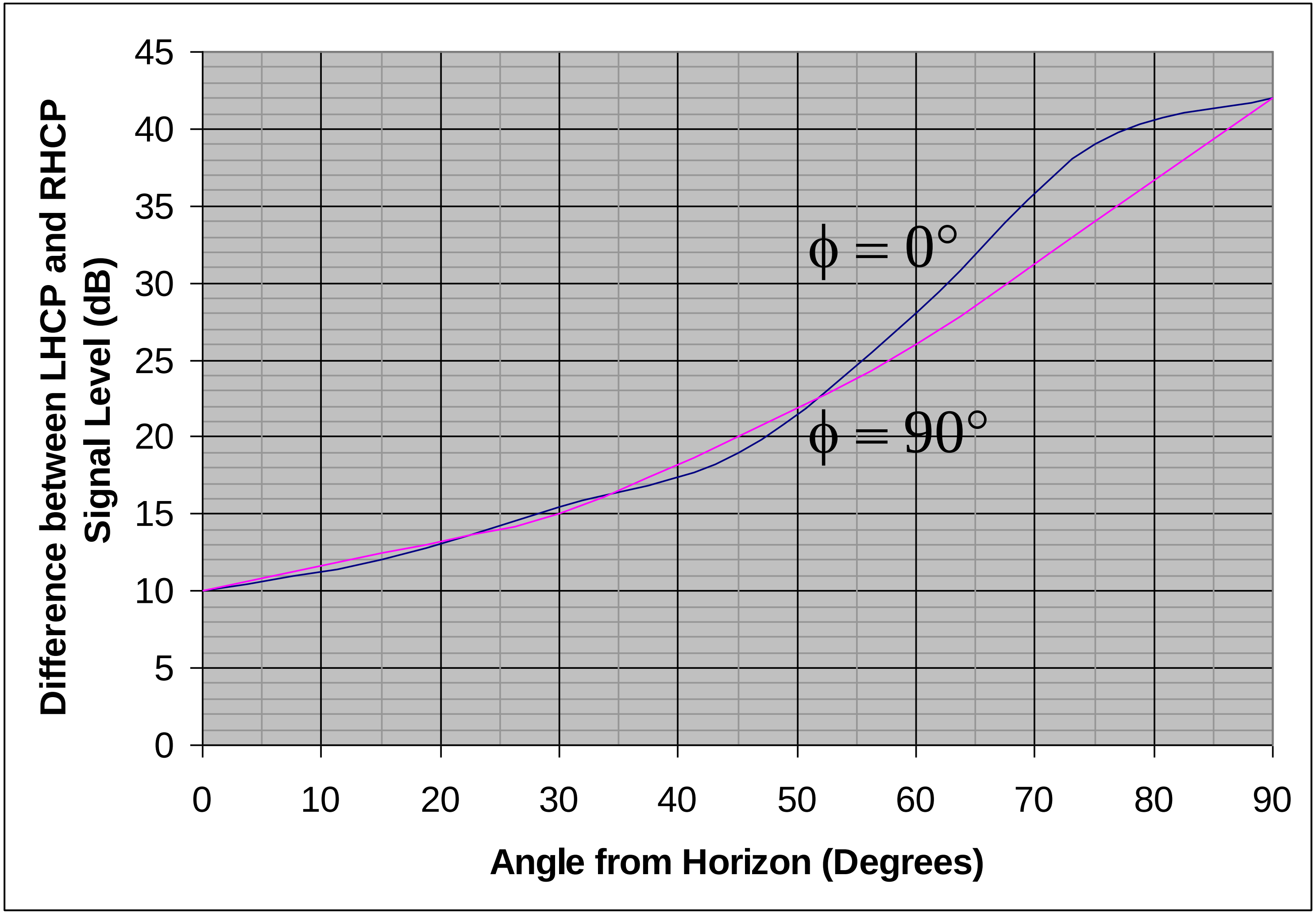


Antenna Patterns for LHCP and RHCP for Quadrifilar Helical (QFH) Antenna





Difference between Received LHCP Signal Levels in a LHCP and RHCP Antenna



Best and Worst Case SoI Levels Received by SATCOM Radio

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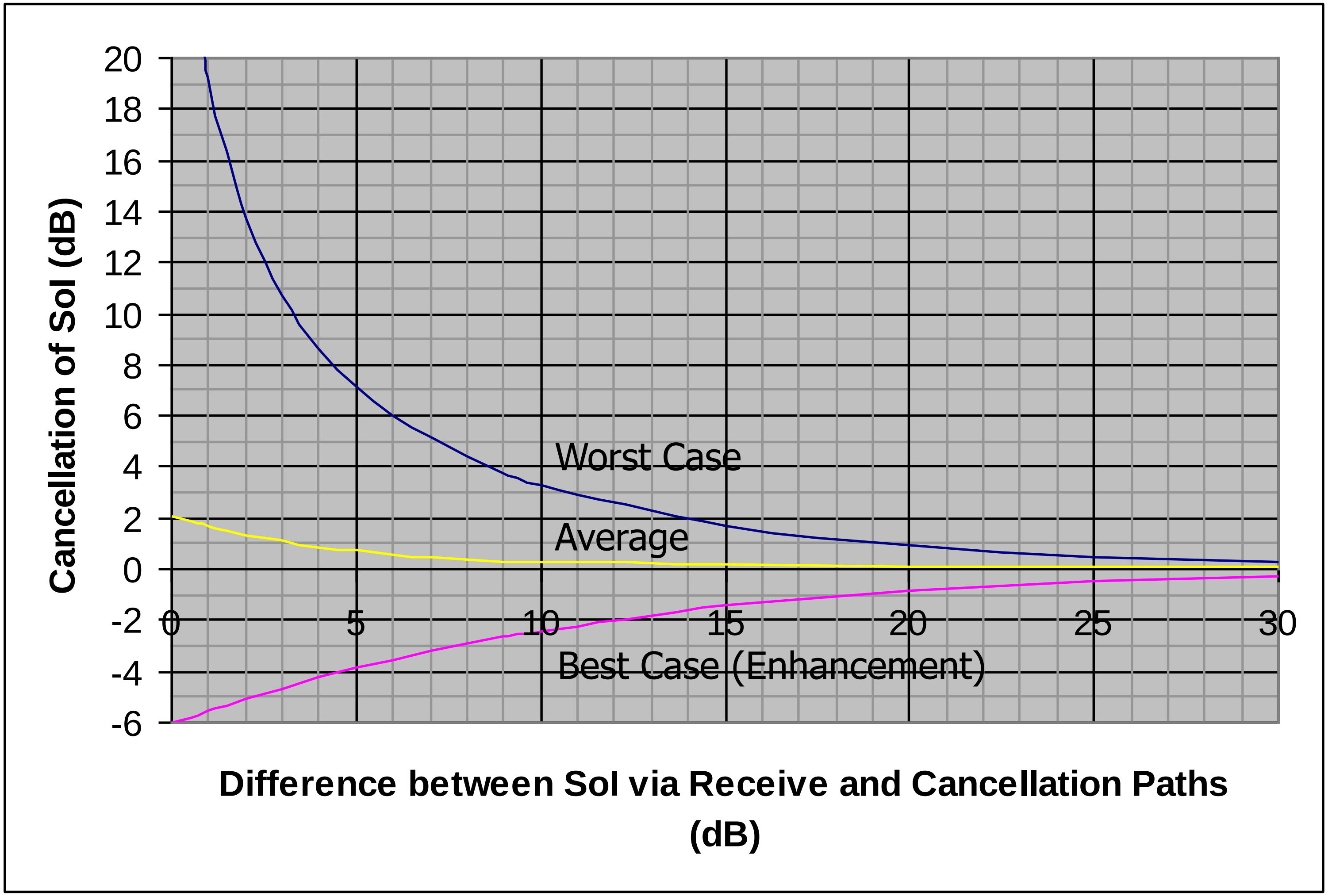
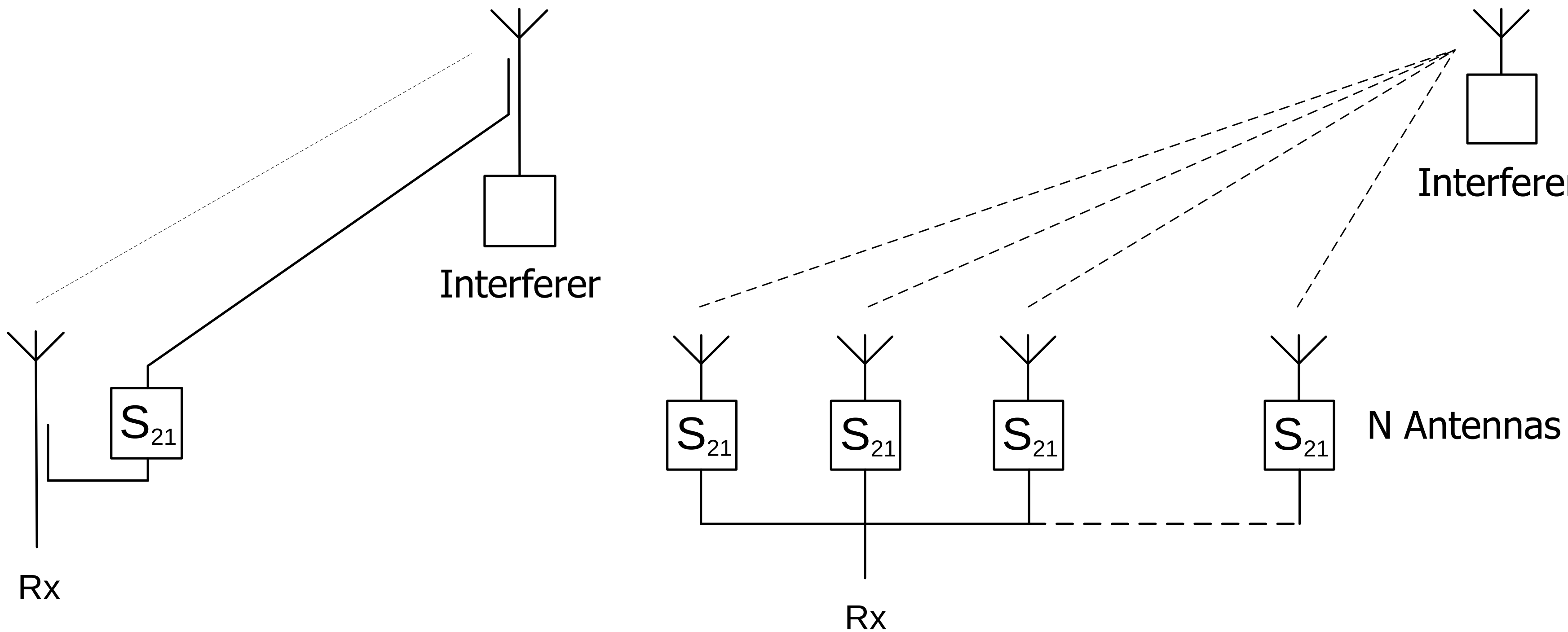


RF Interference Suppression on Fixed and Mobile Platforms – Use of Antenna Polarisation - Summary

- Technique only suitable for the reception of circularly polarised signals, ie satcom signals
- Technique potentially suitable for cancelling both interference from narrowband comms and jamming signals
- Performance dependent on polarisation charcteristics of LHCP and RHCP antennas
- Technique has yet to be investigated in detail to prove its practical feasibility

Suppression of Off-Board Narrowband and Broadband Interfering Signals using Adaptive Antenna Nulling

RF Interference Suppression on Fixed and Mobile Platforms – use of Adaptive Antenna Nulling



2 Samples

On-board

N Samples

Off-board

Number of Nulls from N samples is (N – 1)

NB They are the same type of mathematical problem

RF Interference Suppression on Fixed and Mobile Platforms – use of Adaptive Antenna Nulling

- DACU = Digital Antenna Control Unit
- Technique potentially suitable for cancelling both interference from off-board narrowband comms and jamming signals
- Technique applied to anti-jam GPS antenna for helicopters
- Could be applied to comms frequencies, but size of antenna array could be and issue unless electrically small antennas are used

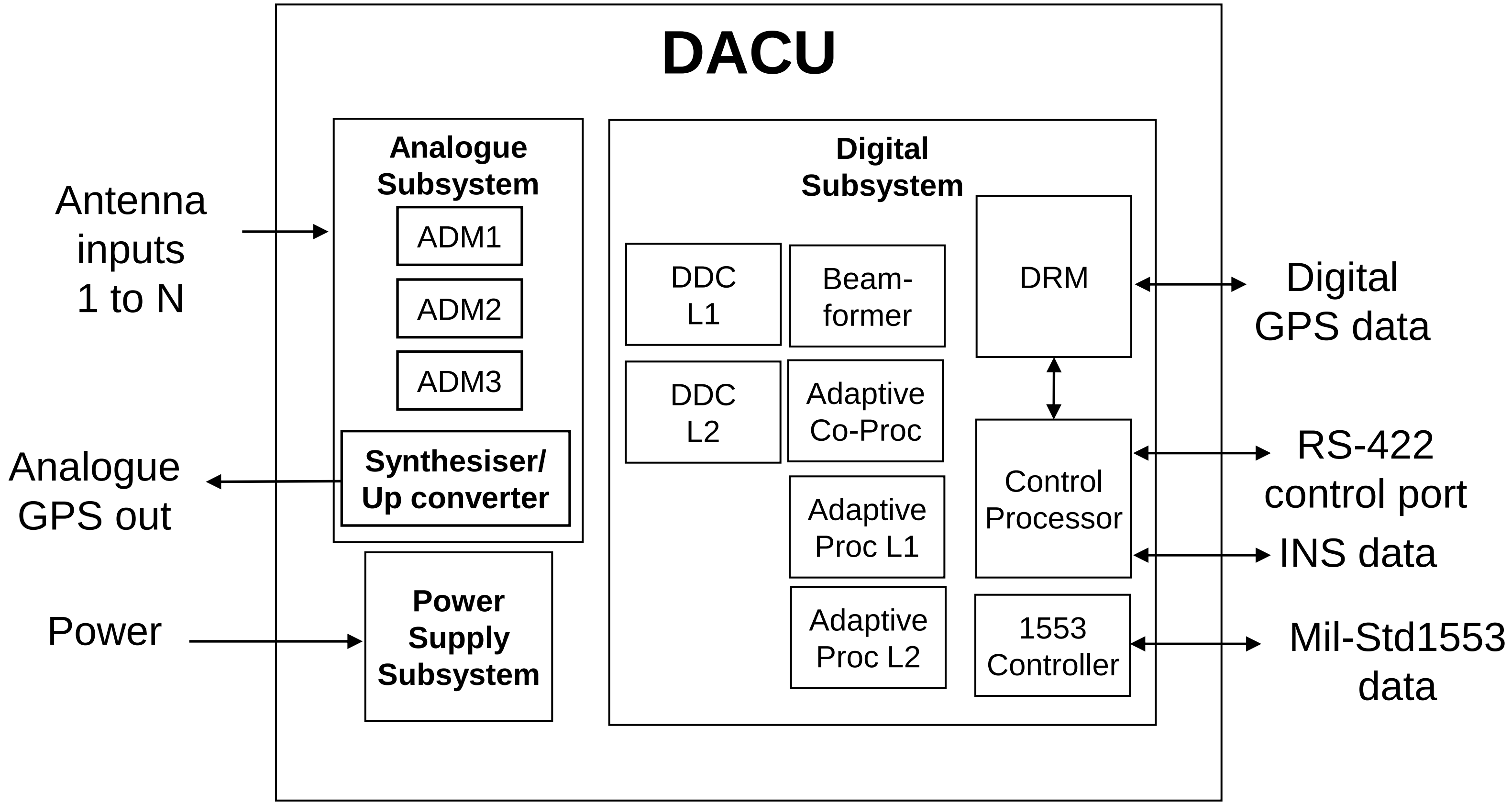
DACU Systems for RF Interference Suppression in a Jamming Environment

4 Antenna DACU

11 Antenna DACU

Digital Antenna Control Unit (DACU) System Architecture

COBHAM

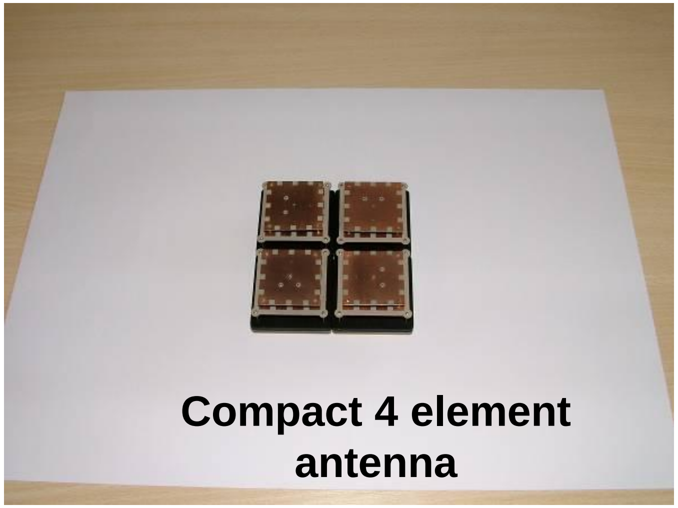


Key Features of Digital Antenna Control Unit (DACU)

- Designed to operate with CRPA (Controlled Reception Pattern Antenna) arrays of up to 11(N) elements
- Fully integrated with GPS DRM (Digital Receiver Module)
- Separate analogue RF output for use with existing GPS receivers
- Adaptive processor is based on Space Time systolic array and provides optimal solution to suppress up to (N – 1) jammers in < 1 ms
- 5 tap digital beamformer allows 8 simultaneous beams to be steered towards the space vehicles being tracked by the DRM
- The DDC (Digital Down Converter) subsystem can be configured to incorporate additional excision filtering in the frequency domain if required
- A direction finding facility is included which calculates the direction of up to (N – 1) jammers using the MUSIC algorithm

Anti-jam GPS Array Antennas

- Range of Controlled Reception Pattern Arrays (CRPAs) available
- Proven performance
- Dual-band with M code bandwidth
- Optimised for use with DACU system

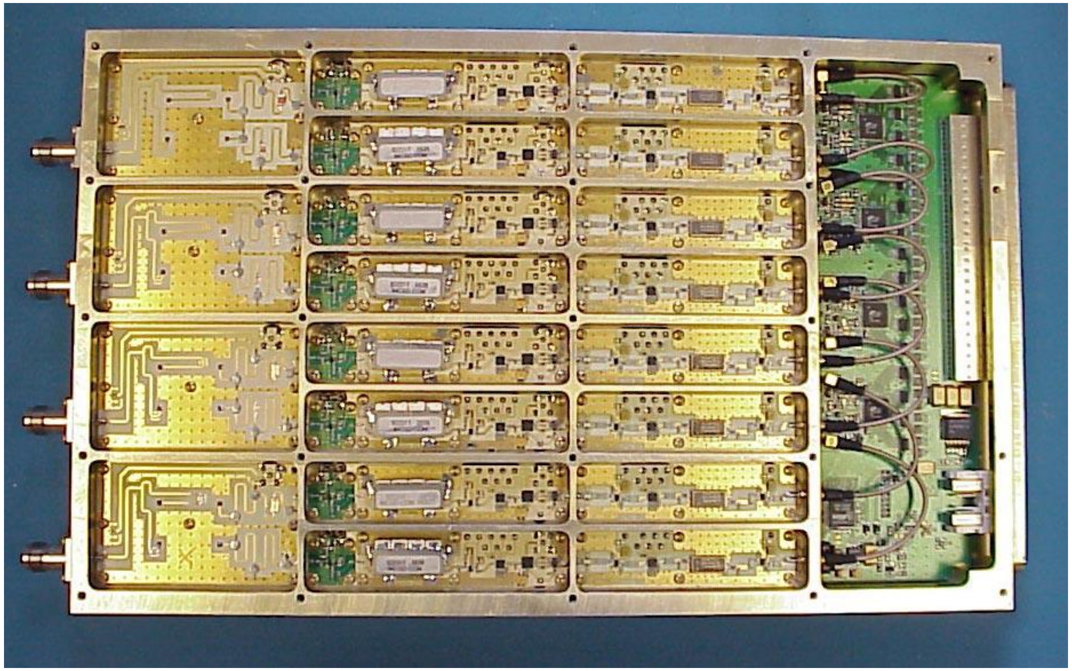

Compact 4 element antenna

CRPA GPS antenna

Digital Antenna Control Unit (DACU) - Analogue Sub-System

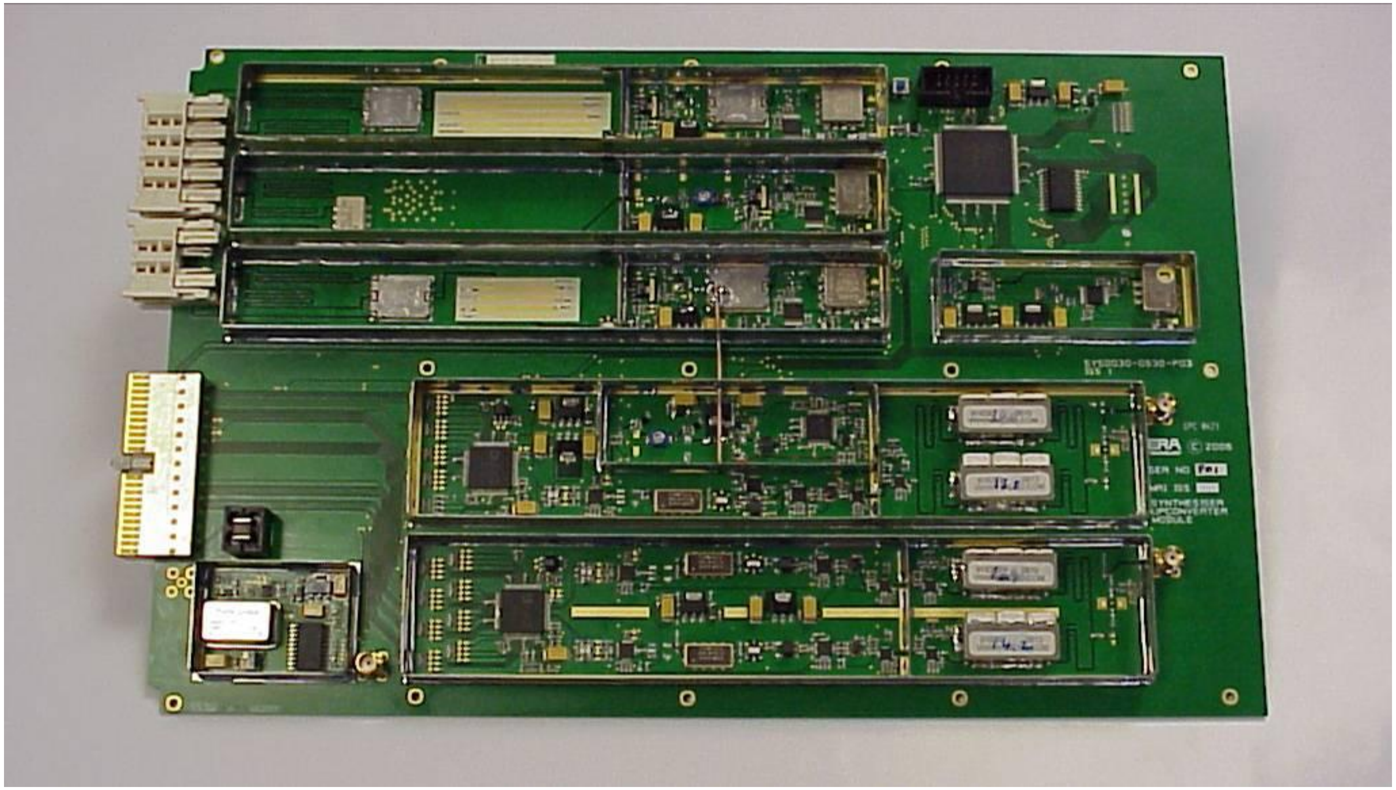
COBHAM

- Four L1+L2 channels
- Accurate phase and amplitude channel matching
- Incorporates high performance ADCs at output



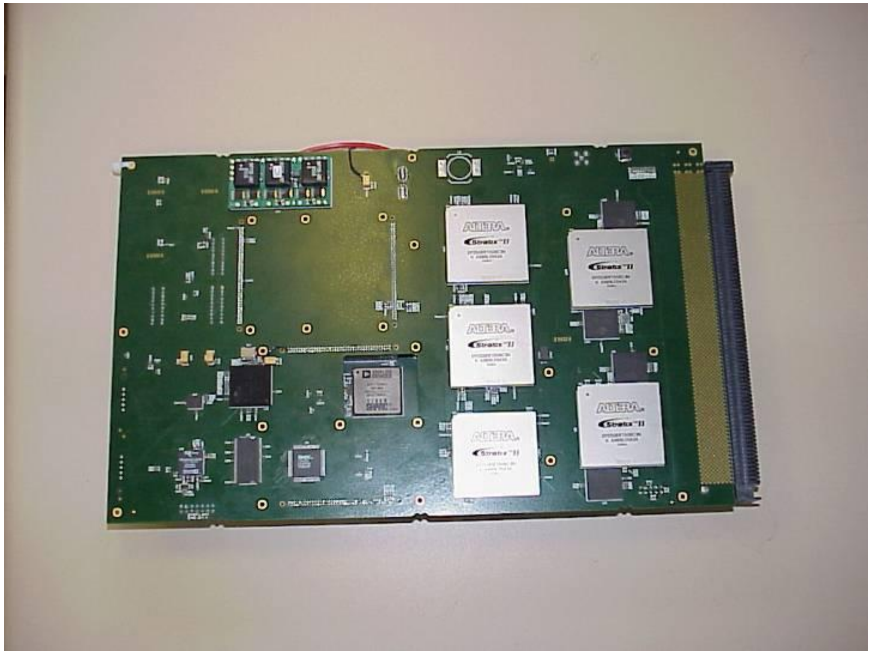
Digital Antenna Control Unit (DACU)
- Upconverter Sub-System

- Incorporates local oscillators for analogue receiver front ends

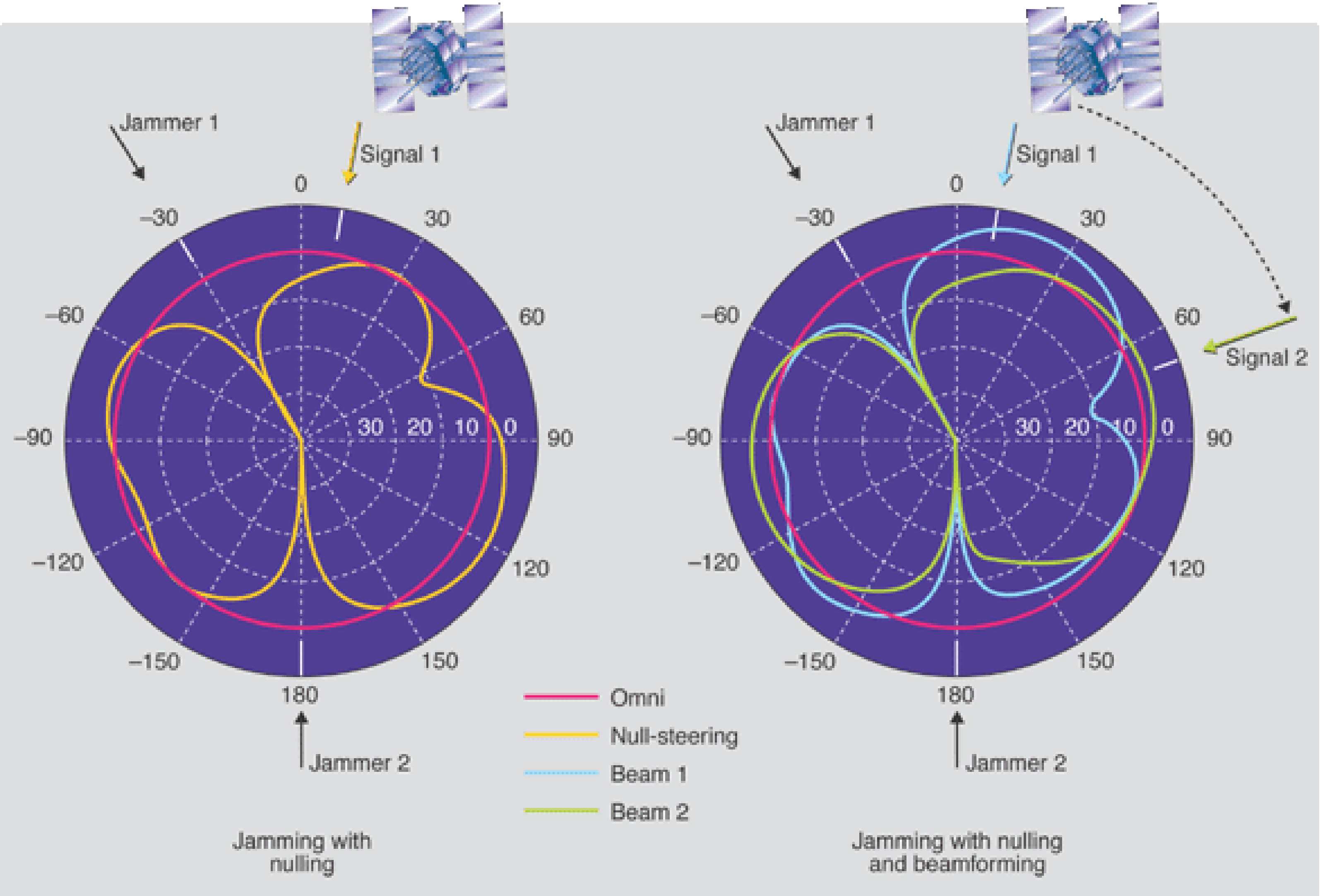


Digital Antenna Control Unit (DACU) - Digital Sub-System

- Digital Sub-system incorporating:
  - digital down conversion
  - adaptive processing (beam steering and nulling)
  - digital beamformer
  - digital receiver module
  - direction finding function (MUSIC algorithm)



DACU Anti-Jam GPS System



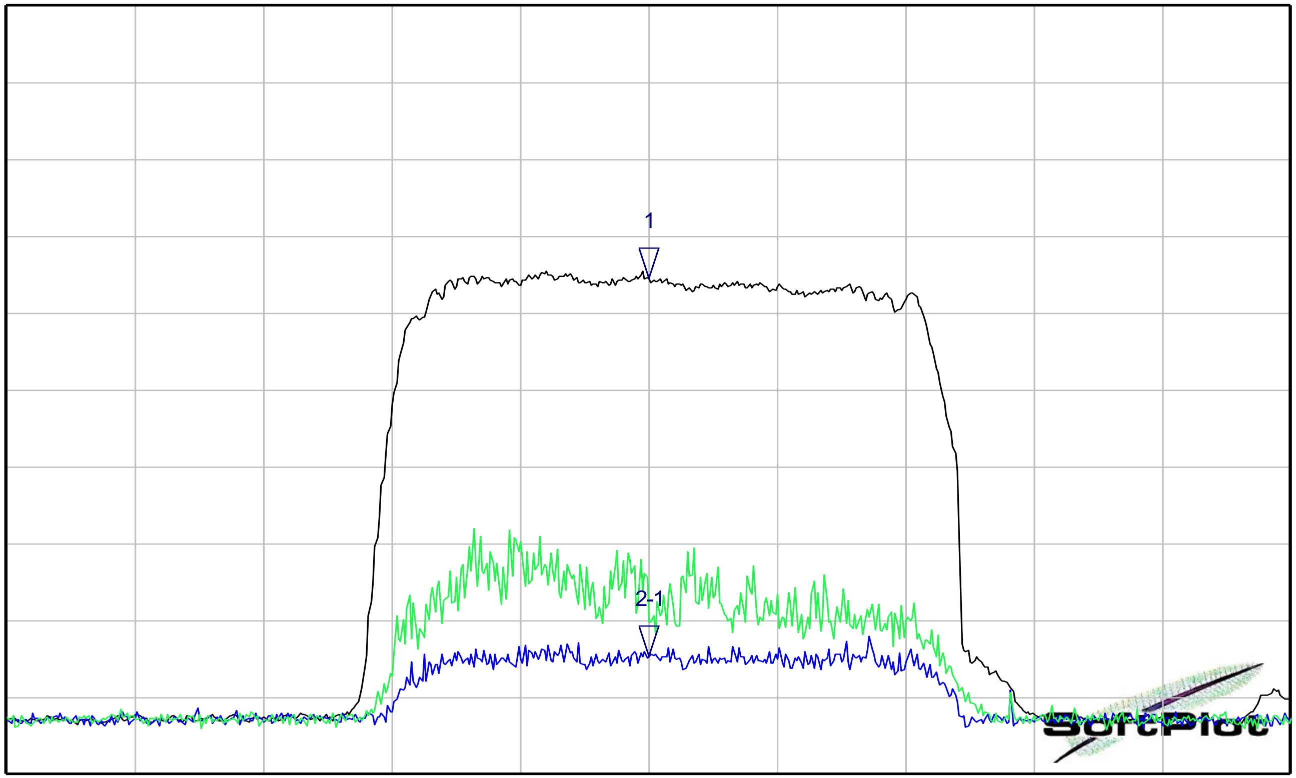
DACU Anti-Jam GPS System
Measured Results

COBHAM

Equalisation Performance Against Chirp

CalSymChirp_100_450_84dB_b.hex

Omni Adapt (with Eq.) Adapt (w/o Eq.)

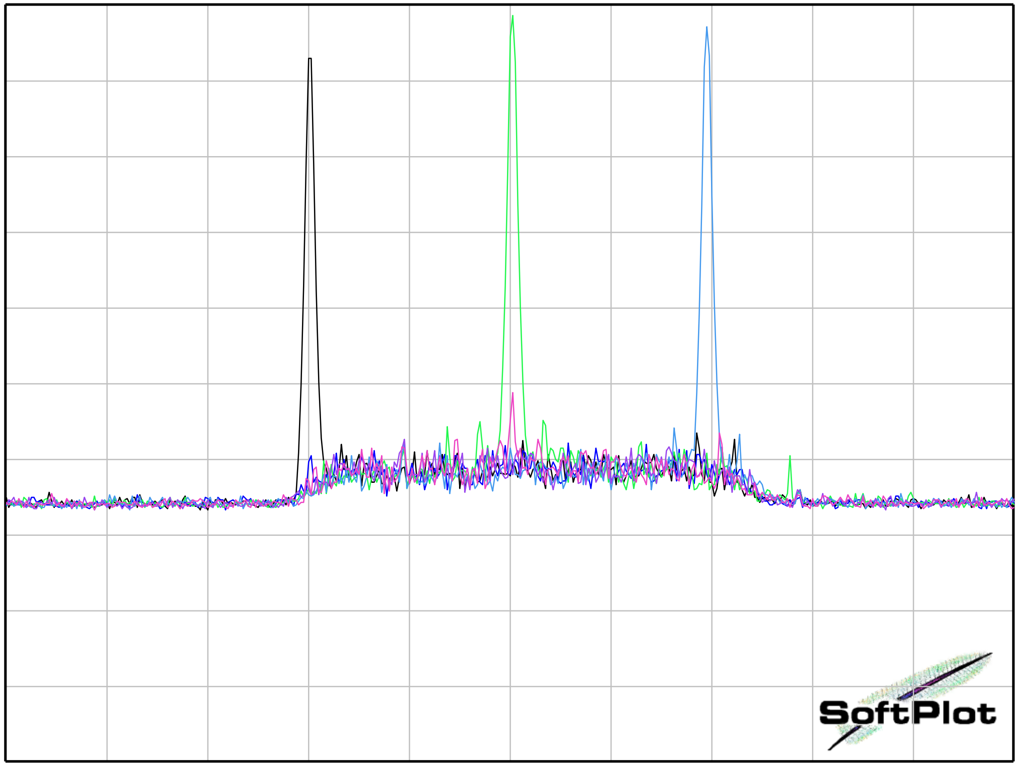


DACU Anti-Jam GPS System
Measured Results

Test 169 Jammers over P(Y) Code Bandwidth L1

1565.4 Omni 1565.4 Adapt 1575.4 Omni 1585 Omni

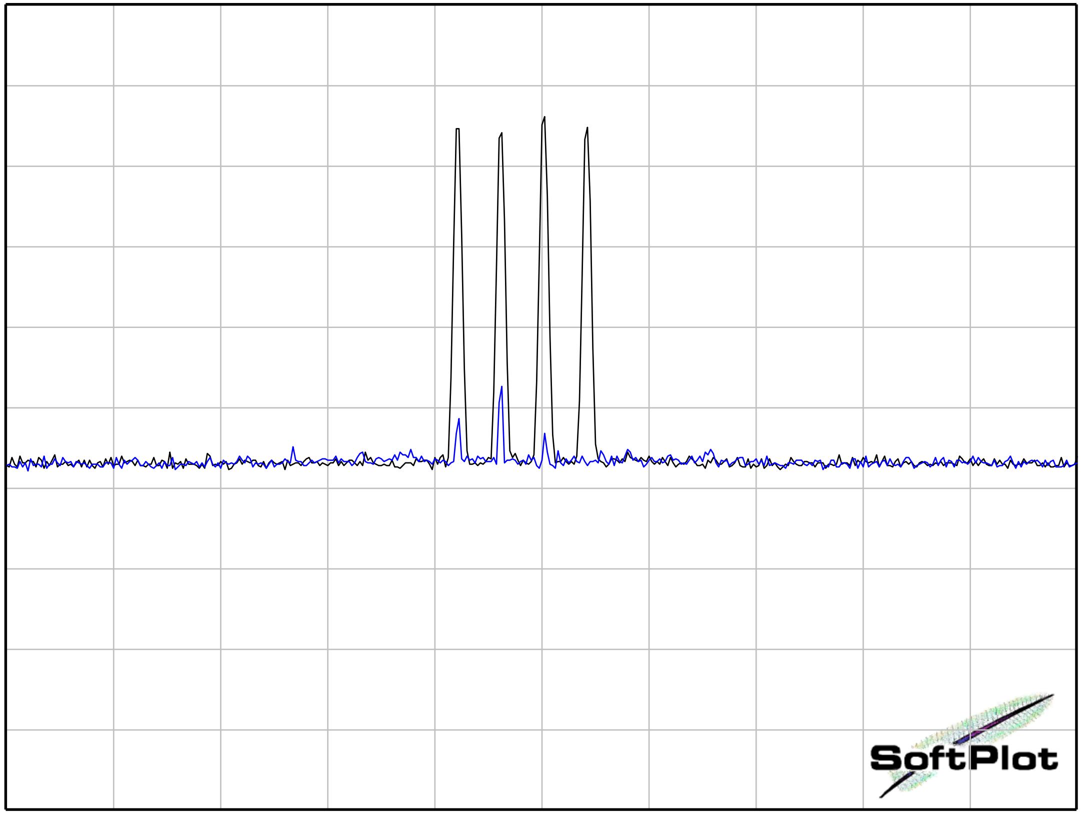
1585 Adapt 1575.4 Adapt



DACU Anti-Jam GPS System
Measured Results

SoftPlot Measurement Presentation

N Jammers Omni L2   N Jammers Adapt L2



DACU Anti-Jam GPS System
for AW159 Lynx Wildcat Helicopter

COBHAM

DACU
Antenna

DACU Anti-Jam GPS System
Apache Helicopter

DACU
Antenna

DACU Summary 1

- 4 and 11 antenna DACU systems developed and demonstrated
- Blackfin processor used with Stratix 3 and 4 FPGAs
- High levels of cancellation over narrowband and broadband
- High speeds of adaptation (10s of microseconds) to cope with agile jammers and rotor blade modulation effects on helicopter platforms
- Considerable effort given to minimise size weight and power

~9″ x 4.5″ x 2″ <3lbs ~22W

DACU Summary 2

- 4 antenna systems developed for AW159 Lynx Wildcat and US Apache helicopters
- 6 systems delivered to UK MoD for trials at Porton Down
- 2 systems delivered to US DoD for flight trials at Holloman AFB, New Mexico and simulated trials at Wright Patterson AFB, Ohio

- 70 production systems ordered by UK MoD for AW159 Lynx Wildcat

RF Interference Suppression on Fixed and Mobile Platforms – Summary

- RF interference cancellation (on-board only? – well proven, mature technology and systems supplied)
- RF interference suppression using time division multiplexing (on- and off-board – proven in a lab environment)
- Antenna polarisation techniques (off-board – yet to be investigated)
- Adaptive antenna nulling (off-board – well proven and systems supplied) – applied to anti-jam GPS

S J Nightingale

14th October 2013

The most important thing we build is trust


AEROSPACE AND SECURITY DIVISION
- Aerospace Communications
- Antenna Systems
- Commercial Systems
- SATCOM
- Tactical Communications and Surveillance


DEFENCE SYSTEMS DIVISION
- Defence Electronics


MISSION SYSTEMS DIVISION
- Aviation Services
- Life Support
- Mission Equipment

Questions?

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