

RF Interference Cancellation - a Key Technology to support an Integrated Communications Environment

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Abstract

This paper describes some of the recent developments in the application of RF interference cancellation techniques to enable an Integrated Communications Environment (ICE). It is well known that the high levels of mutual coupling between antennas on small fixed or mobile platforms causes significant levels of power from the transmitting radios to be coupled to those operating in the receive mode. This can cause compression, overdriving, and, in some cases, permanent damage to the radio front ends. The large transmit signals can be reduced to acceptable levels by RF interference cancellation. However, once this has been achieved, the sensitivities of the receiving radios are frequently limited by the transmitter sideband noise. This presentation will describe the development and application of both large signal and noise cancellation techniques to maximise the sensitivity of all receiving radios on the same platform. Examples are given based on radio equipment installed on typical mobile military platforms.

1. Introduction

Many mobile platforms have the radio antennas positioned in close proximity, which leads to high levels of mutual coupling between them. This means that the transmitting radios can generate high power levels in the receiving radios, which can significantly desensitise or permanently damage the front end electronics. This is particularly an issue on mobile military platforms. Figure 1. illustrates the problem in an army convoy where each vehicle has a number of antennas associated with radios and other equipment.

The received power level at which noticeable desensitisation starts to occur is, typically, in the region of -5 to 0dBm. On many mobile platforms, the mutual coupling between antennas can be as high as 13dB at VHF. Therefore, when transmitting +47dBm (50W), the power coupled into the receiver can be as high as +34dBm (2.5W). This indicates that around 40dB of cancellation is required for each transmitted signal to avoid desensitisation of each receiving radio due to compression. This large signal desensitisation occurs because the front end of the radio is designed to be low noise, relatively broadband and pass signals within the operating band, eg 30 – 88MHz. The low noise requirement inevitably limits the ability of the radio's front end to handle large signals. The front end of a typical radio has two stages of downconversion as shown in Figure 2. There may be some degree of frequency preselection in the front end stages, which restricts the band of signals passing through to IF or A/D conversion to less than the operating band of the radio, but the main filtering that determines the receive channel is in the IF stages or after A/D conversion.



Figure 1: An Army Convoy of Vehicles each with a Number of Omnidirectional Whip Antennas

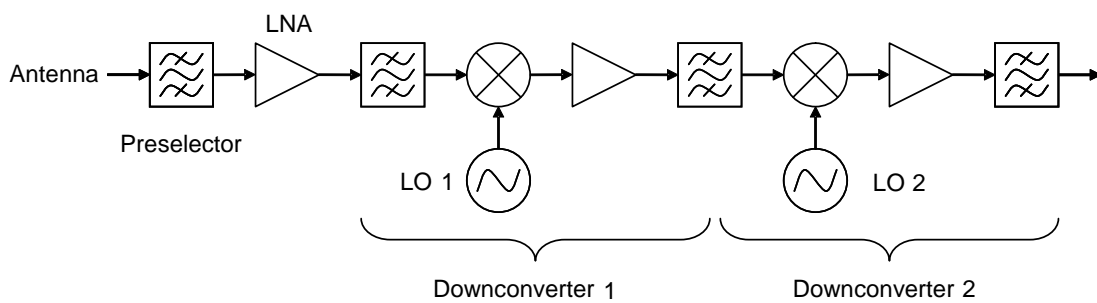


Figure 2: Typical Radio Front End

Furthermore, modern radios with broadband transmit amplifiers and limited transmit filtering tend to have higher sideband noise levels in the main transmit signal compared with older radios due to the compromise associated with their greater flexibility to handle complex modulation schemes. These sideband noise levels are typically in the region of -80dBc (in a 25kHz bandwidth) 1MHz away from the carrier and beyond. Therefore, when transmitting +47dBm (50W), with an antenna

coupling of 13dB, the noise level into the receiver will be in the region of -46dBm . The signal-to-noise ratio of the receiver will now be limited by this received 'on-channel' noise and, for a 10dB signal-to-noise ratio, the radio sensitivity will be reduced to -36dBm . This figure is quite unacceptable, when the expectation, from an operational point of view, is for a sensitivity of around -90 to -100dBm . Measurements in the field have shown that the noise sidebands in some cases can decrease the communication range between mobile platforms to only a few hundred metres.

Figure 3 shows a typical transmitter spectrum from a modern military radio. The noise power levels are measured in a 25kHz bandwidth. The red curve shows the spectrum directly from the radio when transmitting $+40\text{dBm}$ (10W). The blue curve shows the output from the vehicle adapter, which boosts the signal to $+47\text{dBm}$ (50W). In both cases, it can be seen that, at 1MHz away from the carrier, the noise level is $-78\text{dBc}/25\text{kHz}$ indicating that the noise comes primarily from the radio and not the vehicle adapter.

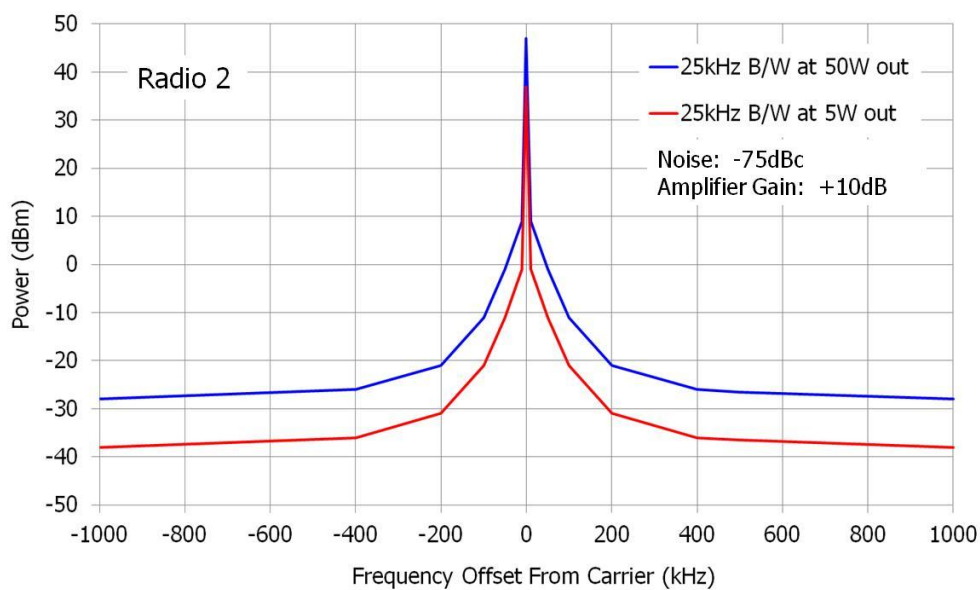
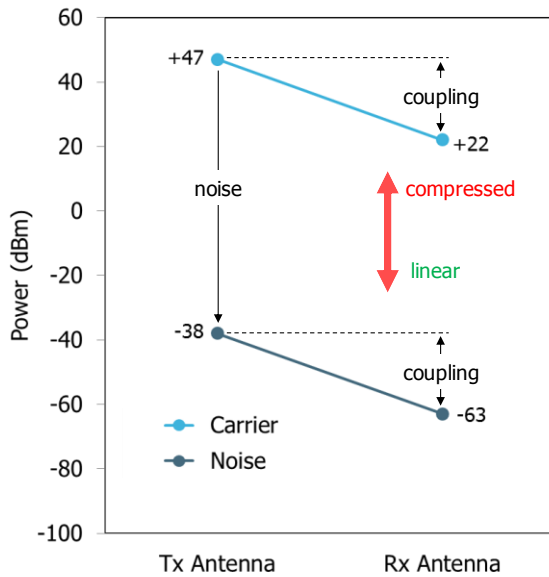


Figure 3: A Typical Comms Radio Transmitter Spectrum

Therefore, in order to restore the receiver sensitivity to an acceptable level, it is necessary to not only reduce the large 'off-channel' power coupled into the receiver from the main transmit signal, but also to decrease the 'on-channel' noise from the noise sidebands coupled to the receiver from that transmitter.

Figure 4 provides a problem summary of a typical measured scenario where the transmitted power is $+47\text{dBm}$ (50W), the noise power is $-85\text{dBc}/25\text{kHz}$ and the antenna coupling is 25dB.



WORKING VALUES

Tx power (dBm)	+47
Noise (dBc)	85
Antenna coupling (dB)	25

OBJECTIVES

- Suppress or cancel large signal to avoid compression
- Suppress or cancel noise to achieve desired sensitivity

Figure 4: Problem Summary

2. Principle of RF Interference Cancellation

The principle of RF interference cancellation can be explained by reference to the block diagram shown in Figure 5. Here, the antennas of two radios are co-sited, one on the right hand side, operating in 'transmit' and the other, on the left hand side, operating in 'receive'.

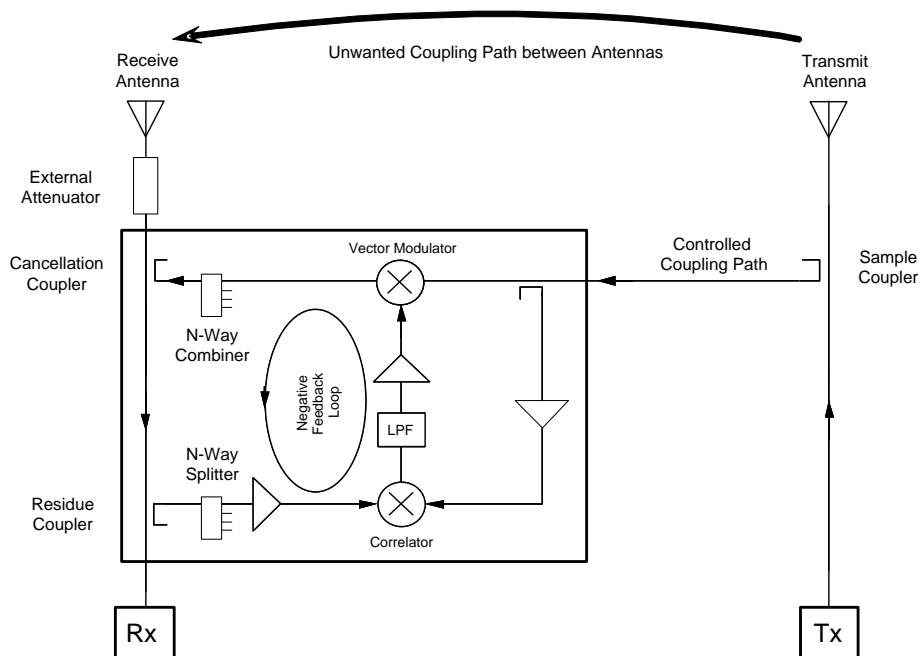


Figure 5: Basic System Block Diagram of RF Interference Cancellation System

The basic principle is to sample the interfering signal, by coupling off a portion from the transmit feeder, adjusting it in amplitude and phase and then injecting it into the receive feeder via another

directional coupler to provide an exact anti-phase replica to effect cancellation of the signal coupled into the receive antenna. This process is optimised by monitoring the residue after cancellation and using this signal to drive a negative feedback loop to minimise the residue thereby maximising the cancellation. The circuit which controls the cancellation process is called a 'weight module', because it applies the correct weight to the amplitude and phase to effect maximum cancellation.

Generally, when cancelling the interfering signals associated with a single radio channel, matching the time delay between the antenna coupling and cancellation paths is not critical. This is because the receive bandwidth of a communications radio operating in AM or FM is narrow, typically, 25kHz. However, time delay matching is important for the case of very broadband cancellation, as required for the removal of interference from high capacity data radios, video links and ECM equipment, where the instantaneous cancellation bandwidth requirements will generally be much larger, eg several MHz.

The principle shown in Figure 5 can be extended to cancel additional interfering signals by using additional weight modules and combining cancellation signals with an N-way combiner prior to the cancellation coupler and splitting the residues from the residue coupler with an N-way splitter as shown.

The implementation of RF interference cancellation to remove both a large signal and noise requires a more complex implementation of weight modules and this will now be described.

3. A Practical RF Interference Cancellation System

Figure 6 shows a more detailed block diagram of a system to deal with the mutual interference between two radios. It should be noted that when both radios are transmitting or both receiving, no RF interference cancellation is required. Cancellation is only required when one radio is transmitting and one is receiving, therefore, only one set of weight modules is required and these are switched in appropriately depending on which radio is transmitting and which is receiving. Mechanical bypass switches are included so that, in the event of a power failure or system malfunction, the radio performance reverts to that without any cancellation. This block diagram contains a combination of weight modules cancelling not only the large transmit signal, but also putting a null in the received transmitter sideband noise at the frequency of the desired receive channel.

Figures 7 and 8 show the typical coupling and group delay characteristics for two antennas on a representative mobile platform. These characteristics were measured by connecting a network analyser to the input of each antenna and measuring S_{21} from which the coupling (dB) and group delay (ns) were derived.

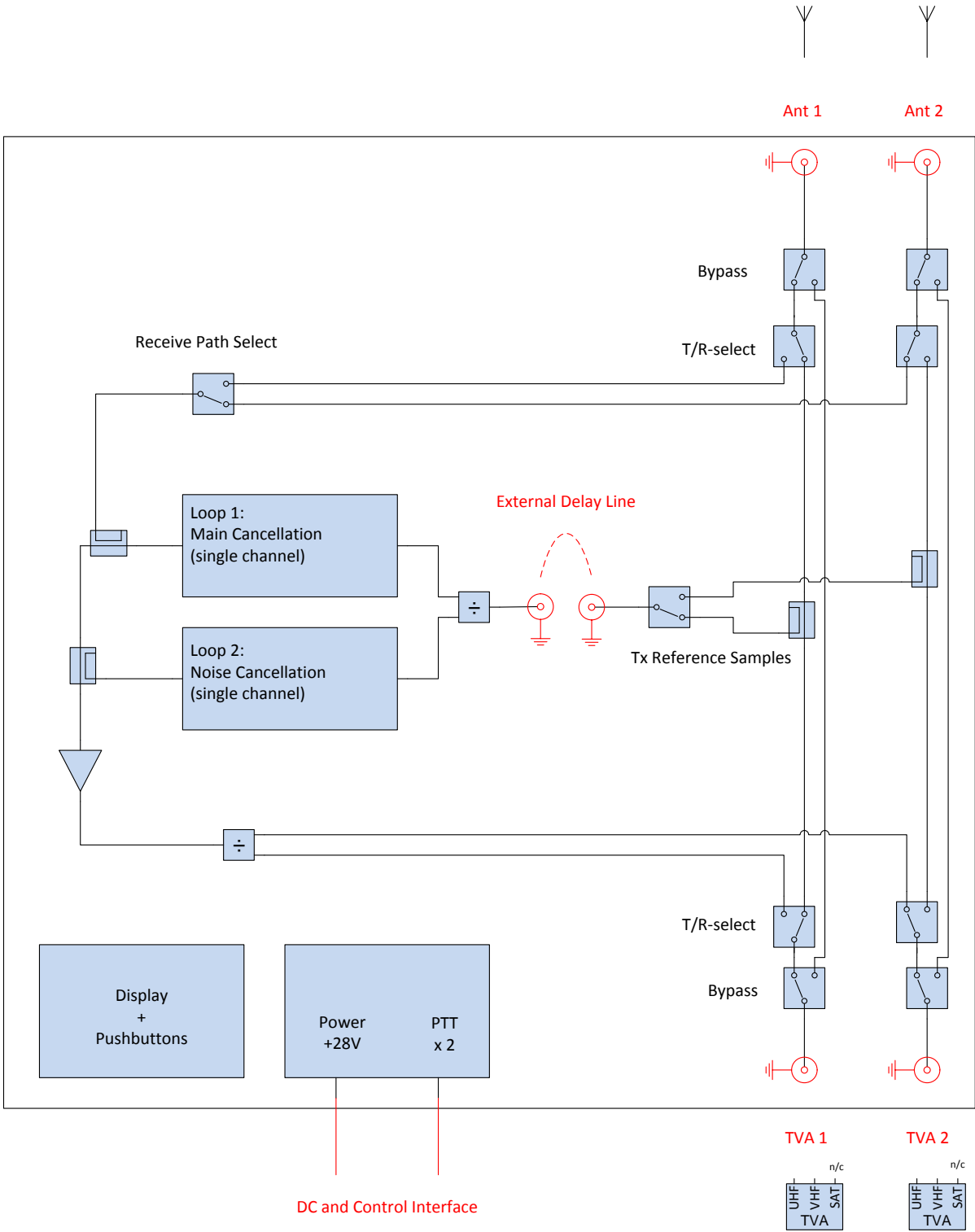


Figure 6: Practical Implementation of a 2-Radio RF Interference Cancellation System

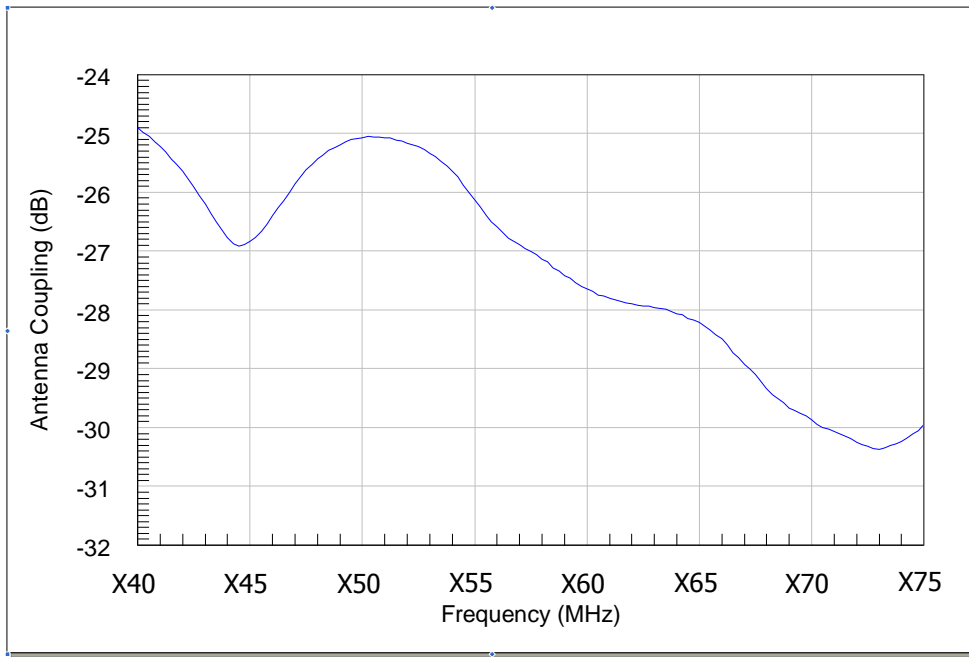


Figure 7: Typical Antenna Coupling v Frequency

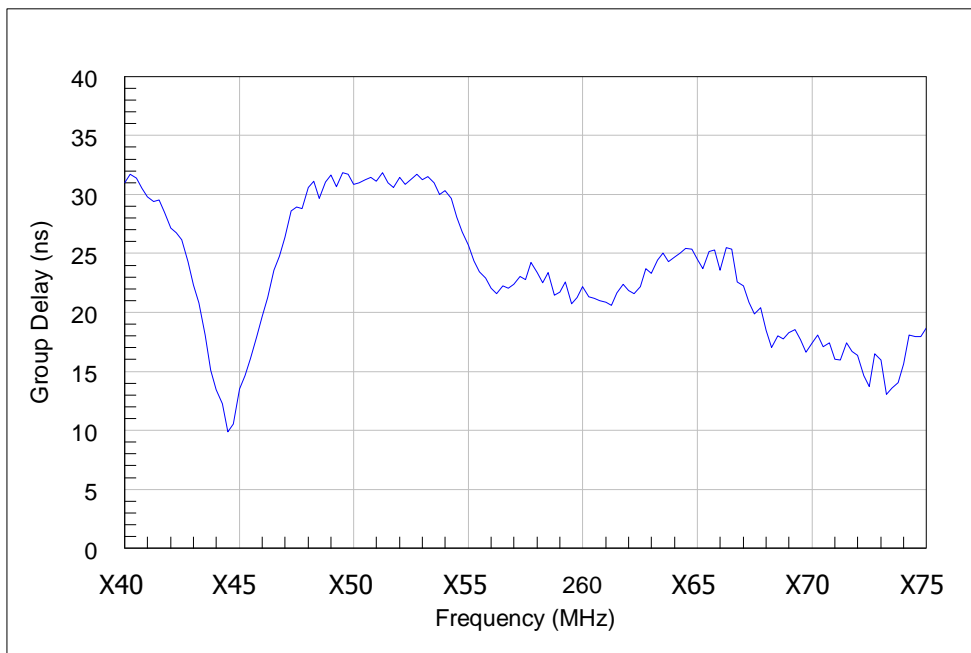


Figure 8: Typical Group Delay v Frequency

The above characteristics, with the peaks and troughs in coupling and group delay, are due to the low Q resonant nature the antenna structures combined with their matching circuits.

The results from Figures 7 and 8 were implemented in a model of the cancellation system in AWR Microwave Office. The delay in the cancellation path was approximately matched to the delay

between the antennas by setting it to the average between the maximum (32ns) and minimum (10ns) values over the frequency band shown, ie 21ns. This ensured that the maximum error in time delay difference between the antenna coupling and cancellation paths was 11ns. Typical cancellation curves are plotted in Figure 9 as the cancellation frequency is stepped across the band.

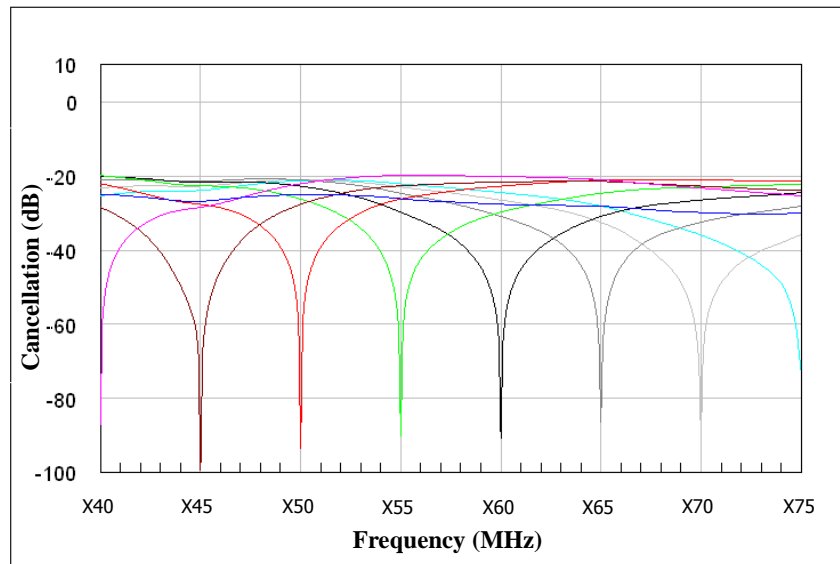


Figure 9: Typical Cancellation Characteristics

The instantaneous cancellation bandwidth is dependent on four main parameters as shown in Figure 10. All these parameters relate to the differences between the antenna coupling and cancellation paths at the centre frequency of the receive channel, f_0 . The loss difference, L_{f_0} , can be set to zero at the centre frequency of the receive channel due to the variable attenuator of the Vector Modulator in the weight module. Since, in the cancellation path, this is constant with frequency, the variation in loss with frequency in the antenna coupling path will define the rate of change of loss, $\frac{dL}{df_{f_0}}$, at the centre of the receive channel. The group delay difference, τ_{f_0} , will be defined by the difference between the fixed value in the cancellation path and the varying value in the antenna coupling path. The rate of change of group delay, $\frac{d\tau}{df_{f_0}}$, is again, determined only by the antenna path.

L_{f_0} = loss (dB) – not important

$\frac{dL}{df_{f_0}}$ = rate of change of loss (dB/MHz)

τ_{f_0} = group delay (ns)

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

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

Figure 10: Cancellation Parameters

Examination of the four parameters shows that for typical practical cases the rate of change of group delay, $\frac{d\tau}{df_{f_0}}$, is not significant unless instantaneous cancellation significantly in excess of 60dB is

required. Therefore, the two important parameters are the rate of change of loss, $\frac{dL}{df_{f_0}}$, and the

group delay, τ_{f_0} . Curves of constant cancellation as a function of these two parameters are given in Figure 11. These curves show that, for 60dB cancellation over an instantaneous cancellation bandwidth of 25kHz, the maximum values for rate of change of loss ($\tau_{f_0} = 0$) and minimum group

delay ($\frac{dL}{df_{f_0}} = 0$) are 0.7dB/MHz and 12.7ns respectively.

4. Results from Practical RF Interference Cancellation System

Typical results, for the characteristics given in Figures 7 and 8, are shown by the small circles in Figure 11, with each representing the cancellation at specific frequencies, and each frequency point joined by dashed lines. These results were in agreement with cancellation versus frequency measurements made on the RF cancellation system.

Figure 12 shows a photograph of a single channel RF interference cancellation system designed to cancel both the large transmit signal and cancel or put a notch in the received transmitter sideband noise.

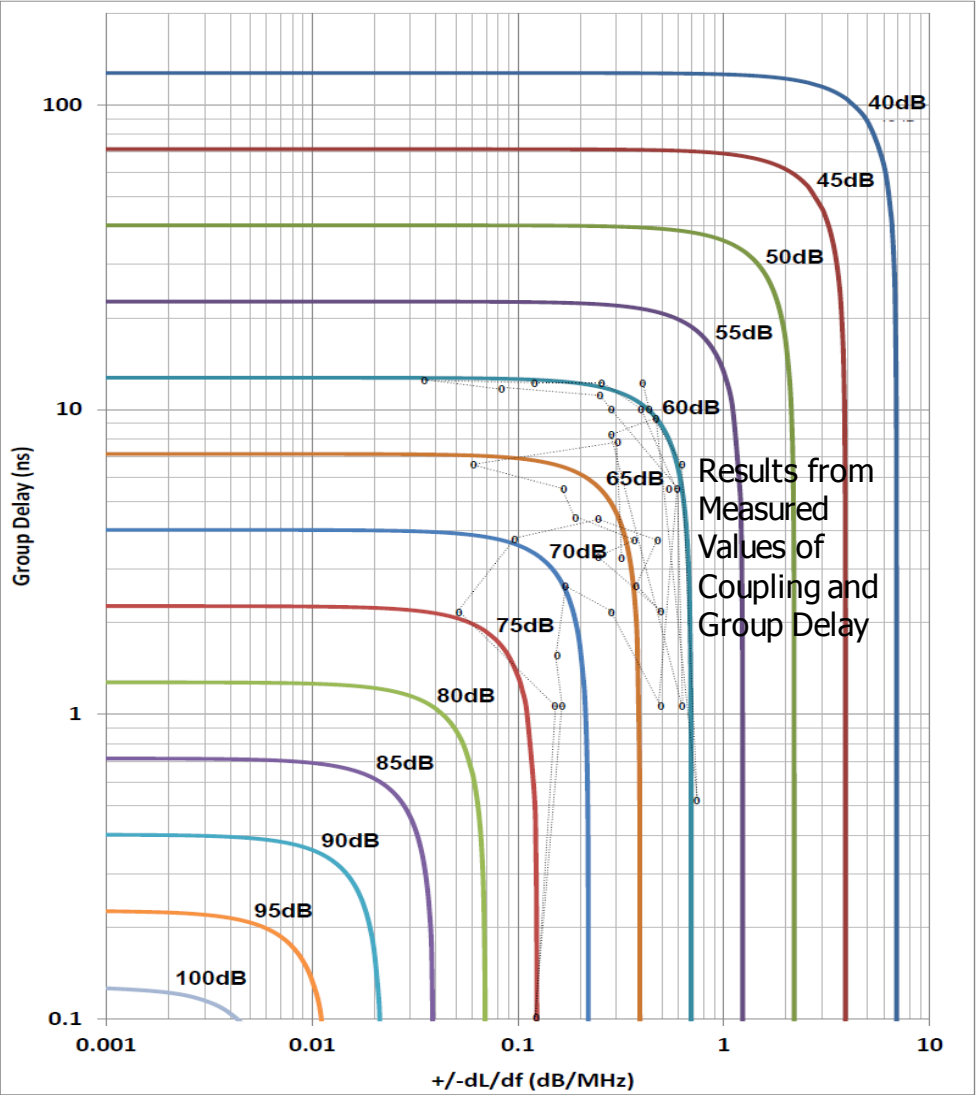


Figure 11: Curves of Constant Cancellation



Figure 12: RF Interference Cancellation System to remove Main Large Comms Signal and Sideband Noise

Figure 13 shows a typical result for the system measured in the lab. The green curve represents the main transmit signal at 265MHz with the sideband noise at -85dBc/25kHz. After large signal cancellation, to prevent compression of the front end of the receiving radio, the large signal has been cancelled or reduced by 58dB as shown by the blue curve. When the noise cancellation is applied for a signal being received at 250MHz, the noise is reduced by 40dB as shown by the red curve.

Figure 14 summarises the performance of the canceller in a typical mobile platform. The transmit power is +47dB (50W) with noise sidedbands at -85dBc/25kHz. The coupling between the transmit and receive antennas is 25dB. Therefore, the transmit power received into the radio will be +22dBm (+47 – 25), which will cause significant desensitisation in the radio due to compression in the front end. The received noise levels will be at -63dBm/25kHz (+47 - 85 – 25). The large signal cancellation will reduce the received carrier by the cancellation level to -36dBm (+22– 58), which will be significantly below the saturation level of the radio, and the noise cancellation will reduce the noise level at the receive channel to -103dBm/25kHz (-63 – 40). The sensitivity of the radio for a signal-to-noise ratio of 10dB will now be -93dBm/25kHz (-103 + 10).

The sensitivity of a radio is often given in terms of *SINAD*, ie:

$$SINAD = SNR - 1$$

where:

SNR = Signal-to-Noise Ratio

$$SINAD = \frac{[Signal + Noise + (Distortion)]}{[Noise + (Distortion)]} \quad \text{NB Distortion} \approx 0$$

Hence the $SINAD$ will be 10.4dB, or, for $SINAD$ of 10dB, the sensitivity will be approximately -93.5dBm.

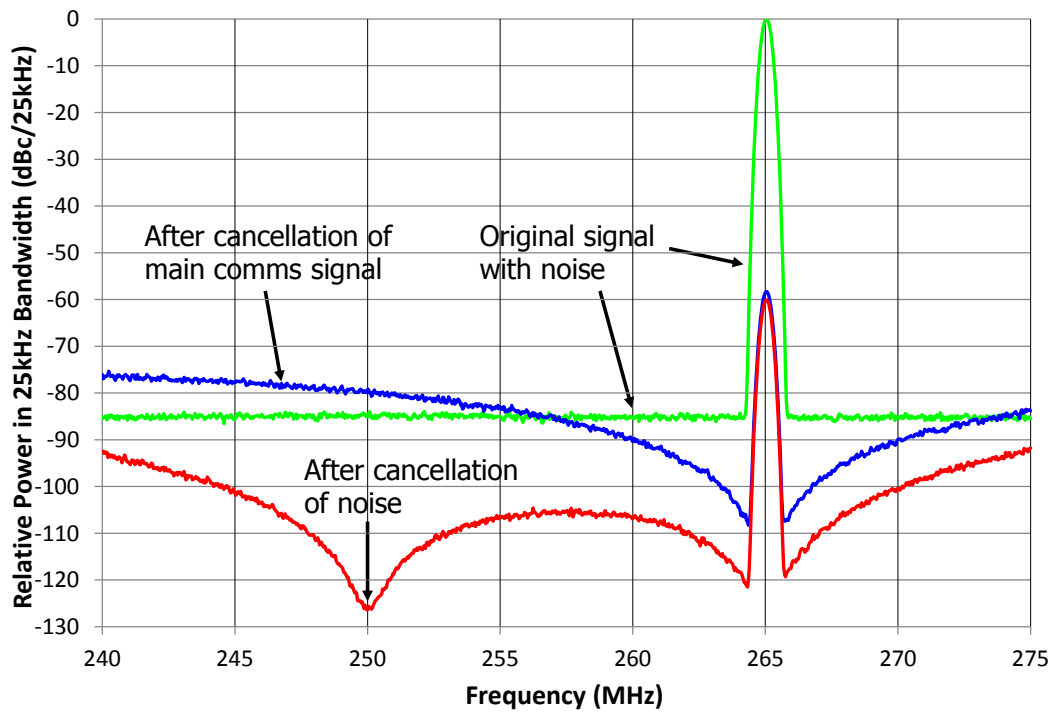
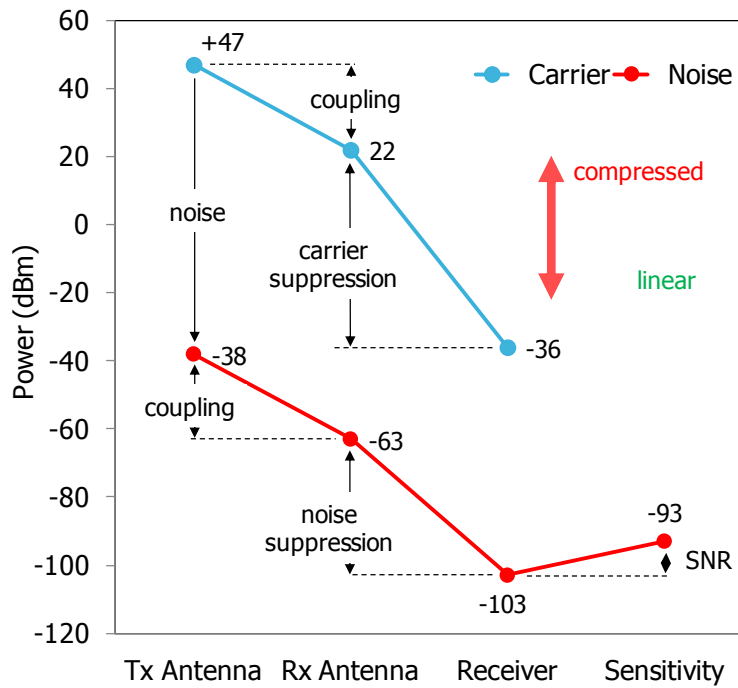


Figure 13: Typical Measured Result for the Cancellation of the Large Transmit signal and Noise



EXAMPLE

Tx power (dBm)	+47
Noise (dBc)	85
Antenna coupling (dB)	25
Carrier cancellation (dB)	58
Noise cancellation (dB)	40
SNR (dB)	10

Sensitivity = < -93dBm

Figure 14: Cancellation of Large Signal and Noise

5. Conclusion

This paper has shown that in modern radios it is necessary to reduce or cancel not only the main transmitted signal coupled to the antenna of the receiving radio, but also the noise sidebands in order to restore the sensitivity to an acceptable operational level. This technique has been proven in the field and is currently being applied to multiple transmitters and receivers operating on the same platform.