Application Note

MEASURING MULTI-ANTENNA ISOLATION USING A MULTIPORT VNA

Products:

- ► R&S®ZNB
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Contents

1 Overview

The proliferation of wireless technology is leading to higher densities of Radio Frequency (RF) transmitter and receiver antennas on many platforms. A single platform such as an automobile, police car, airplane or military platform can have numerous antennas that are located in relatively close proximity to one another.

In this application note, antenna to antenna isolation using a Rohde and Schwarz multiport port Vector Network Analyzer (VNA) is analyzed. These antenna to antenna isolation measurements are presented in generalized real-world deployments that are applicable to Internet of things (Wireless refrigerators, stoves, etc.) automobiles, aircraft, tanks, submarines, boats and ships, etc. Knowing the actual antenna to antenna isolation allows engineers to assess the filtering requirements in wireless receivers, in addition to mitigating Cosite Interference issues at the Platform Level and in System Integration.

2 Introduction

The proliferation of wireless technology is leading to higher densities of Radio Frequency (RF) transmitter and receiver antennas on many platforms. A single platform such as an automobile, police car, airplane or military platform can have numerous antennas that are located in relatively close proximity to one another. The frequency range is likely from 10’s or 100’s of kHz into the 10’s of GHz, and even with different frequencies of operation these systems can interfere with one another. The wireless design cycle can include a cosite interference study to determine the isolation that exists between antennas. This isolation study can allow for the evaluation of optimal antenna placement on vehicles and platforms to maximize antenna to antenna isolation and to minimize Cosite Interference.

In this application note, antenna to antenna isolation using a Rohde and Schwarz multiport port Vector Network Analyzer (VNA) is analyzed. These antenna to antenna isolation measurements are presented in generalized real-world deployments that are applicable to Internet of things (Wireless refrigerators, stoves, etc.) automobiles, aircraft, tanks, submarines, boats and ships, etc. Knowing the actual antenna to antenna isolation allows engineers to assess the filtering requirements in wireless receivers, in addition to mitigating Cosite Interference issues at the Platform Level and in System Integration.

Table 1 shows a list of common wireless systems that may be present in many vehicles. The placement of some of the antennas are outside the engineer's control, yet others are within the engineers control. Knowing how much energy transmits from one system antenna to another allows one to determine filtering requirements early in the design cycle. While Digital Signal Processing can be used to improve signal quality, it comes at the expense of increased power consumption. In many cases, reduced power consumption is expected, and thorough engineering is required to accomplish this.

Engineers can also look at the FCC Frequency Allocation Table and see that there is not any portion of the electromagnetic spectrum below 20 GHz that is unused, and frequencies above 20 GHz are becoming increasingly popular. An ever-increasing number of transmitters across the entire electromagnetic band creates the potential for more interference. Measuring the isolation between collocated antennas using a Rohde and Schwarz Multiport VNA will allow engineers to make informed decisions they can be confident in. Knowing the isolation of an antenna can be the first step to greatly decrease the probability of Noise from Cosite Interference.

Table 1: Common Wireless Systems Carrier Frequencies

	Frequency / Band
AM Radio Receiver	505 kHz to 1705 kHz
FM Radio Receiver	87.5 MHz to 108 MHZ
WiFi	900 MHz, 2.4 GHz, 5 GHz
Bluetooth	2.4 GHz
Cellular	600 MHz, 700 MHz, 850 MHz, 1700 MHz, 2100 MHz, 1900 MHz, 2300 MHz, 2500 MHz, 5200 MHz, 28 GHz, 39 GHz
RFID / EZ PASS	900 MHz
GPS	1575.42 MHz or 1227.60 MHz
Radar - Low Power	24 GHz, 60 GHz, 77 GHz
Satellite Link	Various
TACAN	960 MHz to 1215 MHZ
Identification Friend or Foe (IFF)	1030 MHz and 1090 MHz
Data Links	Various
Radar - High Power	Various

3 5 GHz WiFi Interfering with GPS Example

Engineers may wonder if antenna to antenna isolation measurements are relevant to their wireless systems and their particular situation. It may seem that a 5 GHz WiFi signal will likely not interfere with a 1.57542 GHz GPS Receiver, however this is an assumption and it can have disastrous results if care is not taken to validate assumptions. As illustrated in Figure 1, it is common for filter passbands to occur at the 3rd and 5th harmonics of the fundamental passband. The passband for a GPS Signal of 1.57542 GHz filter may have a 3rd harmonic passband at 4.72626 GHz as illustrated in Figure 1. As illustrated in Figure 1, this leaves 300 MHz of separation from a 5 GHz WiFi signal. Since the GPS filter was not designed to have strong rejection at 300 MHz from the 3rd harmonic of the filter's passband, the filter's rejection at 5 GHz may not be adequate to prevent interference. While a 5 GHz WiFi signal may be beyond the operating frequency of the GPS receiver, the 5 GHz signal can excite nonlinear behaviors in the GPS receiver and result in highly undesirable intermodulation products.

Table 2 illustrates how a 5 GHz WiFi signal may interfere with a GPS receiver. The 5 GHz WiFi signal transmit amplitude is 20 dBm and there is 90 dB of Free Space Path Loss, or Isolation, between the WiFi Antenna and the GPS Antenna. In this example, the GPS Antenna has 10 dB of Rejection at 5 GHz and the GPS Bandpass filter has 30 dB of rejection at 5 GHz. The Received Signal Strength is -110 dBm and the GPS Receiver Noise Floor is at – 120 dBm. The amplitude of the interfering signal is 10 dB greater than the GPS Receiver Noise Floor and its Signal to Noise Ratio is 10 dB. In this example the 5 GHz WiFi signal is likely to cause interference and noise issues in the GPS Receiver.

Engineers are encouraged to perform their own analysis and come to their own conclusions using the specific parameters for their systems and components. Measuring the Antenna to Antenna Isolation provides engineers with absolute data that allows them to make informed and educated decisions that they can be confident in. If one encounters a situation where the loss is greater than what can be measured, the engineer at least knows the loss is greater than the measurement range of the VNA, 120 dB for example.

Table 2: 5 GHz WiFi Signal Interfering with a GPS Receiver

5 GHz WiFi Transmit Power	20	dBm
Free Space Path Loss / Isolation	-90	dB
GPS Antenna Rejection	-10	dB
Filter Rejection	-30	dB
Received Signal Strength	-110	dBm
GPS Receiver Noise Floor	-120	dBm
Interfering Signal Amplitude	10	dB

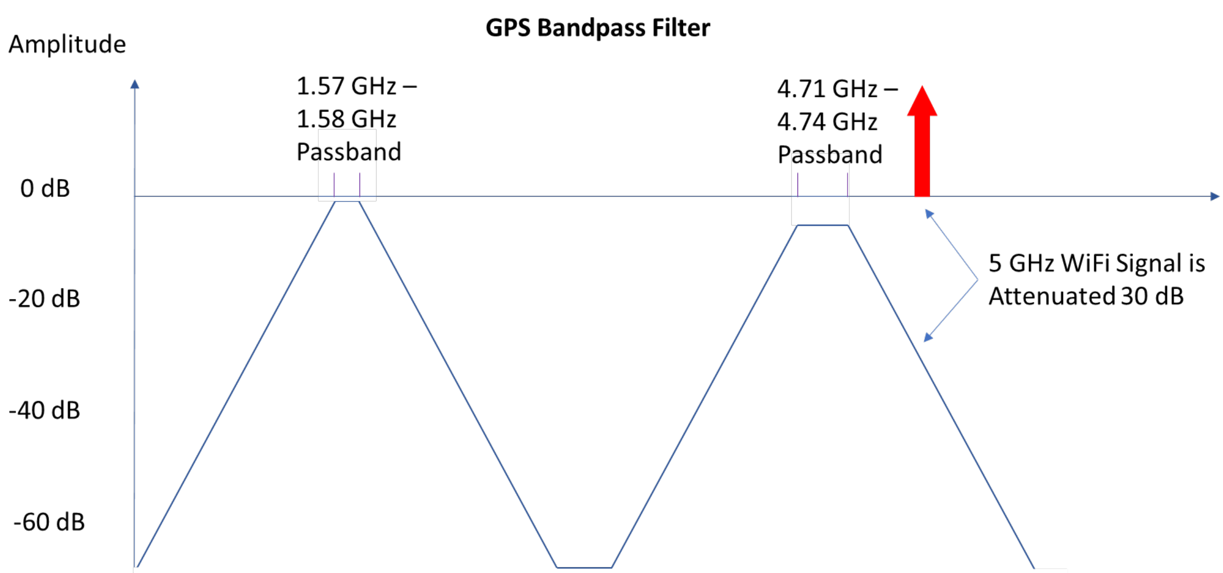

Figure 1: Generic GPS Bandpass Filter and an Interfering 5 GHz WiFi Signal

Isolating the GPS antenna from the 5 GHz WiFi antenna to the maximum extent possible may be performed in an Electromagnetic Modeling environment, however electromagnetic models should always be validated against actual measurements. Not only does this ensure the model is valid, it also accounts for final Installation Effects and Manufacturing Variance that are difficult to include in electromagnetic models. Manufacturing Variance can include antenna locations and heights; ground plane dimensions, dielectric constants, dielectric thicknesses and just about anything else that can affect an antennas radiation pattern. These small manufacturing “defects” can result in higher than expected antenna sidelobes than what is predicted by the electromagnetic models.

Increased antenna sidelobes result in stronger than expected antenna to antenna coupling. Antenna sidelobes can also increase from final installation mechanical components (e.g. dash boards, mirrors, tires, etc.) that are not in the electromagnetic models. Defining the mechanical dimensions of every item on a platform can be very time consuming and challenging. After the mechanical dimensions are defined in an electromagnetic modeling environment, the material properties (e.g. Conductivity, Complex Permittivity and

Complex Permeability) have to be defined. Reliable Dielectric Constant and Loss Tangent data may not exist, and performing antenna to antenna isolation measurements on production representative hardware can identify antenna sidelobe coupling that can't be predicted by electromagnetic modeling.

4 Automotive Applications

The proliferation of wireless technology and the Internet of Things is leading to ever increasing transceiver densities. On the surface it may seem like the majority of issues can be eliminated through the use of timing schemes, modulation and Digital Signal Processing (DSP). These solutions are only one component of a larger wireless management solution and there is no substitute for high quality hardware. Choosing antenna locations that maximize the isolation from other antennas can greatly increase the overall capacity of wireless systems and minimize cosite interference and noise. This can allow engineers to increase either the overall Quality and Reliability of their system, or to increase the antenna density from what is possible with "software fixes."

Figure 2 Shows what wireless systems may be on an automobile and the potential locations of the antennas. In this example, one may be interested in knowing how isolated the GPS antenna is from other antennas. Figure 3 shows what a multiport VNA measurement may look like to determine how isolated the GPS antenna is from the other antennas. Table 3 shows what the S-Parameter test matrix may look like for this particular example. This matrix can be expanded to include any combination of up to 24 antennas using the Rohde and Schwarz ZNBT VNA product line.

Ideally, an engineer will use a production representative antenna that is mounted in a final production representative location. This measurement process can also be performed early on in product development to validate electromagnetic models on engineering mock ups of the platform. Figure 3 shows a 4 port VNA being used to measure the isolation of a GPS antenna from 3 other antennas. In Figure 3 Port 1 is connected to a WiFi Antenna, Port 2 is connected to a Cellular Antenna, Port 3 is connected to a Satellite Antenna and Port 4 is connected to the GPS antenna.

During product development, the antennas can be moved around and the WiFi and Cellular antenna main lobes can be pointed in the direction of the GPS antenna to simulate a worst-case transmission event. While this can also be performed in an electromagnetic modeling environment, electromagnetic models should always be validated against a measurement to ensure accuracy. With Autonomous Vehicles on the technology horizon, the transceiver antenna density is likely to dramatically increase. Performing antenna to antenna isolation measurements to validate electromagnetic models will be critical to ensure Cosite Interference isn't a problem once production begins.

Figure 2: Automotive Wireless System Example

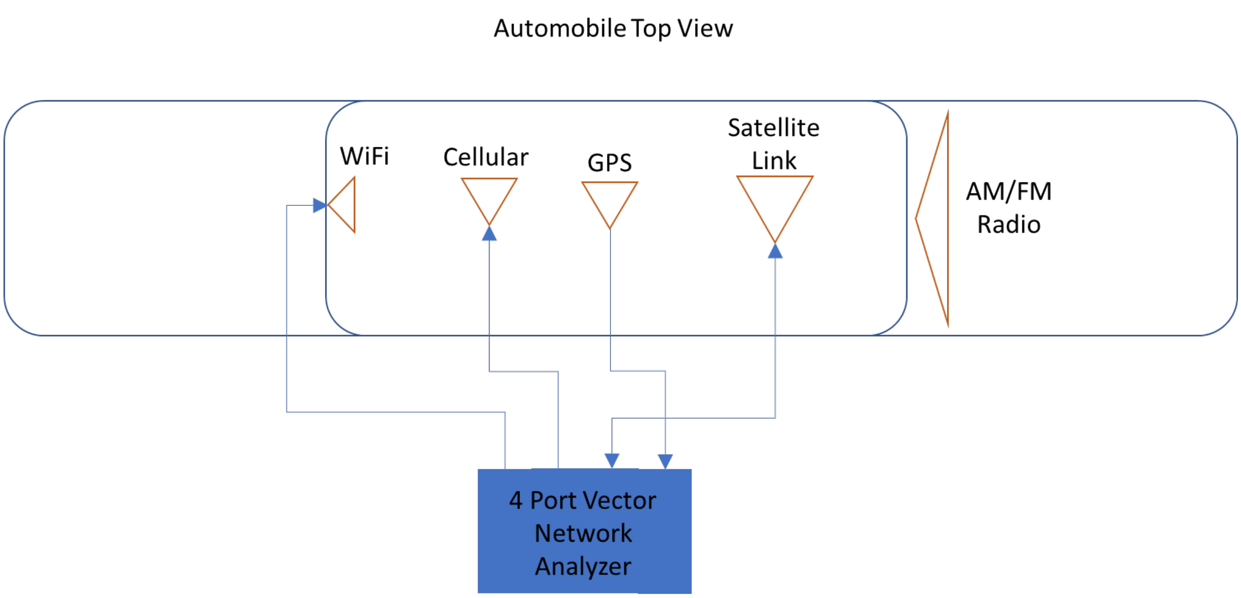

Figure 3: Automotive GPS Antenna Isolation Tet Setup

Table 3: Automotive GPS Antenna Isolation VNA S-Parameters

S-Parameter	System to System Coupling
S41	WiFi to GPS Coupling
S42	Cellular to GPS Coupling
S43	Satellite Datalink to GPS Coupling

Figure 4 shows what a full automotive antenna isolation measurement may look like. In this example, the systems represent a wide range of frequencies and system architectures. The AM / FM Radio Receiver may be manufactured from discrete components and it's filtering components may not work as needed from 600

MHz to 6 GHz. The high frequency signals may couple right through the receiver and excite nonlinear behaviors, possibly resulting in intermodulation products and noise.

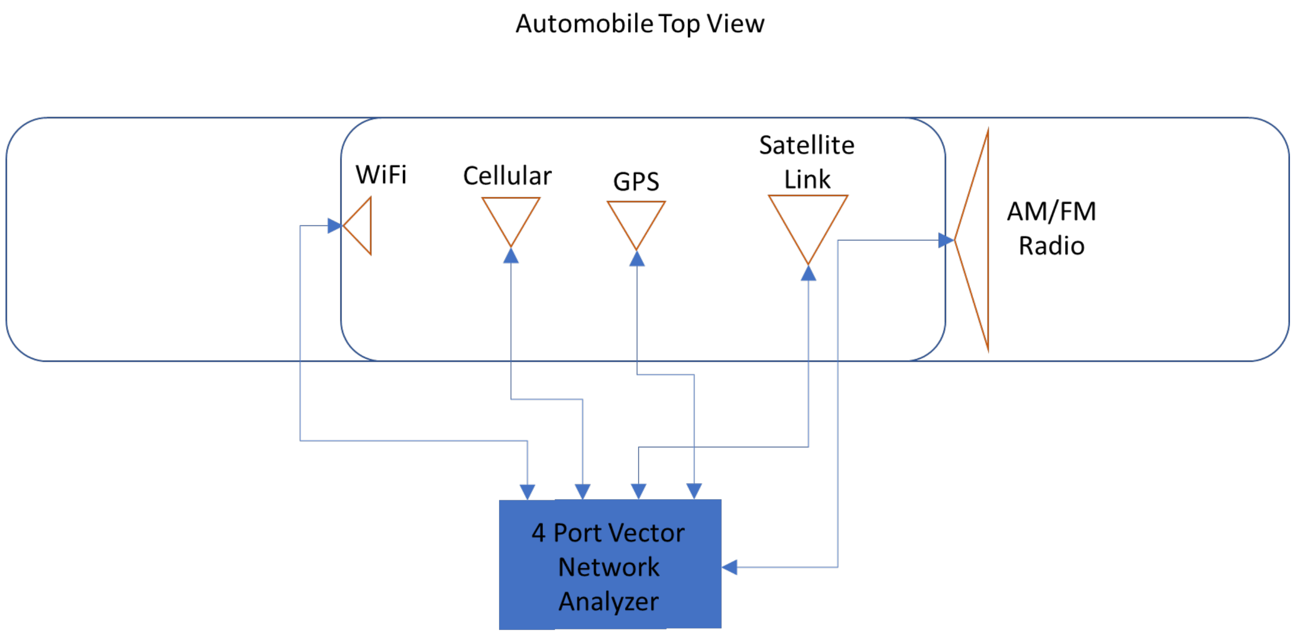

Figure 4: Automotive Wireless Systems Antenna Isolation Measurement

Figure 5 shows an automobile with 6 different radar antennas that are all operating at the same frequency. A radar may be reporting false returns without explanation and an engineer may be investing the possibility of an adjacent radar antenna creating in band interference. Figure 5 shows a simplified version of what this measurement may look like. This version will only evaluate antenna to antenna isolation and a test of this nature can become very complex. Phase steering of the antennas and Radar Cross Section targets can be added to the measurement, making for a more realistic evaluation of the possible interference. There is no substitute for knowing the actual antenna to antenna isolation.

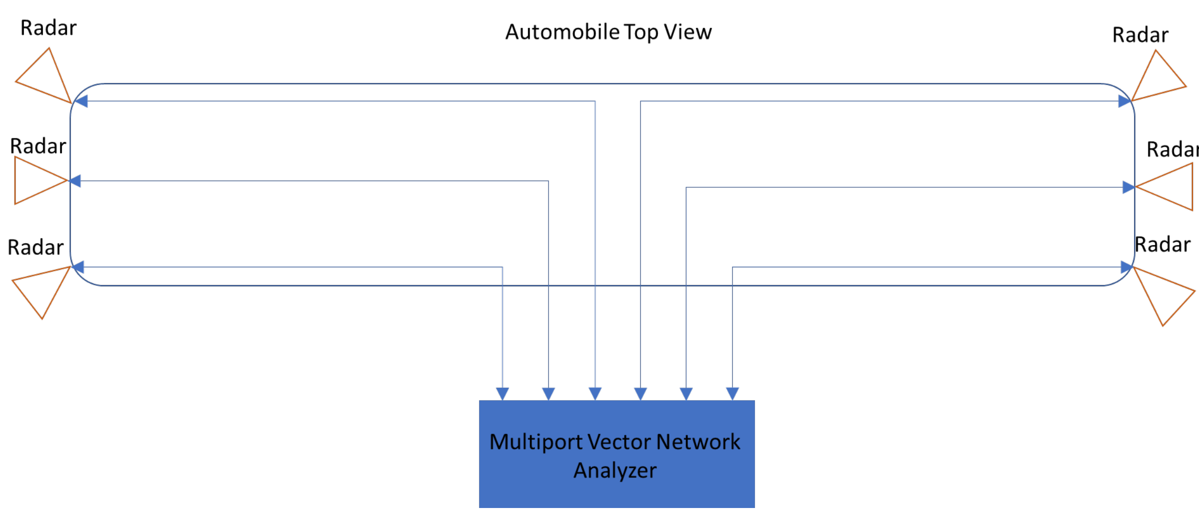

Figure 5: Automotive Radar Antenna Isolation Tet Setup

5 Military and Defense Applications

Military platforms can have a large number of antennas that are connected to high power transmitters and very sensitive receivers. Some of the individual wireless systems operate in the kHz range, while others operate in the MHz region and others operate in the GHz. Many of these systems are in close proximity to one another and can transmit significant amounts of power. Figure 6 shows what the antennas on a generalized military platform may look like. In military operating environments that can often be conflicting requirements between systems. For example, the HF Communications need to transmit and receive in any direction and this can potentially cause Cosite Interference with passive “listening” systems such as a Radar Warning Receiver. Radar and communications jammers can also transmit across wide frequency ranges, and these systems can potentially interfere with other onboard systems.

Figure 7 shows what an Antenna to Antenna isolation measurement setup might look like for a general military platform. A Rohde and Schwarz Multiport VNA can allow engineers to assess any combination of isolation between antennas that are connected to the VNA. For example, an engineer can determine how isolated the Passive Listening antennas are from the Identification Friend or Foe (IFF) antenna. Knowing how isolated antennas are from one another gives engineers the information they need to make informed decisions. Furthermore, knowing how isolated antennas are from one another can help explain interference issues. Additionally, knowing how isolated antennas are from one another can help determine filtering requirements, and whether or not Band Stop filters are required and how much rejection is needed.

As previously mentioned, measurements should always be performed to validate electromagnetic models. Performing antenna to antenna isolation measurements will not only validate models, it will identify increased sidelobes that may arise as a result of platform installation effects that are too difficult to model. Performing antenna isolation measurements can also assist in locating antennas so that maximum isolation is achieved.

Figure 6: Military Platform Antenna Example

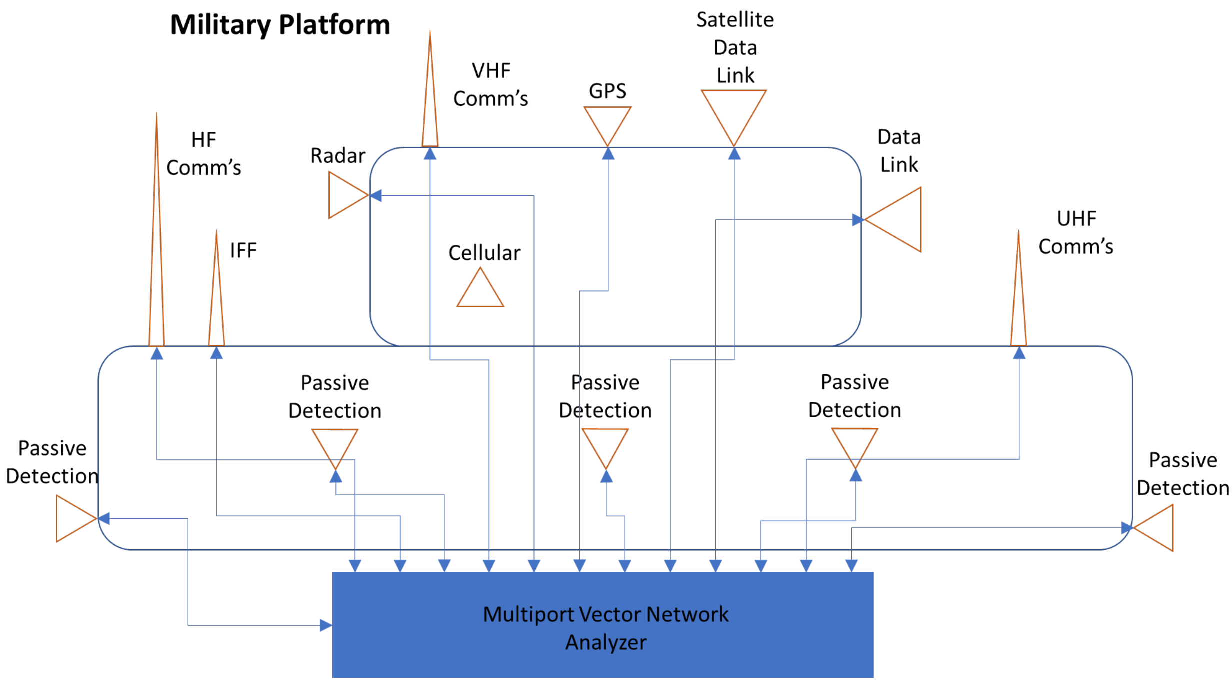

Figure 7: Military Platform Antenna Isolation Measurements

5.1 Military Fighter Jet

Figure 8 shows the variety of antennas that may be located on a Military Fighter Jet. The antennas may be omnidirectional or directional depending on the system. TACAN, IFF and Communications antennas may be omnidirectional while Data Link, GPS and Radar may be directional to varying degrees. Radar Warning Receiver antennas can be semi-directional and can be susceptible to in band frequencies from other on wing systems. Even signal levels from omnidirectional communications antennas can interfere with receivers that are “listening” for low level radar signals.

High Gain Radar antennas that are in the nose of an aircraft typically have back lobes, and some power radiates behind them. These signals may interfere with any of the other wireless systems on board, and performing antenna to antenna isolation measurements as illustrated in Figure 9 is an excellent component in the Cosite Interference Mitigation Plan. Knowing antenna to antenna isolation measurements not only validate electromagnetic models, but it also provides actual data that helps determine filtering requirements. Antenna to antenna isolation measurements can also help determine the location of high-power Radar and Communication Jammer antennas.

Figure 8: Military Fighter Jet Antenna Example

Figure 9 shows what a full antenna to antenna isolation measurement may look like on a fighter jet using a multiport Rohde and Schwarz ZNBT VNA. Due to the very dense antenna population, the probability that systems interfere with one another is very high. Knowing the antenna to antenna isolation can help prevent damage to sensitive and costly receivers from high power sources. Knowing the antenna to antenna isolation is useful when specifying Band Stop filter requirements.

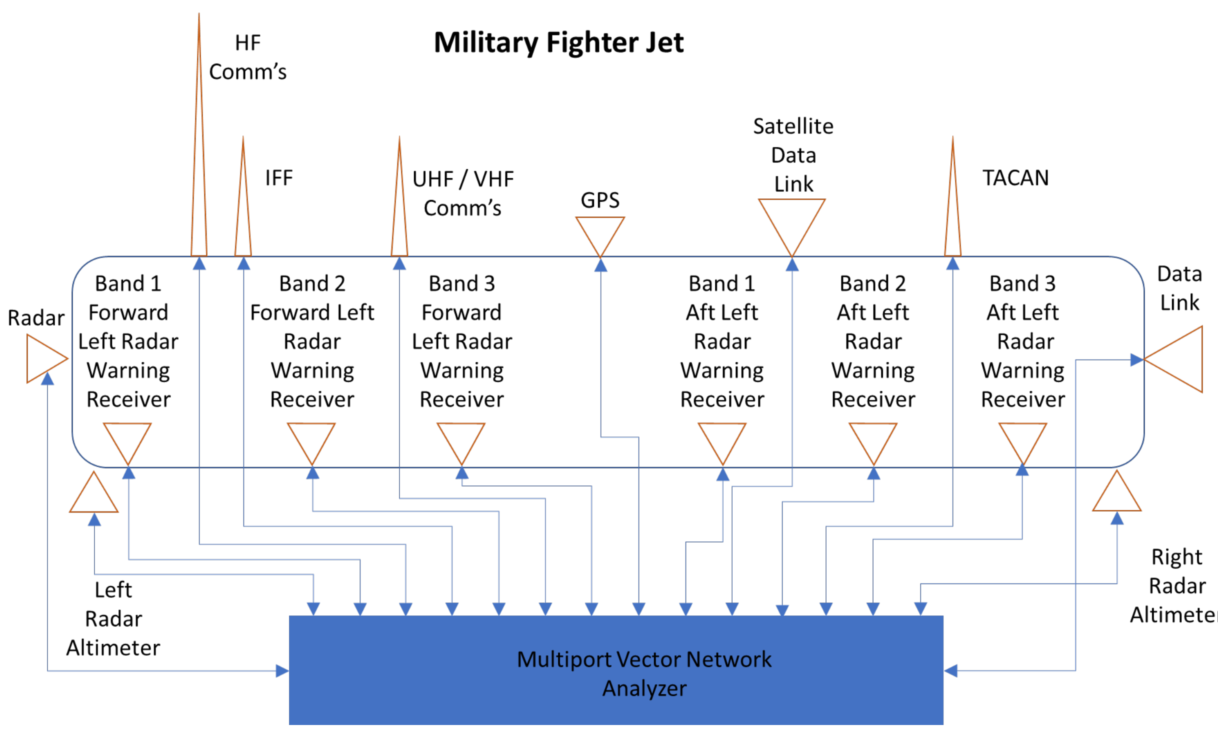

Figure 9: Military Fighter Jet Antenna Isolation Measurement

5.2 Navy Ship Mast

Navy Ship Masts typically have multiple high-power radars that serve different functions. There may be Surface Search Radar, Navigation Radar, Long Range Air Search Radar, Surface Search / Fire Control Radar, and Missile Fire Control Radar. There may also be HF/ UHF / VHF Communications antennas, Data Link antennas, Satellite Data Link antennas, GPS antennas, Passive Detection (e.g. “listening”) antennas and more. While there can be 10’s of meters of physical separation between antennas, Radar antennas may transmit 10’s or 100’s of Megawatts. When this much power is transmitted from a 20 dBi to 40 dBi high gain antenna, physical separation distances of 100 meters may not be enough to prevent these systems from interfering with sensitive receivers. Figure 10 shows what a Navy Ship Mast may look like and the diversity of antennas that may be present.

Many of the receivers may be designed to detect very small signals, while many of the transmitters need to transmit significant amounts of power. Ensuring Interoperability and preventing Cosite Interference can be an incredibly difficult challenge. The remedies and solutions come with engineering and security tradeoffs. For example, if a Radar interferes with a Radar Warning Receiver (RWR) for 1 second it may seem obvious to turn the RWR off for that 1 second timeframe. The drawback is that RWR is not listening during that 1 second duration and it might not detect a small signal of interest. While Band Stop Filters may also seem like a viable solution, the will likely have loss in their passbands, in addition to creating a notch in the passband of the RWR. The increased loss in their passband will increase the Receiver Noise Figure. This increased Receiver Noise Figure results in less sensitivity and a reduced detection range.

Measuring the antenna to antenna isolation is an important first step to determine minimum filter attenuation requirements. While these measurements may be challenging, they will provide engineers with absolute antenna to antenna isolation data. Figure 11 shows what a Navy Ship Mast antenna to antenna isolation measurement may look like. Figure 12 shows what the same Navy Ship Mast antenna to antenna isolation measurement may look like with inline amplifiers to overcome the losses in long runs of coaxial cable. Using a single VNA to perform this kind of measurement will require long runs of coaxial cable, and cable losses on the order of 35 dB / 100’ can be expected at 5 GHz. Inline amplifiers may be necessary to overcome the cable and path losses and accurately measure the isolation. Extreme care should be taken when using amplifiers in VNA test setups to avoid overdriving and damaging the VNA receiver.

Figure 10: Navy Ship Mast Antenna Example

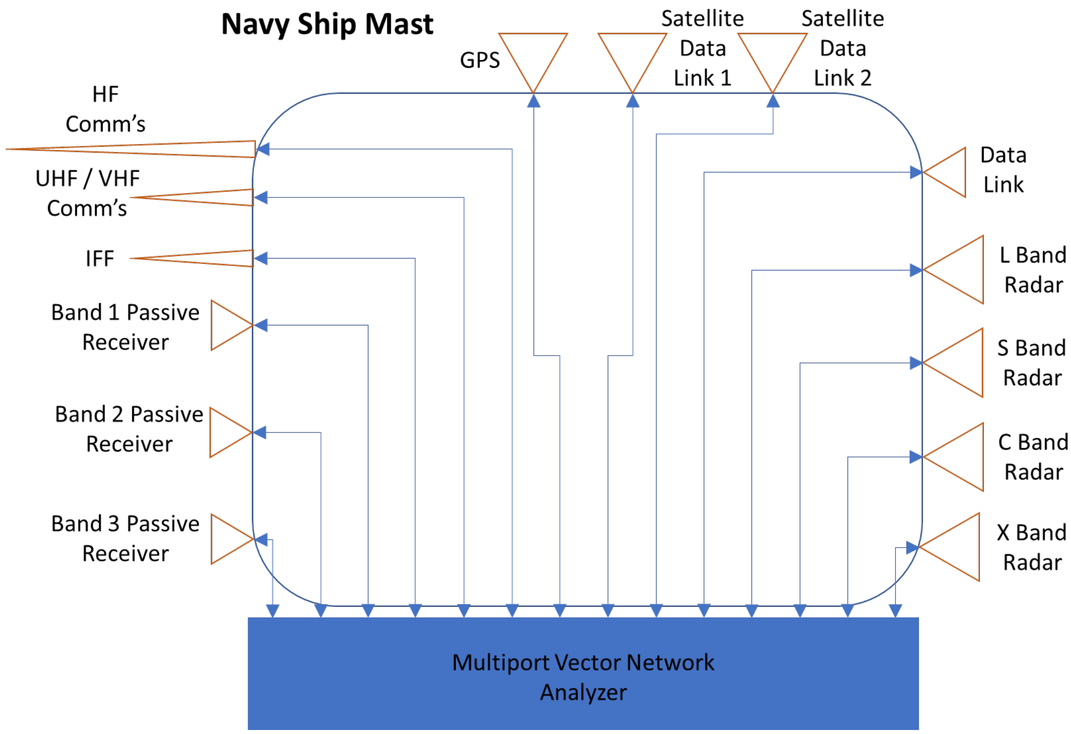

Figure 11: Navy Ship Mast Antenna Isolation Measurements

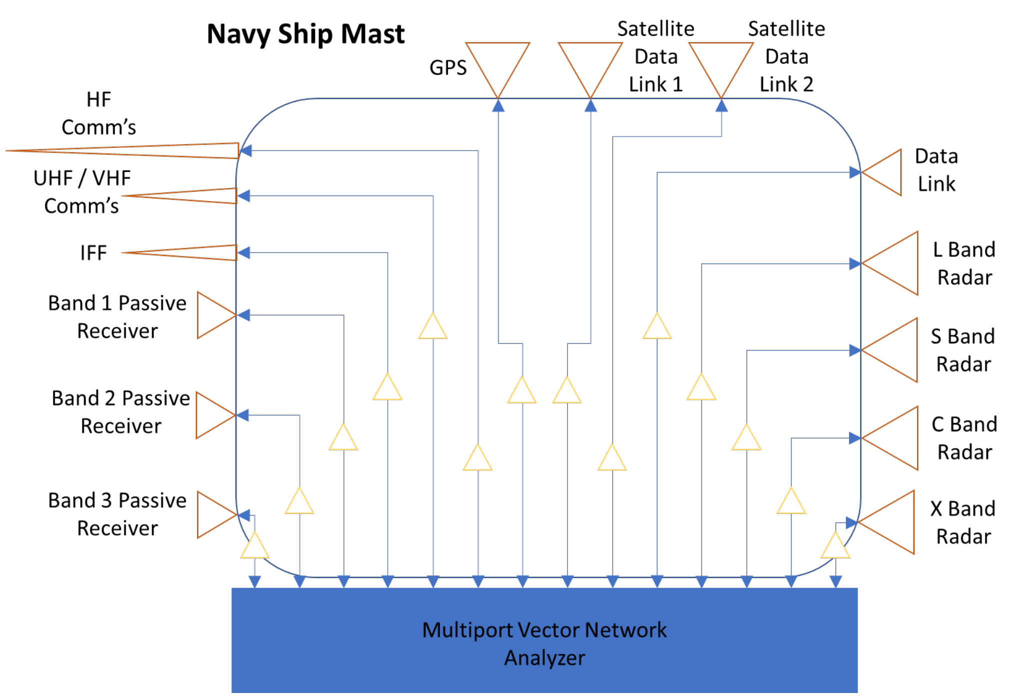

Figure 12: Navy Ship Mast Antenna Isolation Measurements with Amplifiers

6 Commercial Aviation

Commercial Aviation has grown significantly in recent decades and many modern wireless conveniences have been added to modern day jumbo jets. Figure 13 shows the diversity of wireless systems that may be present on a modern day commercial aviation jumbo jet. While antenna separation distances can be as long as 200’ or more, systems may still need to operate simultaneously and not interfere with one another. Figure 13 does not show the wireless systems that the passengers may have on board the aircraft.

These systems may be grouped together on various locations of the platform, and Figure 14 shows what a localized antenna to antenna isolation measurement may look like. For example, engineers may be interested in knowing the antenna to antenna isolation between the Terminal Wireless Local Area Network (LAN) Unit (TWLU), the Air Traffic Control / Traffic Collision Avoidance System (ATC / TCAS), Global Positioning system (GPS), VHF L and Terminal Cellular System (TCS) antennas. Since these antennas are in somewhat close proximity to one another and may be reasonably accessible, determining the isolation between them may be reasonable.

Figure 15 shows what a full antenna to antenna isolation measurement may look like on a modern day commercial jumbo jet. Cable losses on the order of 20 dB / 100’ are likely at 1 GHz and inline amplifiers may be necessary to overcome cable and path loss. Overcoming these losses will likely be necessary to accurately measure the isolation between antenna elements. As previously stated, extreme care should be exercised when using amplifiers in VNA test setups to avoid overdriving and damaging the VNA receiver.

Figure 13: Commercial Jumbo Jet Antenna Example

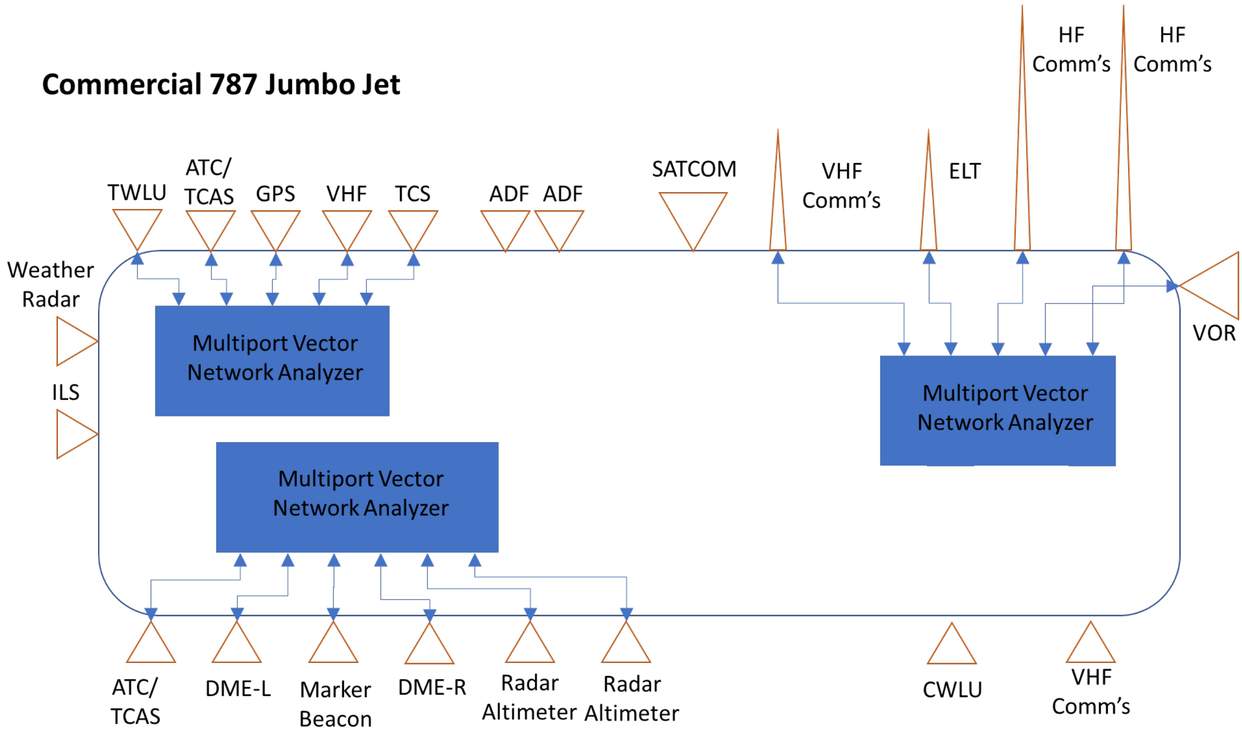

Figure 14: Localized Commercial Jumbo Jet Antenna Isolation Measurements

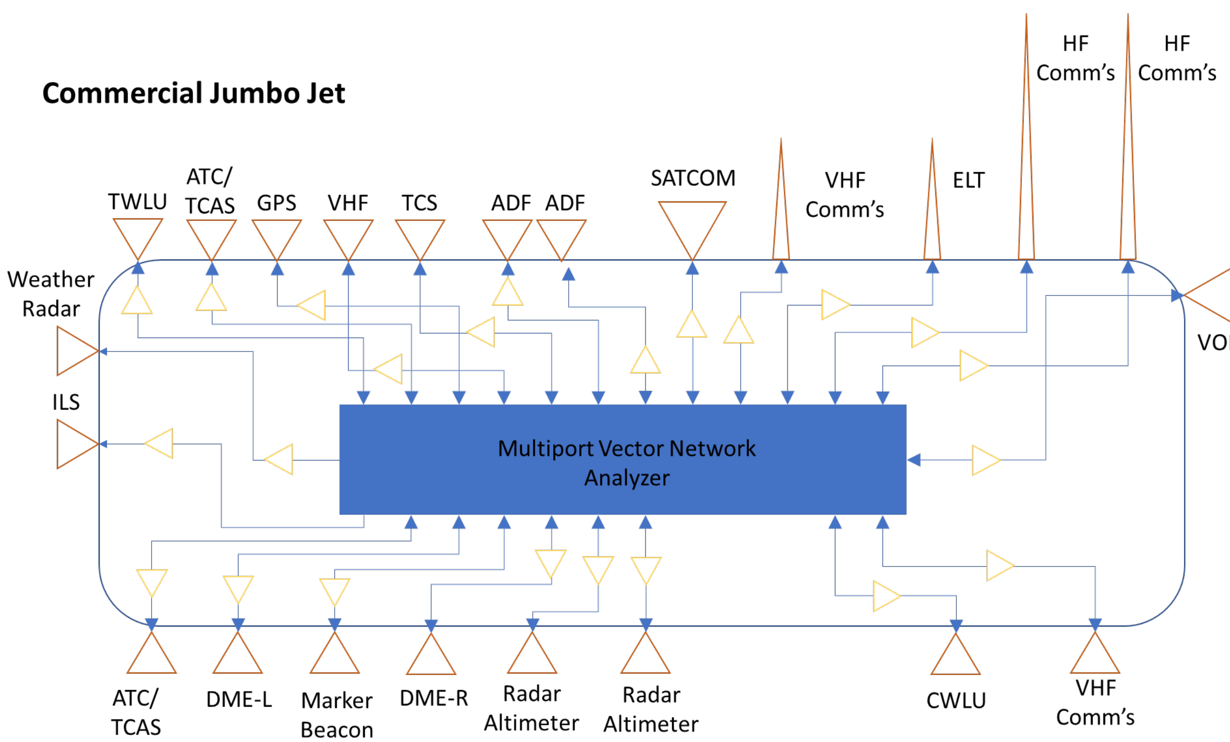

Figure 15: Commercial Jumbo Jet Antenna Isolation Measurements with Switching Amplifiers

7 Reduction in Test Time

Figure 16 shows the test setup combinations for measuring the isolation between 8 antennas using a 2 port VNA, while Figure 17 shows the test setup using an 8 port VNA. A significant reduction in test time can be achieved on an 8 antenna to antenna measurement by migrating from a 2-port measurement system to an 8-port measurement system. Measuring the isolation between 8 separate antennas with a 2 port VNA can require 28 test setups to fully evaluate all of the combinations of antenna to antenna isolation as Illustrated in Figure 16. Using an 8 port VNA reduces these 28 test setups to 1 test setup as illustrated in Figure 17 and significant test time savings can be achieved.

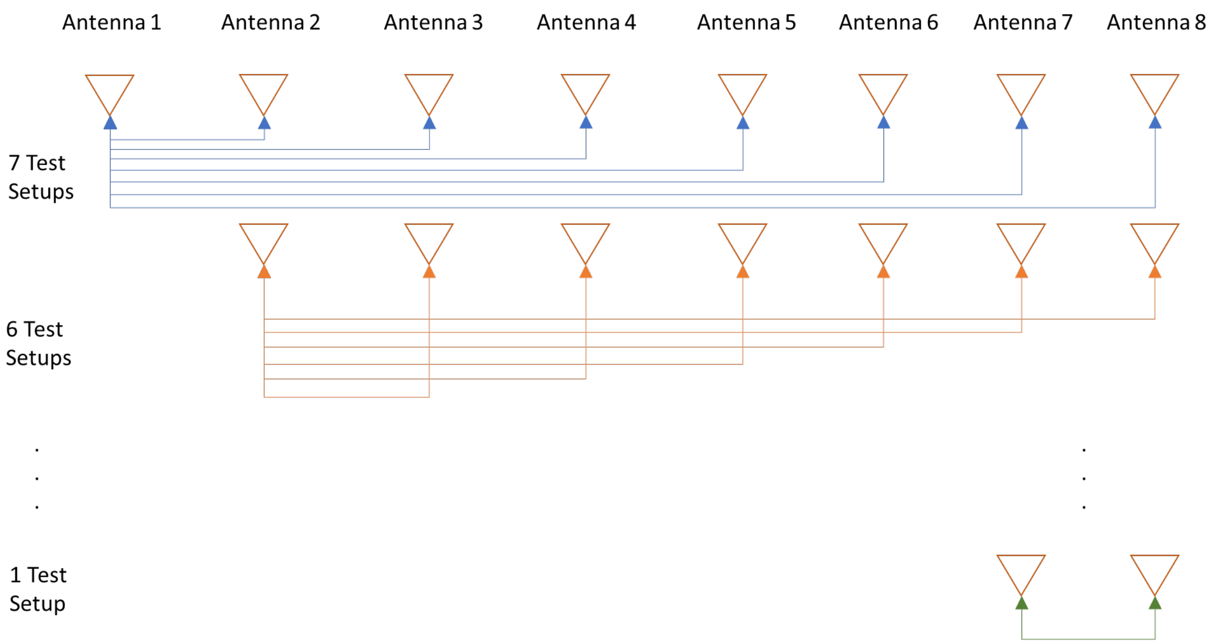

Figure 16: Basic Test Setups for 8 Separate Antennas

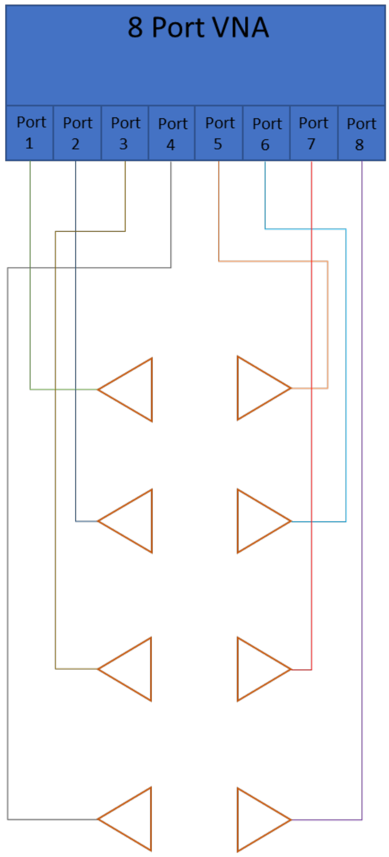

Figure 17: 8 Port VNA Test Setup on 8 Antennas

Figure 18 shows the Scattering Matrix for an 8 Port VNA. Using Figure 17 as a visual reference, we can see that S21 will evaluate the transmission from antenna 1 to antenna 2, while S12 will evaluate the transmission from antenna 2 to antenna 1. Reciprocity should be true for a Linear Time Invariant Passive Network, and one S Parameter can verify the other.

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & \cdots & S_{18} \\ S_{21} & & & & \\ S_{31} & & & & \vdots \\ \vdots & & & & \\ S_{81} & & \cdots & & S_{88} \end{bmatrix}$$

Figure 18: Scattering Matrix for an 8 Port VNA

When migrating from 28 test setups to 1 test setup, significant time savings can be achieved. This can also reduce the number of mating cycles of the test cables and increase their life expectancy, thus decreasing the probability of damage to them. Similarly, this can reduce the number of mating cycles to the Antennas and decrease the probability of damage to it. Engineers and technicians are encouraged to evaluate their situation and come to their own conclusion by performing evaluations with VNA demonstration units. Rohde and Schwarz ZNBT Vector Network Analyzers are available for demonstration purposes and our applications engineers can assist in performing evaluations. Please contact Rohde and Schwarz to schedule a free demonstration today.

An increase in the life of a test cable occurs when migrating from a 2 port VNA to an 8 port VNA. This occurs because the test cable connectors have a finite number of mating cycles. A connector pair mating cycle is defined as each time the cable connectors are connected to a test setup and disconnected. When testing 8 antennas with a 2 port VNA, there are 28 test setups there are many mating cycles. When testing 8 antennas with an 8 port VNA, there is 1 test setup there is one mating cycle. Reducing the number of mating cycles will increase the life of the test cables and the antenna.

Decreasing the number of mating cycles decreases the probability of damage to a test cable and an antenna. When a test cable or antenna connector is worn out or damaged failures can be intermittent. When intermittent connections occur one test can fail and the very next test can pass, making intermittent issues very difficult to diagnose. Replacing worn out test cables is used as preventive maintenance to prevent issues. Migrating to an 8 port VNA from a 2 port VNA can decrease the frequency of preventive maintenance.

8 Multiport VNAs from Rohde & Schwarz

The R&S®ZNBT is the first multiport vector network analyzer offering up to 24 integrated test ports. The instrument can simultaneously test multiple DUTs or measure one DUT with up to 24 ports. It offers short measurement times even in scenarios with a large number of ports. In addition, it includes a wide dynamic range, high output power levels and inputs featuring high power-handling capacity.

The instrument is available in two different frequency ranges:

► The R&S®ZNBT8 operates in a range from 9 kHz to 8.5 GHz

► The R&S®ZNBT20, R&S®ZNBT26 and R&S®ZNBT40 operates from 100 kHz to 20 GHz, 26.5 GHz and 40 GHz, respectively.

These features make the R&S®ZNBT ideal for applications in the mobile radio, wireless communications and antenna test. The instrument is primarily used in the development and production of active and passive multiport components such as GPS, WLAN, Bluetooth® and frontend modules for multiband mobile phones. Its outstanding performance also allows efficient analysis of base station filters and other highly selective components.

The R&S®ZNBT outperforms switch matrix based multiport systems. Its high integration density makes it a very compact solution for analyzing components with up to 24 ports while requiring no more rack space than an R&S®ZNB.

The convenient user interface makes it easy to handle even very complex multiport measurements. The R&S®ZNBT supports various remote control options and is easy to integrate into automated test systems, for example for carrying out phased-array antenna measurements. A 24 Port R&S®ZNBT Vector Network Analyzer is illustrated in Figure 19.

Figure19: Rohde and Schwarz 24-Port ZNBT Vector Network Analyzer

The following are the features and benefits of an R&S®ZNBT Vector Network Analyzer.

- ► Platform for challenging multiport measurements
  - – True multiport network analyzer
  - – Multiport measurements made easy
  - – Measurements at high power levels
- ► When speed counts
  - – Short test times with a large number of ports
  - – Data transfer simultaneously with sweep
  - – Fast switchover between instrument setups
  - – Test sequence control via TTL signals
  - – Handler I/O interface for control of external parts handlers
  - – Simultaneous testing of multiple DUTs
  - – Segmented sweep for optimized speed and accuracy
  - – Extended dynamic range for fast measurements on high-blocking filters
- ► Excellent measurement characteristics
  - – Fast and accurate
  - – High long-term stability for long calibration intervals
  - – Calibration methods for every application
  - – Calibration units speed up multiport calibrations
- ► Complex analysis of active and passive components
  - – More than 100 traces and channels for characterizing complex components
  - – Wide range of virtual matching networks for realtime embedding/deembedding
  - – Frequency-converting measurements on amplifiers and mixers
  - – Simple and fast characterization of balanced DUTs

– Time domain analysis with gating function and display of eye diagrams
– Voltage and current measurements
– Measurements on frontend modules (FEMs)

While it is possible to analyze electrical lengths and errors and speculate on the outcome, the best way to evaluate an outcome is by conducting an actual test. Engineers and technicians are encouraged to evaluate their situation and come to their own conclusion by performing evaluations with VNA demonstration units. The best way to evaluate if a high-performance Rohde and Schwarz ZNBT VNA can help reduce product failure rates and test times is by performing an in-house evaluation. Rohde and Schwarz ZNBT Vector Network Analyzers are available for demonstration purposes and our application engineers can assist in performing evaluations. Please contact Rohde and Schwarz to schedule a free in-house demonstration today.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

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Data without tolerance limits is not binding | Subject to change