Infinimode Systems Inc. InfiniMUX G4 Technical Evaluation

The Office for Interoperability and Compatibility
Department of Homeland Security

Homeland Security

Test Procedures and Results

TE-08-0002
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Homeland Security

Science and Technology

Command, Control and Interoperability: Communication, Interoperability and Compatibility

Defining the Problem

Emergency responders—police officers, fire personnel, emergency medical services—need to share vital voice and data information across disciplines and jurisdictions to successfully respond to day-to-day incidents and large-scale emergencies. Unfortunately, for decades, inadequate and unreliable communications have compromised their ability to perform mission-critical duties. Responders often have difficulty communicating when adjacent agencies are assigned to different radio bands, use incompatible proprietary systems and infrastructure, and lack adequate standard operating procedures and effective multi-jurisdictional, multi-disciplinary governance structures.

OIC Background

The Department of Homeland Security (DHS) established the Office for Interoperability and Compatibility (OIC) in 2004 to strengthen and integrate interoperability and compatibility efforts to improve local, tribal, state, and Federal emergency response and preparedness. Managed by the Science and Technology Directorate, and housed within the Communication, Interoperability and Compatibility thrust area, OIC helps coordinate interoperability efforts across DHS. OIC programs and initiatives address critical interoperability and compatibility issues. Priority areas include communications, equipment, and training.

OIC Programs

OIC programs, which are the majority of Communication, Interoperability and Compatibility programs, address both voice and data interoperability. OIC is creating the capacity for increased levels of interoperability by developing tools, best practices, technologies, and methodologies that emergency response agencies can immediately put into effect. OIC is also improving incident response and recovery by developing tools, technologies, and messaging standards that help emergency responders manage incidents and exchange information in real time.

Practitioner-Driven Approach

OIC is committed to working in partnership with local, tribal, state, and Federal officials to serve critical emergency response needs. OIC's programs are unique in that they advocate a "bottom-up" approach. OIC's practitioner-driven governance structure gains from the valuable input of the emergency response community and from local, tribal, state, and Federal policy makers and leaders.

Long-Term Goals

- Strengthen and integrate homeland security activities related to research and development, testing and evaluation, standards, technical assistance, training, and grant funding.
- Provide a single resource for information about and assistance with voice and data interoperability and compatibility issues.
- Reduce unnecessary duplication in emergency response programs and unneeded spending on interoperability issues.
- Identify and promote interoperability and compatibility best practices in the emergency response arena.

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Department of Homeland Security (DHS)

Science and Technology Directorate (S&T)

Office for Interoperability and Compatibility (OIC)

TECHNOLOGY EVALUATION PROJECT

Technical Evaluation of the InfiniMUX G4

Manufactured by Infinimode Systems, Inc.

Test Procedures and Results

Document No. TE-08-0002

January 2008

Prepared by

National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES) via

National Telecommunications and Information Administration (NTIA)/Institute for Telecommunication Sciences (ITS)

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Homeland Security

Publication Notice

Abstract

This report describes the test procedures and results of the product evaluation for the InfiniMUX G4. The InfiniMUX G4 is an audio gateway device manufactured by Infinimode Systems Inc. An audio gateway device (also called an audio matrix or a cross-band switch) links disparate radio systems to support communications interoperability between dissimilar wireless systems. Such a device simply passes baseband (audio) signals from the receiver portion of one radio to the transmitter portion of a dissimilar radio system.

Disclaimer

The U.S. Department of Homeland Security's Science and Technology Directorate serves as the primary research and development arm of the Department, using our Nation's scientific and technological resources to provide local, state, and Federal officials with the technology and capabilities to protect the homeland. Managed by the Science and Technology Directorate, the Office for Interoperability and Compatibility (OIC) is assisting in the coordination of interoperability efforts across the Nation.

Certain commercial equipment, materials, and software are sometimes identified to specify technical aspects of the reported procedures and results. In no case does such identification imply recommendations or endorsement by the U.S. Government, its departments, or its agencies; nor does it imply that the equipment, materials, and software identified are the best available for this purpose.

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Table of Contents

List of Figures

List of Tables

Executive Summary

Working on behalf of the National Institute of Standards and Technology (NIST)/Office of Law Enforcement Standards (OLES), the National Telecommunications and Information Administration's Institute for Telecommunication Sciences (ITS) conducted a series of tests to evaluate the functionality of the InfiniMUX G4 interoperability communications controller. The InfiniMUX G4 is manufactured by Infinimode Systems Inc (http://www.infinimode.com). It is part of a collection of bridge, or audio gateway, technology products offered by various manufacturers.

An audio gateway device (also called an audio matrix or a cross-band switch) links disparate radio systems to support communications interoperability between dissimilar wireless systems. Such a device simply passes baseband (audio) signals from the receiver portion of one radio to the transmitter portion of a dissimilar radio system.

The InfiniMUX G4 enables interoperability between wireless and wireline communication systems by multiplexing audio input signals to the audio input ports of several radios. The InfiniMUX G4 serves to connect radios that operate within different radio frequency (RF) bands and that use analog or digital modulation. This is accomplished by fanning out a single audio input source to multiple radio audio inputs.

The InfiniMUX G4 is designed to enable one user to simultaneously broadcast to 12 radios, four phone lines, and two direct audio channels, each of which can be programmed for one of eight available talk groups, referred to in the InfiniMUX G4 user's manual as net 1 through net 8. There is a minimum of two radios per net.

To exercise the functionality of the InfiniMUX G4, ITS developed a series of focused test procedures to evaluate:

- Balanced Input Audio Impedance
- Balanced Output Audio Impedance
- Input Audio Level
- Output Audio Level
- Audio Frequency Response
- VOX[1] Input Threshold
- VOX Attack Time and Throughput Delay
- Audio Distortion – Signal + Noise + Distortion to Noise + Distortion (SINAD) and Total Harmonic Distortion plus Noise (THD+N)
- Crosstalk

In general, the InfiniMUX G4 performed as specified, as the test results in this report demonstrate. This report notes areas of small concern. A small potential exists for interference from RF emissions from the InfiniMUX G4 in the very high frequency (VHF) public safety band. If a VHF receiver is near the InfiniMUX G4, RF emissions can affect the VHF receiver even when no transmission is active through the InfiniMUX G4. Also, the AC power supply provided with the InfiniMUX G4 introduced audibly discernable noise into the communications path. These interference and noise issues have been reported to the manufacturer for consideration.

[1] VOX means voice operated transmit.

The InfiniMUX G4 comes with software, which requires a computer for configuration. The manufacturer was very responsive to the one hardware failure during testing. The manufacturer shipped overnight a replacement part to enable the testing to continue virtually uninterrupted.

Document Scope and Intended Audience

This report presents the procedures employed in the technical evaluation testing for the InfiniMUX G4, and also summarizes the results. The InfiniMUX G4 falls under the category of cross-band technology devices that public safety organizations may use to perform wireless communications interoperability between dissimilar wireless systems. By necessity, this document is quite technical in nature.

1 Introduction

Public safety operations require effective command, control, coordination, communication, and sharing of information with numerous criminal justice and public safety agencies. Thousands of incidents that require mutual aid and coordinated response happen every day. High-profile incidents, such as bombings or plane crashes, test the ability of public safety service organizations to mount well-coordinated responses. In an era where technology can bring news, current events, and entertainment to the farthest reaches of the world, many police officers, firefighters, and emergency medical service (EMS) personnel cannot communicate with each other during major emergencies, as evidenced by September 11, 2001, and Hurricanes Katrina and Rita, or even during routine traffic accidents or fire operations.

1.1 Bridging Communications Gaps

There are more than 18,000 state and local law enforcement agencies in the United States. Approximately 95 percent of these agencies employ fewer than 100 sworn officers. Additionally, more than 32,000 fire and EMS agencies exist across the Nation. Due to the fragmented nature of this community, many public safety communications systems are stovepiped, i.e., individual systems do not communicate with one another or help bring about interoperability. Just as the public safety community is fragmented, so is radio spectrum. Public safety radio frequencies are distributed across isolated frequency bands, from very high frequency (VHF) (25 to 50 megahertz (MHz)) to 800 MHz (806 to 869 MHz), and now 4.9 gigahertz (GHz).

The convergence of information and communication technologies requires a coordinated approach to bridge the gaps in interoperability. By focusing on enabling technologies and open standards for interoperability, the Department of Homeland Security's (DHS) Office for Interoperability and Compatibility (OIC) Technology Evaluation Project provides this needed link.

1.2 The OIC Technology Evaluation Project

The OIC Technology Evaluation Project is focused on assessing the applicability of currently available and evolving products and services to the interoperability requirements of users in public safety agencies. To accomplish this, products and services are evaluated to determine if they are both cost-efficient and effective for users. They also are evaluated consistent with the tenets of the long-term standardization approach developed by OIC for nationwide interoperability.

Evaluation comprises classic techniques, including observation, analysis, demonstration, and testing. In many cases, products or services may be comprehensively evaluated within an independent laboratory or other closed environment. For other products or services, however, a more extensive approach may be necessary to determine the ramifications of placing those products or services in an agency conducting actual job functions. To help with the demonstrations and testing of selected products or services of this type, operational test beds (OTBs) may be established. This aim is to assess the operational impacts of technologies that assist interoperability. In addition, focused “pilot projects” are also used to evaluate solutions to specific operational requirements.

While evaluation processes conducted at independent laboratories may take weeks to complete (for example, 4 to 8 weeks), evaluations within the OTB may take months (for example, 6 to 12 months). This is because such evaluations carefully characterize the impact of the new product or service on existing operations. In addition, they project how future operations may change with a permanent application of the technology.

2 Background

A fundamental interoperability challenge today is wireless voice communications among agencies that have different radio systems operating on various radio frequencies. OIC will ultimately address this issue through promotion of interoperability standards, including standardized methods of bridging between systems operating in different frequency bands.

While interoperability standards are being developed, however, other mechanisms are needed to address interoperability requirements. One such mechanism is the audio gateway device (also called an audio matrix or a cross-band switch) that links disparate radio systems. Not unlike a dispatcher’s patch panel, such a device simply passes base band (audio) signals from the receiver portion of one radio to the transmitter portion of a dissimilar radio system. For example, audio from the receiver function of a very high frequency (VHF) transceiver is passed to the transmitter circuitry of an ultra high frequency (UHF) transceiver.

2.1 Audio Gateway Advantages

An audio gateway has several advantages over the dispatcher’s patch panel. One big advantage is that an audio gateway requires no manual intervention once it is configured. The device automatically routes voice calls from one radio system to another via control signals (e.g., dual-tone multi-frequency (DTMF) signals) that are input by a radio user. Audio gateways also support connections between radios, telephone lines, and cellular phones. In addition, an audio gateway offers mobile versatility over dispatchers’ patch panels. For example, an audio gateway can be configured for use in a van or sport utility vehicle (SUV), and so become part of an incident commander’s command post. This way, the audio gateway becomes a mobile repeater, allowing the disparate radio systems to communicate in a wide geographical radius around the incident.[2]

2.2 Overview of the Infinimode Systems InfiniMUX G4

The Infinimode Systems InfiniMUX G4 is an audio gateway device. It is designed to enable interoperability between wireless and wireline communication systems by multiplexing audio

[2] The ability to configure and operate an audio gateway device in the field is a powerful feature. However, proper training is crucial to operating an audio gateway. Field personnel not properly trained in the technical operation of the device, or with relevant agency policies, may go on to create connections that cause unforeseen problems. It is incumbent on the operating agency to ensure appropriate policies and procedures for the use of any audio gateway device in its possession.

input signals to the audio input ports of several radios. The InfiniMUX G4 serves to connect radios that operate within different radio frequency (RF) bands and that use analog or digital modulation. This is accomplished by fanning out a single audio input source (for example, a radio) to multiple radio audio inputs.

One user can simultaneously broadcast on several radios using the InfiniMUX G4. It can connect to a total of 12 land mobile radios (LMRs), four phone lines, and two direct audio channels, each of which potentially can be programmed into any of eight available talk groups. The InfiniMUX G4 user's manual refers to talk groups as net 1 through net 8. Note there is a minimum of two radios per net.

Figure 1 shows the grab-handled four-module chassis of the portable InfiniMUX G4. It supports:

- Up to 18 channels. A larger seven-module chassis (without grab-handle) supporting 28 channels is also available.
- PC audio input/output (I/O)
- Line I/O
- Two local microphone ports
- An Ethernet port
- RS-232 port
- Optional quad port radio module
- Optional dual and quad, public, switched telephone network (PSTN) module
- Optional 8 in (8DI) and 8 out (8DO) modules
- Optional input/output module
- Optional DC power input module
- Optional mixed I/O module
- Eight software-selectable talk-groups capable of supporting cross-band communications between 28 channels

Figure 1: InfiniMUX G4

The grab-handled InfiniMUX G4, which was the device tested, is metal with metal face plates. Configuration of the device is primarily conducted through a computer connected via an Ethernet or RS-232 serial line. Software is provided to perform device programming; however, a computer is not provided. A handset is provided with the InfiniMUX G4, as is a latching cradle for when the handset is not in use.

For all tests, setup and operation of the unit were conducted according to manufacturer documentation. This report refers to the Revision 1, May 2005 version of the *InfiniMUX G4 Communications Controller – Configuration and Operations Guide* as "the InfiniMUX G4 user's manual." The unit was conformance-tested in accord with vendor-supplied product specifications, detailed on the Infinimode Systems Inc. Web site (http://www.infinimode.com).

3 General Evaluation Approach – Laboratory Testing

The first phase of evaluation involves laboratory testing and analysis. The aim is to answer two basic questions:

- Does the product operate and perform "as advertised," and successfully address the interoperability problems that it was designed to confront?
- Did issues arise during the testing that might affect the use of the product for the purposes advertised?

ITS conducted a series of tests to confirm that the device operates in conformance with published specifications. In addition, ancillary tests, of significant interest to the users and agencies in general, were performed to provide a means to benchmark or compare this device to others in its class.

The next sections outline the types of tests and analysis performed. Section 4 lists detailed test and analysis procedures for the InfiniMUX G4.

3.1 Specifications Testing

Specifications testing determines how well the unit performs relative to the manufacturer's specifications. This report evaluates the following InfiniMUX G4 specification parameters:

- Input Audio Impedance
- Output Audio Impedance
- Input Audio Level
- Output Audio Level
- Audio Distortion
- Audio Frequency Response

3.2 Performance Testing

Performance testing quantifies the performance of the InfiniMUX G4 gateway device by evaluating the degradation, if any, it inflicts on end-to-end (radio system-to-radio system) operation. Although not specified by the manufacturer, the following performance parameters were considered important for this evaluation and were assessed:

- VOX input threshold
- VOX attack time and throughput delay
- Crosstalk

3.3 Observations

Section 4.3 describes significant observations concerning:

- RF emissions
- Power supply noise
- Use of setup and control software on computer
- Manufacturer responsiveness

4 InfiniMUX G4 Evaluation

The InfiniMUX G4 is physically configured by inserting communications modules (cards) into slots in the chassis. Each module contains either 4 LMR ports, four telephone ports, or four microphone ports that connect the radio port cables to the InfiniMUX G4 via audio jacks.

Ports are designated by a two-digit number such as, port 24. Consider port 24 as an example where the first digit of the port number, *2* in this case, indicates the chassis slot in which the communications module is inserted, and the second digit indicates the port within the module that is being identified. In the port 24 example, the digits indicate that the communications module is in slot 2 of the chassis and the port identified on the module is port 4. The tested version of the InfiniMUX G4 had 12 ports, numbered 11 to 14, 21 to 24, and 31 to 34.[3]

The InfiniMUX G4 accepts both audio input and output (I/O) signals at its interface ports. Figure 2 shows how connections to the audio input and output signals at these radio ports were made using audio I/O cables. ITS engineers custom-made the cables that mate with the quad radio module, PSTN module, and microphone ports. Each cable provides the connections to InfiniMUX G4's interface ports using a pigtail with XLR connectors on each end: one for audio input and one for audio output. Connector pin-out information can be found in the InfiniMUX G4 user's manual.

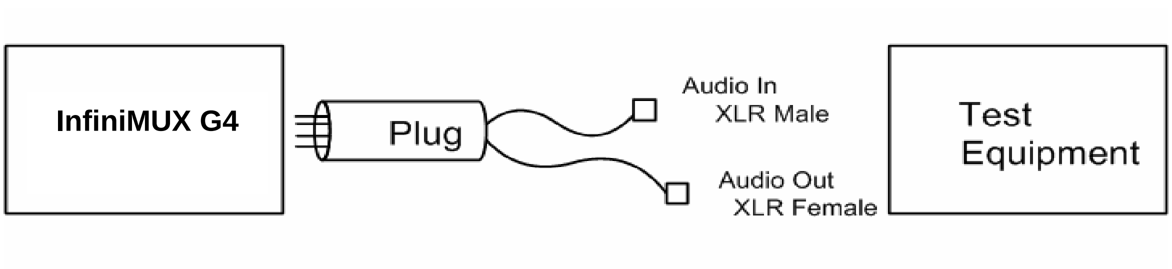

Figure 2: Audio I/O Cable

The following test equipment was used to conduct these tests:

- Tektronix TDS 3012B Digital Phosphor Oscilloscope
- Audio Precision ATS-1 Dual Domain Audio Test System Audio Analyzer
- IET Labs Precision Resistance Substituter (model number RS-201)

[3] The *Plus* version of the InfiniMUX G4 is capable of 12 channels because it can be configured with the maximum of 3 quad radio modules. The standard version InfiniMUX G4 is only capable of 8 channels from a maximum of 2 quad radio modules. The standard version InfiniMUX G4 can be upgraded to the *Plus* version by firmware.

- Agilent E4443A PSA Series Spectrum Analyzer

In this report, the Tektronix TDS 3012B Digital Phosphor Oscilloscope is referred to as *DPO*. The Audio Precision ATS-1 Dual Domain Audio Test System Audio Analyzer is referred to as *ATS*.

The power supply provided by the manufacturer introduced 60 Hz noise into the device sufficient to interfere with the measurements. As a consequence, the measurements described here were conducted using a laboratory grade power supply.[4]

4.1 Conformance to Manufacturer's Specifications

The following tests measure the InfiniMUX G4's quad radio module conformance to published specifications, and summarize the results obtained. Each test comprises the following components:

- Datasheet Specification
- Test Procedures
- Test Case Results and Summary

4.1.1 Input Audio Impedance

Impedance refers to the amount of resistance to an electrical current. Input impedance provides information on the types of electrical signals that can be input into the device. If this parameter is out of specification, potential effects include increased noise in the audio signal.

Datasheet Specification

- Software adjustable, balanced or unbalanced: 0 to 10,000 ohms

Test Procedures

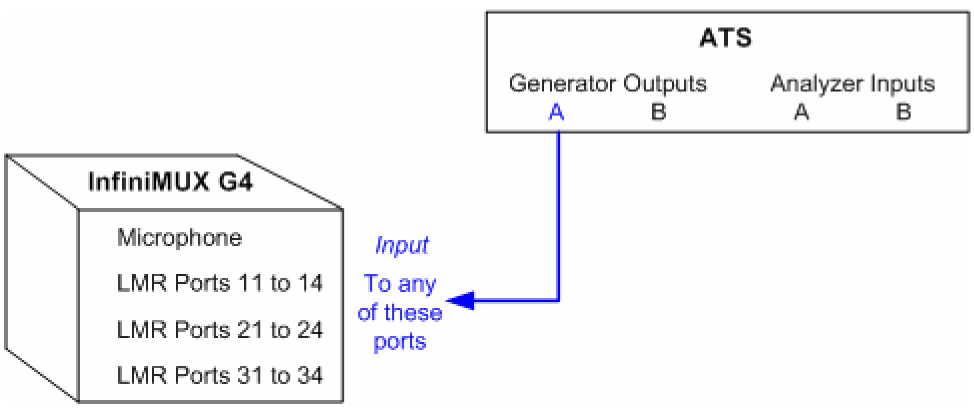

Figure 3: Balanced Input Audio Impedance

1. For each radio port, connect the InfiniMUX G4 audio input to the Generator Output A port of the ATS.
2. Configure a 1 kilohertz (kHz) sine wave as the input signal to the InfiniMUX G4 from the Generator Output A port of the ATS.

[4] The laboratory grade power supply was a Harrison Laboratories Model 800A-2 DC power supply.

3. From the front panel of the ATS, select the Gen Load softkey. This will automatically measure the input impedance of the radio port being tested.
4. Record the input impedance measurement from the front panel display of the ATS.

Test Case Results and Summary

Table 1: Input Impedance, Software Set to 10,000 ohms

Radio Port	Measured Impedance (ohms)
11	3670
12	3740
13	3680
14	3450
21	3540
22	3600
23	3760
24	3590

Table 2: InfiniMUX G4's Radio Module Port Input Impedance

Input Impedance (ohms)	Measured Impedance (ohms)
0	218
100	218
200	218
300	218
400	555
500	555
600	555
700	555
800	850
900	850
1000	850
1100	852
1200	1100
1300	1100
1600	1350
1960	1350
1970	1570
2000	1560

Input Impedance (ohms)	Measured Impedance (ohms)
2300	1560
2400	1750
2500	1750
2800	1930
3000	1930
3300	1930
4000	2370
5000	2610
6000	2910
7000	3090
8000	3300
9000	3490
10000	3590

Table 3: Input Impedance Calibration

Reference (ohms)	Measured Impedance (ohms)
30000	> 20000[5]
24000	19600
20000	16800
10000	9100
7000	6600
5000	4770
3000	2910
1000	991
700	694
500	497
300	300
100	101

[5] Limit of the audio test set impedance measurement

Table 4: Balanced Input Impedance, Software Set to 600 ohms

Radio Port	Measured Impedance (ohms)
11	606
12	607
13	612
14	607
21	638
22	632
23	635
24	634
31	602
32	604
33	609
34	608

Although the InfiniGUI software can set the received impedance to single ohms accuracy, the measured input impedance is only roughly accurate. The measured input impedance has discrete steps as seen in Table 2. In addition, at high values of receiver or input impedance (above 1,500 ohms, for example), the software setting varies significantly relative to the measured impedance. At the extreme upper end of the software-set receiver impedance of 10,000 ohms, the measured impedance is approximately 3,600 ohms. For typical applications, a setting of anything greater than 600 ohms will provide appropriate impedance for a proper connection.

4.1.2 Output Audio Impedance

Output impedance provides information on the electrical signal that can be provided to other devices. When output audio impedance is greater than the specified value, potential effects include increased noise in the audio signal.

Datasheet Specification

- Software adjustable, balanced or unbalanced: 0 to 10,000 ohms

Test Procedures

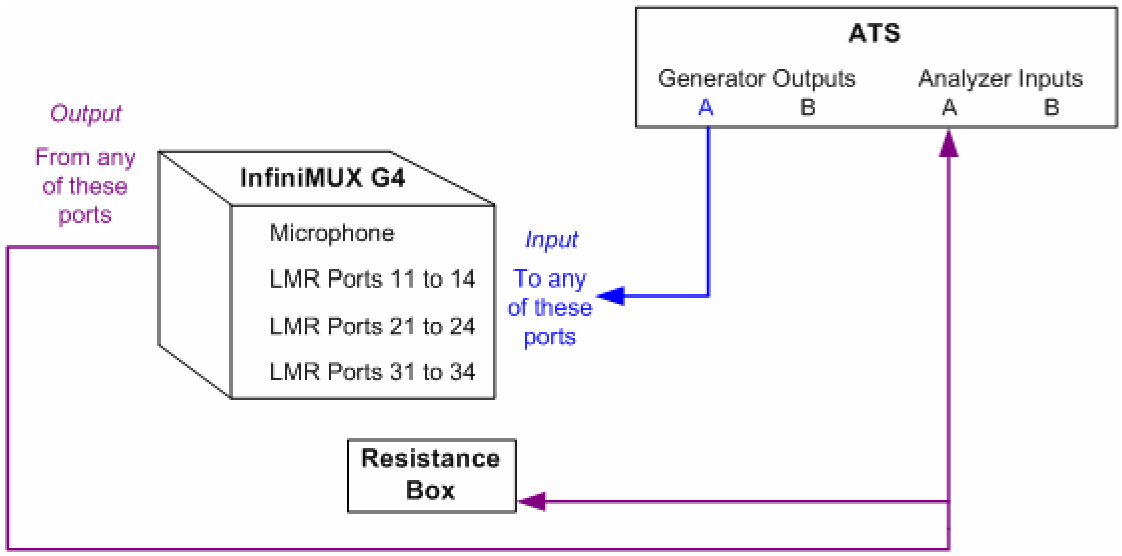

Figure 4: Output Audio Impedance

1. For each radio port, assign the radio port being tested to net 1 (*net* means network).
2. Assign one of the other radio ports to net 1. This will be the input interface. Ensure that no other radio ports are assigned to net 1.
3. Connect the ATS I/O cables to the radio port tested and the input radio port.
4. At the input radio port, connect the audio cable's input pigtail to the Generator Output A port of the ATS.
5. At the radio port tested, connect the audio cable's output pigtail to an adjustable resistance box. Split the signal to connect the Analyzer Input A port of the ATS in parallel with the resistance box.
6. Configure the ATS to provide a 1 kHz sine wave at a value of 287 mVp (peak level in millivolts).
7. Record the non-terminated voltage reading from the ATS. Calculate the value for a 50 percent reduction in voltage.
8. Connect the resistance box on the output radio port. Adjust its load resistance until the 50 percent reduction in voltage is measured at the ATS. The value of the resistance box, when connected in parallel with the output radio port that yields a 50 percent reduction in the output voltage, should equal the output impedance of the radio port.
9. Record the output impedance value.

Test Case Results and Summary

Table 5: Output Impedance

Input Radio Port	Output Radio Port	Open Channel Voltage (mV)	Half V (mV)	Gateway Setting (ohms)
11	12	459	229.5	308
	13	452	226	296
	14	470	235	295
	21	460	230	291

Input Radio Port	Output Radio Port	Open Channel Voltage (mV)	Half V (mV)	Gateway Setting (ohms)
	22	460	230	294
	23	455	227.5	293
	24	456	228	294
	31	462	231	290
	32	459	229.5	292
	33	457	228.5	293
	34	462	231	295

Table 5 shows the impedance of the device when it has been configured to 600 ohms. Taking into consideration the crudeness of this measurement method, the output impedance given in the table is quite reasonable and should operate satisfactorily with other audio equipment that requires 600 ohms input.

4.1.3 Input Audio Level and Distortion

Input audio level shows the range of acceptable input signal levels to achieve an acceptable output signal level. Having a wide range of acceptable input levels means that the device should provide a good quality signal without extensive calibration of the levels provided from external devices. One example is that the output volume from a handheld radio is not calibrated. The ability to accept a wide variety of signal levels means that a technician does not have to spend time ensuring that the volume levels have been set precisely. Instead, volume can just be set by ear to a reasonable level.

Datasheet Specification

- Software adjustable. -30 dBm to +6 dBm (24mV to 1.54 V). dBm represents the power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW).

Test Procedures

This measurement was taken in two parts. Separate measurements had to be conducted to confirm the minimum and maximum inputs.

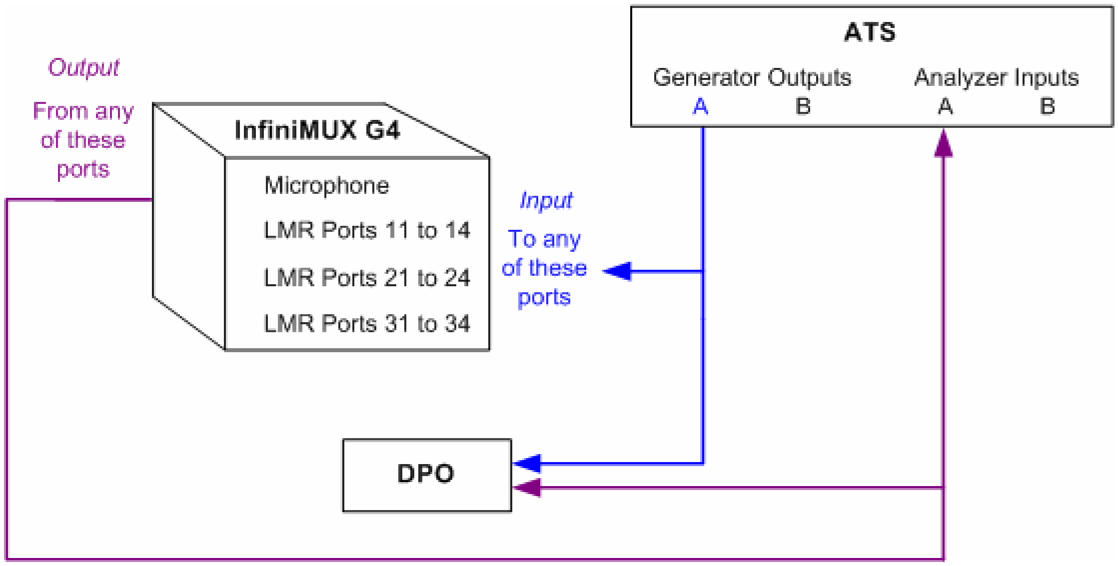

Figure 5: Input Audio Level

1. Assign the radio port to be tested to net 1. This will be the input interface.
2. Assign the output radio port to net 1. Ensure that no other radio ports are assigned to net 1.
3. For the minimum level tests, connect ATS I/O cables to the InfiniMUX G4 and DPO.
4. For the maximum level tests, connect the ATS I/O cables to the radio port being tested and the input radio port.
5. At the input radio port or the filter input, connect the audio cable's input pigtail to the Generator Output A port of the ATS.
6. At the output radio port, connect the audio adaptor's output pigtail to the Analyzer Input A port of the ATS in parallel with the DPO.
7. Set the output level of the ATS to the desired input level measured at the DPO. Record the setting as Vp (peak voltage).
8. Configure the radio ports to the following:

   General settings:
   - Node priority 0
   - Balanced audio ON

   TX settings:
   - PTT (Push to Talk) active high OFF
   - TX (Transmit) level 1000 mV
   - TX impedance 600 ohms
   - TX Delay 0 ms (milliseconds)
   - DBL (Double) PTT delay 0 ms

   RX settings:
   - RX (Receive) impedance 600 ohms
   - COR (Carrier Operated Relay) active high OFF
   - VOX (Voice Operated Transmit) enabled ON
   - VOX level 10dB
   - VOX hang time 10 ms
9. Set the RX Level on the input port to match the level tested.

10. Record the THD+N (Total Harmonic Distortion + Noise) and SINAD (Signal + Noise + Distortion to Noise + Distortion) values reported by the ATS.

Test Case Results and Summary

Table 6: THD+N and SINAD Values for Various Input Levels

Input Level (mVp)	Input Port RX Level Setting (mV)	THD+N (%)	SINAD (dB)
24	20	1.44	36
50	50	1.03	39.3
75	75	1.19	38
100	100	1.08	38.6
150	150	0.975	40
200	200	1.1	39.2
250	250	1.09	38.6
300	300	1.1	38.4
400	400	1.15	38.7
500	500	1.12	38.8
600	600	1.05	39.1
700	700	1.05	39.1
800	800	1.15	38.7
900	800	1.07	39.3
1000	1000	1.17	38.5
1100	1100	1.03	39.3
1200	1200	0.999	39.5
1250	1250	0.957	40.1

Table 7: Distortion and Output Level vs. Input Level for a Fixed RX Level of 600 mV

Input Level (mVp)	THD+N (%)	SINAD (dB)	Output (mVpp)
150	No Trigger	No Trigger	No Trigger
170	1.65	34.7	146
250	1.36	37.3	184
500	1.37	37.3	301
600	1.05	39.1	343
750	1.57	36	421
1000	1.51	36.4	476
1250	1.12	38.8	588
1500	1.71	34.5	712

Input Level (mVp)	THD+N (%)	SINAD (dB)	Output (mVpp)
2000	1.42	36.9	952

The results in Table 6 show that distortion is fairly low across the full range of input values when the Input Port RX Level Setting matches the level of the input signal. As might be expected, the distortion does increase as the input signal level decreases, but even at 20 mV, the distortion should provide acceptable quality.

Table 7 Indicates that the InfiniMUX G4 operates at moderately higher levels of distortion when the input signal level does not match the Input Port RX Level setting. Even though these levels do increase when the signal levels do not match, the data indicates that the communication quality should still be acceptable even when the input levels do not match. This makes the device easier for an inexperienced technician to configure, and still provides a functioning system.

Table 7 also indicates the InfiniMUX G4's output is linear relative to the input voltage.

4.1.4 Output Audio Level

Output audio level shows the range of available output signal levels that would be available to another device. Having a wide range of acceptable output levels means that the device tested can provide an appropriate signal to a variety of devices.

Datasheet Specification

- Software adjustable. -30 dBm to +2 dBm (24mV to 0.97 V)

Test Procedures

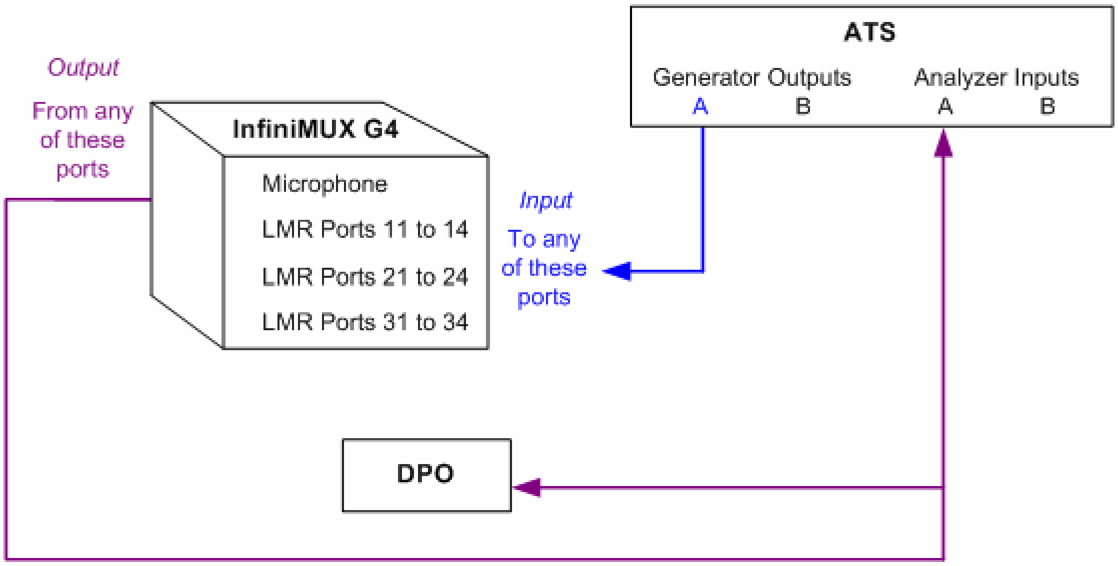

Figure 6: Output Audio Level

1. Connect the Generator Output A port of the ATS to the desired InfiniMUX G4 input radio port.
2. Connect the InfiniMUX G4 output radio port being tested to the Analyzer Input A port of the ATS and DPO.
3. Adjust the radio port setting to the following:

   General settings:
   - Node priority 0
   - Balanced audio ON

   TX settings:
   - PTT active high OFF
   - TX level 1250 mV
   - TX impedance 600 ohms
   - TS delay 0 ms
   - DBL PTT delay 0 ms

   RX settings:
   - RX level 1000 mV
   - RX impedance 600 ohms
   - COR active high OFF
   - VOX enabled ON
   - VOX level 10 dB
   - VOX hang time 10 ms
4. Determine the output voltage from the DPO, recorded in millivolts peak-to-peak (mVpp).

Test Case Results and Summary

Table 8: Output Level – Input Radio Port 11, Output Radio Port 21

Output Setting (mV)	Measured Output (mVpp)	Comments
10	54	Noisy
20	56	Noisy
30	70	Noisy
40	83	Noisy
50	92	Noisy
60	103	Noisy
70	108	Noisy
80	115	Noisy
90	128	Noisy
100	132	Noisy
110	142	
120	155	
130	160	
140	165	
150	180	
160	190	
170	202	
180	209	
190	212	
200	230	
250	274	
300	315	
350	353	
400	400	
450	452	
500	504	
550	552	
600	596	
650	650	
700	700	
750	750	
800	795	

Output Setting (mV)	Measured Output (mVpp)	Comments
850	840	
900	890	
950	940	
1000	980	
1100	1080	
1200	1200	
1250	1.26	

The specified maximum output for the device is 970 mV. However, the software will allow adjustment of the output above 1000 mV, outside the range indicated in the specifications. From approximately 1000 to 1250 mV, the output is visibly distorted when examined through the display of the DPO. The device does operate without any visible distortion within the specified range (110 to 970 mV). The ability to modify receive and transmit levels allows use of the InfiniMUX G4 beyond the manufacturer's specification.

4.1.5 Audio Frequency Response

Audio frequency response indicates how accurately the device outputs a speech signal from a given input signal. The frequency band that the telephone industry has used for decades is 300 Hertz (Hz) to 3.5 kHz. It is generally accepted that accurate reproduction across this band will allow for good speaker recognition and for speaker voice characteristic (e.g., emotional state) recognition.

Datasheet Specification

- Infinimode Systems quad radio port module: 100 Hz to 3.4 KHz

Test Procedures

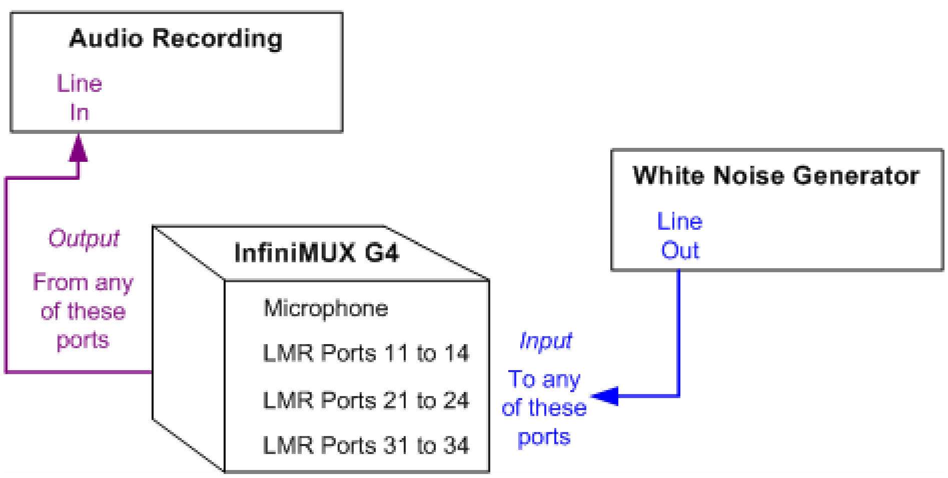

Figure 7: Frequency Response

This test is performed non-invasively by combining the input and output frequency response tests.

1. For each output radio port to be tested, assign a single input by making the appropriate net selection.
2. Inject white noise into the port.
3. Record the audio output.
4. Calculate the Fast Fourier Transform (FFT) of the audio output response.
5. Plot the device frequency response.

Test Case Results and Summary

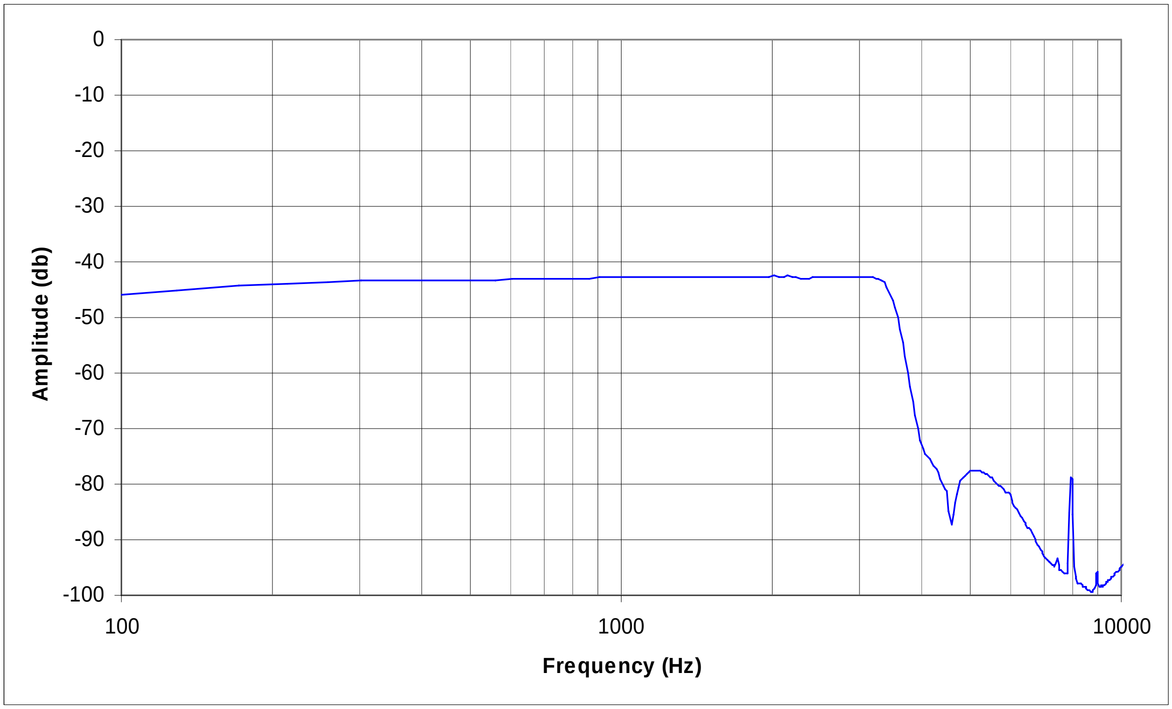

Figure 8: Frequency Response – Input Port 13 to Output Port 14

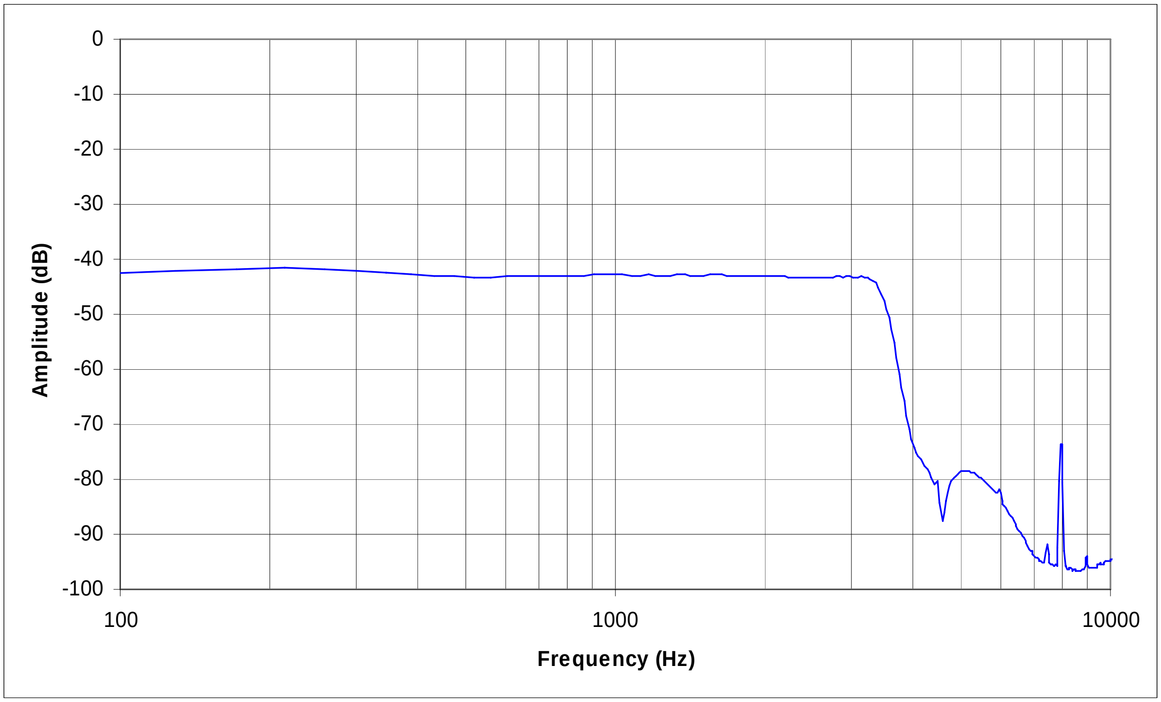

Figure 9: Frequency Response – Console Port 2 to Output Port 22

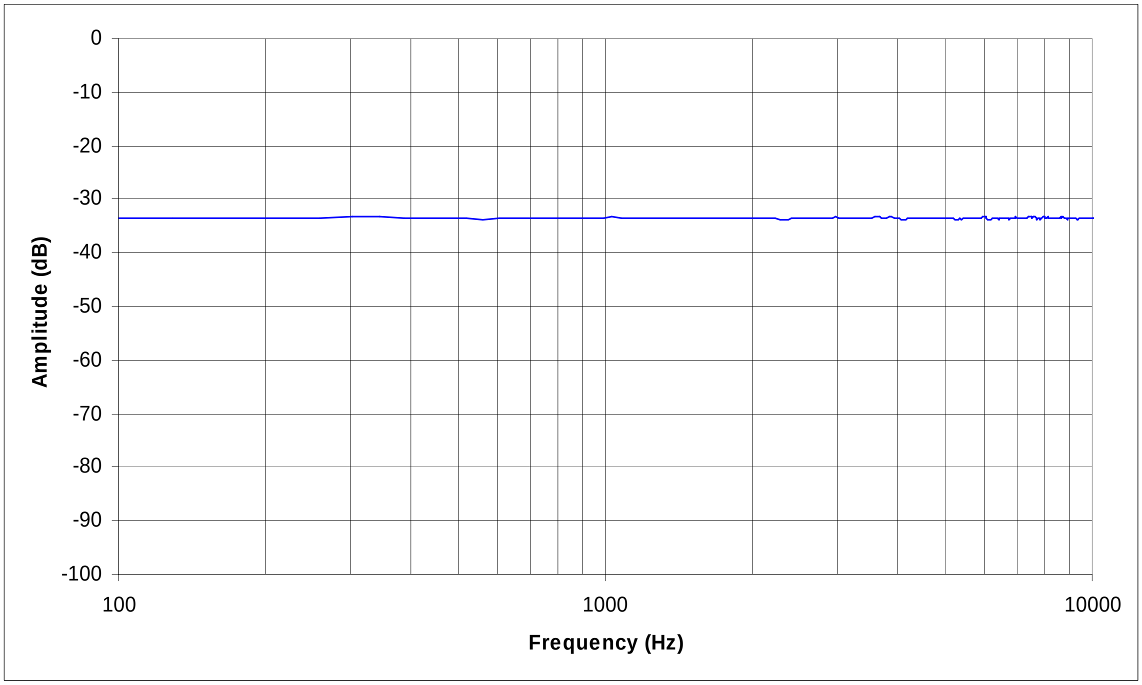

Figure 10: FFT of Input Noise Used To Determine Frequency Response

The frequency response measurements conform to the audio response specification of the Infinimode Systems quad radio port module.

4.2 Characteristics Not Specified by the Manufacturer

The next sections list measurements for performance parameters not specified by the manufacturer. They are:

- VOX input threshold
- Throughput and transmit delay
- Audio distortion
- Crosstalk

4.2.1 VOX Input Threshold

The VOX input threshold is the level of signal at which the device switches open the channel to allow a transmission. It is an audio signal equivalent to a radio squelch control, helping the device to distinguish a valid signal from background noise. How the threshold is set may affect how the device reacts to quiet sounds, such as someone whispering over a radio channel or someone who talks very quietly.

Datasheet Specification

- o Software-adjustable

Test Procedures

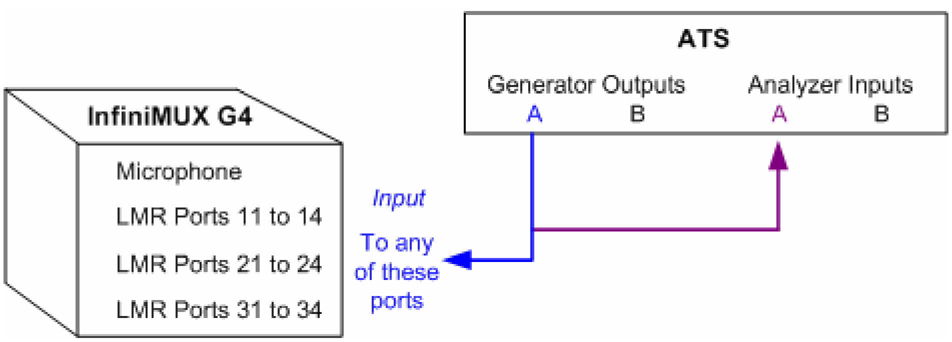

Figure 11: VOX Input Threshold

1. For each radio port, connect the InfiniMUX G4 audio input to the Generator Output A port of the ATS.
2. Configure a 1 kHz sine wave as the input signal to the InfiniMUX G4 from the Generator Output A port of the ATS. Use either the maximum or minimum specified input level.
3. Adjust the radio ports to the desired VOX level.
4. Increase the Generator Output A port level of the ATS until the VOX circuitry activates.
5. Record the output amplitude from the ATS and the VOX level on the InfiniMUX G4.

Test Case Results and Summary

Table 9: VOX Input Threshold Meaurement Results

VOX Level (dB)	VOX Hang Time[6] (ms)	GEN A Setting (mVp)	Measured GEN A Level (mVpp)	InfiniMUX G4 Output Amplitude (mVpp)
-24	10	114.9	216	193
-22	10	137.7	254	232
-21	10	150.9	277	255
-20	10	172.7	314	290
-19	10	187.4	342	316
-18	10	208.3	374	350
-17	10	235.8	430	398
-16	10	259.3	462	438
-15	10	295.7	534	496
-14	10	331.4	590	558
-13	10	372.7	662	626
-12	10	418	736	708
-11	10	469.4	836	796
-10	10	525.7	932	892
-9	10	588.4	1004	1000
-8	10	659.3	1170	1120
-7	10	740.9	1320	1260
-6	10	831.7	1460	1420
-5	10	936	1690	1590
-4	10	1043	1870	1770
-3	10	1170	2100	2000
-2	10	1310	2335	2240
-1	10	1467	2620	2510
0	10	NA	NA	No Response

Table 9 shows the measured VOX threshold setting for the entire range settable in the InfiniGUI software that comes with the InfiniMUX G4.

[6] Hang time indicates the duration that a channel is open following the most recent audio signal to exceed the VOX level setting.

4.2.2 Throughput Delay and Transmit Delay

Throughput delay is the amount of time it takes the device to reproduce an audio signal on the output port that is presented at the input port. It is separate from, but often related to, VOX attack time.

VOX attack time is the time interval between the device's receipt of a valid audio signal, and when the device recognizes that the signal is valid and actually starts allowing the audio signal to be reproduced at the output. Longer attack times can lead to pieces of words getting clipped from the beginning of a message.

The VOX transmit delay is an additional, programmable delay to allow time for transmitters to ramp up before the audio signal starts. This helps to avoid the loss of words or syllables in transmission.

Datasheet Specification

- N/A

Test Procedures

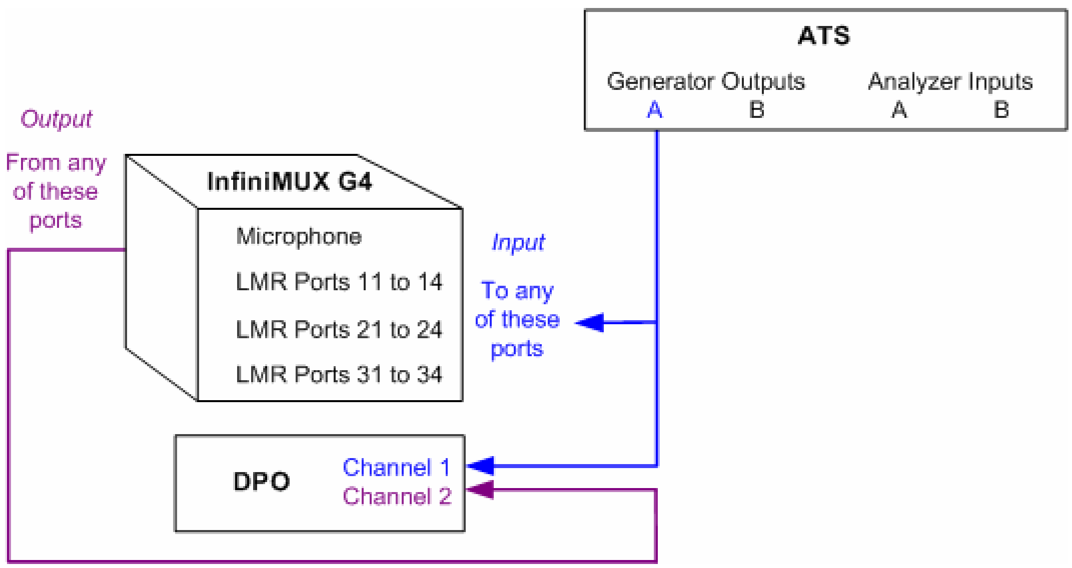

Figure 12: VOX Attack Time and Throughput Delay

1. Connect the output of an input source, such as the ATS, to the InfiniMUX G4 input port under test and to the DPO.
2. Configure the ATS to give a 20 millisecond (ms) 1 kHz burst with a 0.8 second duty cycle.
3. Set the DPO to single sweep mode, externally triggered from the ATS.
4. Connect the output radio port to the DPO.
5. Adjust the DPO as appropriate.
6. Each time the signal is initiated, it will simultaneously trigger the DPO and the voice activation feature of the InfiniMUX G4 radio port. Record the time difference from the input signal to the output signal.

Test Case Results and Summary

Table 10: Audio Throughput Delay (Input on Radio Port 11)

Radio Port	Delay (ms)
12	100
13	100
14	100
21	100
22	100
23	100
24	100
31	100
32	100
33	100
34	100

Table 11: Audio Transmit Delay (Adds to the 100 ms Throughput Delay)

TX Delay (ms)	Measured Delay (ms)
10	110
50	150
100	200
150	250
300	400
500	600
1 second	1100

The measured transmit delay is precise as set in the InfiniMUX G4 control software.

The InfiniMUX G4 has 100 ms of throughput delay. It appears the 100 ms of delay is a manufacturer design to avoid having the VOX attack time cause temporal clipping of speech (for example, having the first syllable or word not transmitted). This is borne out by the observation of no measurable VOX attack time delay.

4.2.3 Audio Distortion – SINAD and THD+N

SINAD is the ratio of Signal + Noise + Distortion to Noise + Distortion. SINAD is a rough, commonly used estimation of audio quality. Radio thresholds are commonly set at the point where SINAD equals 10, 12, or 20 dB. As long as the device does not approach these values (i.e., it has a significantly higher value), this matter is not a source of concern.

Total Harmonic Distortion + Noise (THD+N) is a measurement of how changed the audio signal is as it passes through a device. A THD+N higher than 0.3 percent would generally be considered slightly audible distortion, and a THD+N higher than 3.0 percent is generally considered audible distortion. Exceeding that threshold may cause difficulty in speaker recognition or in the identification of the emotional state of a speaker.

Test Procedures

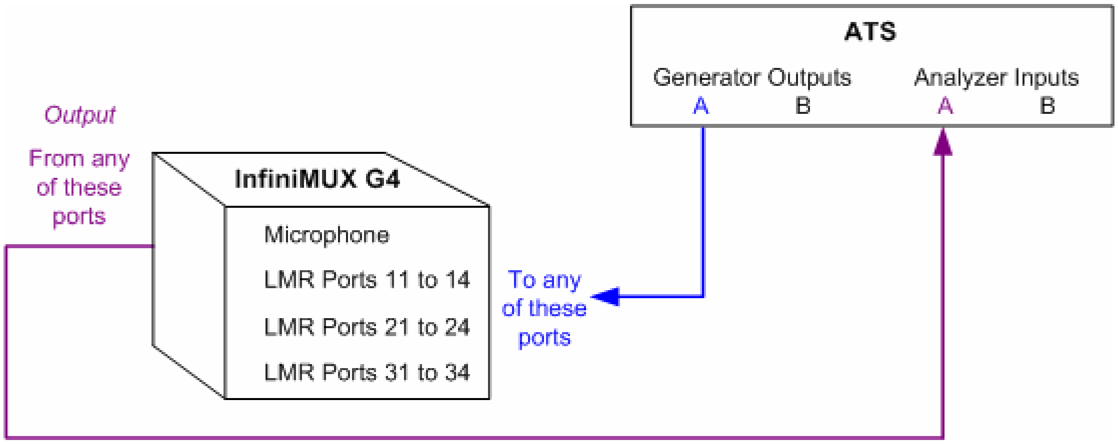

Figure 13: Audio Distortion: THD+N

1. Configure the ATS to measure THD+N using the front panel softkeys.
2. Connect the input radio port to the ATS, and apply a 1 kHz sine wave at an amplitude of 1 Vp.
3. Configure the radio ports to the following:

   General settings:
   - Node priority 0
   - Balanced audio ON

   TX settings:
   - PTT active high OFF
   - TX level 1000 mV
   - TX impedance 600 ohms
   - TS delay 0 ms
   - DBL PTT delay 0 ms

   RX settings:
   - RX level 1000 mV
   - RX impedance 600 ohms
   - COR active high OFF
   - VOX enabled ON
   - VOX level 10 dB
   - VOX hang time 10 ms
4. Using the ATS, measure the THD+N and SINAD levels across a bandwidth of 22 Hz to 22 kHz.
5. Repeat the above steps for all output radio ports.

Test Case Results and Summary

Table 12: Summary of Measurement Results

Input Radio Port	Output Radio Port	THD+N (%)	SINAD (dB)
R11	R12	1.22	38.2
	R13	1.21	38.4
	R14	1.23	38.1
	R21	1.22	38.2
	R22	1.19	38.4
	R23	1.18	38.4
	R24	1.19	38.2
	R31	1.23	38.1
	R32	1.24	38
	R33	1.17	38.5
	R34	1.22	38.2

The SINAD and THD+N are consistent over all ports tested.

4.2.4 Crosstalk

Crosstalk occurs where the content of a signal on one path through a system bleeds over into other parts of the system. Being significantly off the specification could cause conversations of different groups to become confused or unintelligible. Further, a conversation from one net could be heard on a net for which it was unintended.

Test Procedures

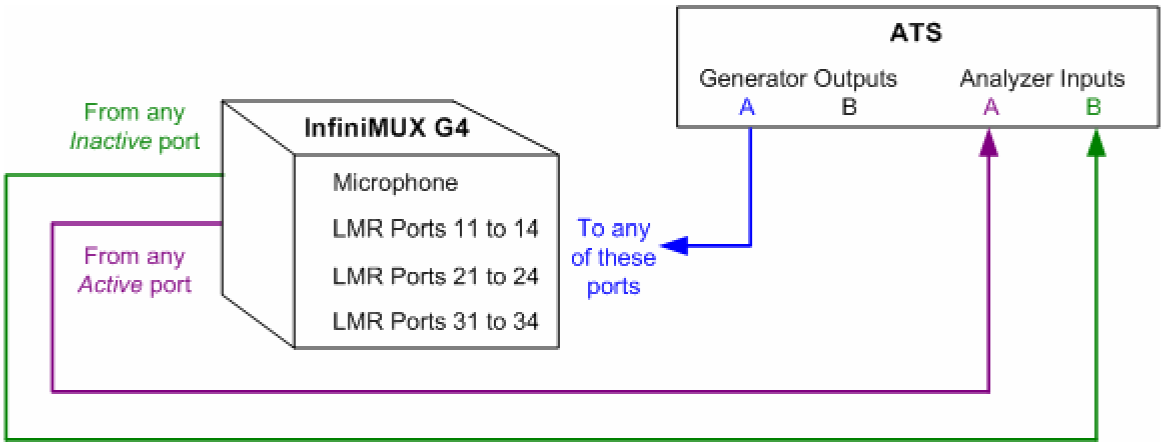

Figure 14: Crosstalk Measurement

1. Configure the ATS to measure crosstalk using the front panel softkeys.
2. Connect the input radio port to the ATS, and apply a 1 kHz sine wave with an amplitude of 2 Vp to trigger the input filter on the ATS.
3. Using the ATS measurement, determine the crosstalk in dBV.[7]
4. Repeat step 3 for all output radio ports.

Test Case Results and Summary

Table 13: Summary of Crosstalk Measurement Results

Measured Radio Port	Driven Radio Port (Input Amplitude)	Crosstalk (dBV)	GEN A input
13	12 (-7.7 dBV)	-92	11
14	12 (-7.7 dBV)	-89	11
21	12 (-7.7 dBV)	-97	11
22	12 (-7.7 dBV)	-95	11
23	12 (-7.7 dBV)	-96	11
24	12 (-7.7 dBV)	-91	11
31	12 (-7.7 dBV)	-97	11
31	12 (-7.7 dBV)	-97	11
33	12 (-7.7 dBV)	-96	11
24	12 (-7.7 dBV)	-91	11
13	11 (-7.8 dBV)	-93	12
23	22 (-7.5 dBV)	-86	21
24	22 (-7.5 dBV)	-89	21
11	22 (-7.5 dBV)	-97	21

[7] dBV means decibels relative to 1 volt peak to peak.

Measured Radio Port	Driven Radio Port (Input Amplitude)	Crosstalk (dBV)	GEN A input
12	22 (-7.5 dBV)	-96	21
13	22 (-7.5 dBV)	-100	21
14	22 (-7.5 dBV)	-92	21
31	22 (-7.5 dBV)	-97	21
32	22 (-7.5 dBV)	-96	21
33	22 (-7.5 dBV)	-96	21
34	22 (-7.5 dBV)	-92	21
23	21 (-7.7 dBV)	-97	22
24	21 (-7.7 dBV)	-91	22
33	32 (-8.0 dBV)	-88	31
34	32 (-8.0 dBV)	-90	31
11	32 (-8.0 dBV)	-97	31
12	32 (-8.0 dBV)	-96	31
13	32 (-8.0 dBV)	-100	31
14	32 (-8.0 dBV)	-92	31
21	32 (-8.0 dBV)	-98	31
22	32 (-8.0 dBV)	-95	31
23	32 (-8.0 dBV)	-97	31
24	32 (-8.0 dBV)	-91	31
33	31 (-8.0 dBV)	-89	32
34	31 (-8.0 dBV)	-91	32

The crosstalk is consistent between radio ports on a single module and between radio ports on differing modules.

4.3 Observations

The next sections list observations that may interest public safety organizations, including: RF emissions, power supply noise, use of a computer for setup, and manufacturer responsiveness.

4.3.1 RF Emissions

Gateway devices like the InfiniMUX G4 must operate in environments with other RF equipment. Therefore an informal RF emissions scan was made in the 20 MHz to 500 MHz range on the InfiniMUX G4, with no transmitters attached or active. This section details those measurement procedures and results.

Test Procedures

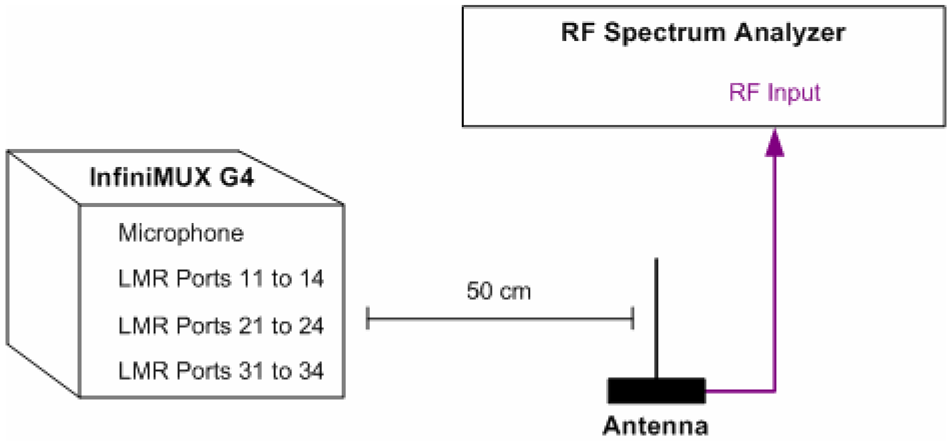

Figure 15: RF Emission Measurement

1. Configure the RF Spectrum Analyzer to measure RF energy from 20 MHz to 500 MHz, which encompasses the VHF band where interference was observed.
2. Position the antenna probe at 50 centimeters (cm) from the device under test.
3. Using the spectrum analyzer, record the RF energy across the frequency band of interest with the device under test powered off.
4. Repeat step 3 with the device under test powered on.

Test Results and Summary

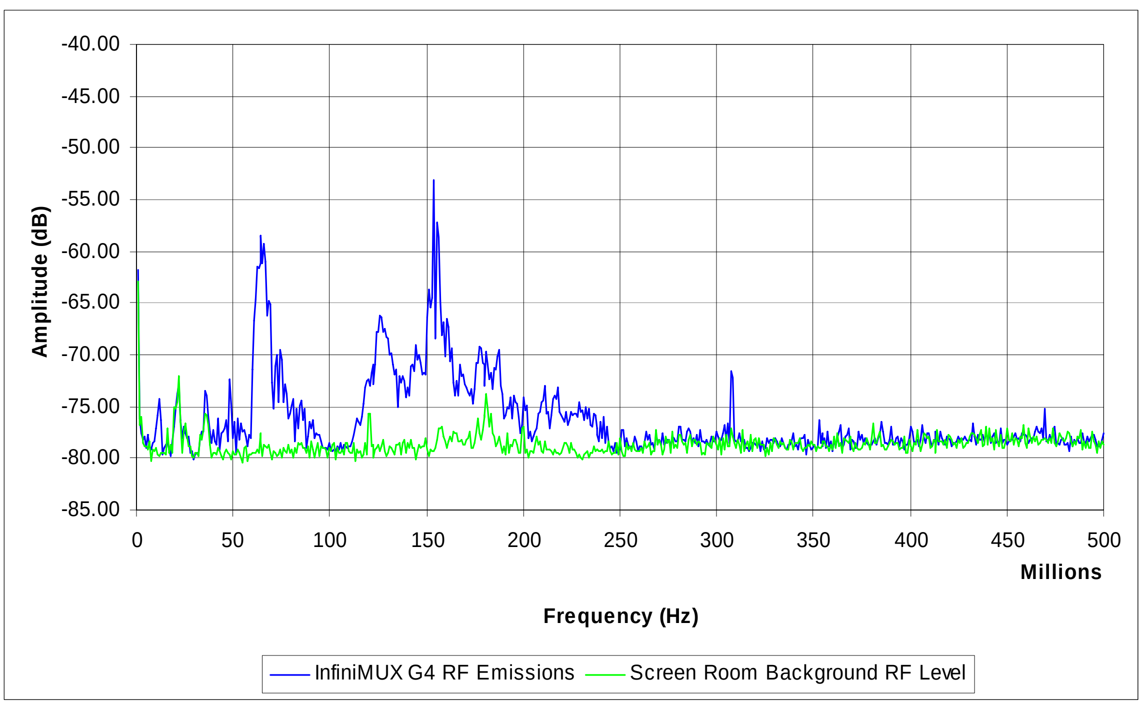

Figure 16: InfiniMUX G4 Horizontally Polarized RF Emissions from 20 MHz to 500 MHz

The InfiniMUX G4 appears to introduce significant RF energy into the environment. Most notable are the spikes at 153.68 MHz (-53.2 dBm), 155.34 MHz (-57.3 dBm), and 64.60 MHz (-58.5 dBm). The 153.68 and 155.34 MHz spikes are in the VHF public safety band. They could cause interference with weaker radio signals if the receiver is in close proximity to the communications gateway. These findings have been reported to the manufacturer for its consideration.

4.3.2 Power Supply Noise

The manufacturer-provided AC power supply provided with the InfiniMUX G4 introduced measurable and audible amounts of 60 Hz noise into the communications path. This has been reported to the manufacturer for its consideration.

4.3.3 Use of a Computer for Setup

The device is generally configurable and usable through the keypad interface provided on the device. However, for setup and initial configuration, it is very helpful for programming purposes to use the provided software while running on a separate computer. A computer to perform this operation is not provided, but a user-supplied computer can be connected to the InfiniMUX G4 via the serial port or the Ethernet port on the device.

4.3.4 Manufacturer Responsiveness

During the testing period, a DC input board on the device failed. The manufacturer was very responsive, shipping a replacement part overnight, thus enabling the testing to continue virtually uninterrupted.

Appendix: Glossary of Terms and Acronyms

AGC (Automatic Gain Control) – A process or means by which a signal level is adjusted in a specified manner. AGC attempts to keep a consistent output signal level regardless of the level of the input signal

Crosstalk (Xtalk) – Undesired coupling or bleeding of a signal in one portion of an electronic circuit or channel into another, causing undesired effects if the crosstalk is too great

dBV – Decibels relative to 1 volt peak to peak

DHS – U.S. Department of Homeland Security

DPO – Digital Phosphor Oscilloscope, for the tests in this document, the Tektronix TDS 3012B

DTMF (Dual-tone multi-frequency) – A method of coding the numbers on a telephone touch pad into combinations of frequencies that machines can interpret.

FFT (Fast Fourier Transform) A computationally efficient means of computing the frequency content of a waveform

Hang Time – Indicates the duration that a channel is open following the most recent audio signal to exceed the VOX (voice operated transmit) level setting

InfiniMUX G4 – An interoperability communications controller manufactured by Infinimode Systems, Inc.

I/O – Input/Output

LMR (Land Mobile Radio) – A common descriptor of the type of radio communication system frequently used by public safety practitioners

ms – Milliseconds

OIC – The Office of Interoperability and Compatibility within the DHS Science and Technology (S&T) Directorate

RF (Radio Frequency) – Of, or pertaining to, any frequency within the electromagnetic spectrum normally associated with radio wave propagation

RX – Received or Receiver

S&T – Science and Technology Directorate of DHS

SINAD – The ratio of Signal + Noise + Distortion to Noise + Distortion

THD+N – The sum of the Total Harmonic Distortion plus Noise. THD is the ratio of the power of all harmonic frequencies introduced by a system to the power of the fundamental frequency to which they are added.

Throughput Delay – The time from when a specific signal is introduced into the system being tested until that signal appears on an output port of the device tested.

Transmit Delay – A delay intentionally introduced into an audio signal path to enable a transmitter to ramp up to appropriate power levels before the audio signal is presented to the transmitter. This is to avoid temporal clipping (for example, words or syllables being chopped off) at the beginning of a transmission.

TX – Transmitted or Transmitter

UHF (Ultra High Frequency) – Frequencies from 300 MHz to 3,000 MHz

VHF (Very High Frequency) – Frequencies from 30 MHz to 300 MHz

VOX (Voice Operated Transmit) – A device that transmits a signal only when an active audio signal (that is, voice) above the detection of a defined threshold

VOX Attack Time – The amount of time it takes a voice detection circuit to recognize that an audio signal is above the defined threshold and to begin transmitting that audio signal

Vp – Peak voltage

Vpp – Peak-to-peak voltage