Link Communications, Inc. TCB-2 Technical Evaluation

The Office for Interoperability and Compatibility
Department of Homeland Security

Test Procedures and Results

Homeland Security

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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 Tactical Communications Bridge-2

Manufactured by Link Communications, Inc.

Test Procedures and Results

Document No. TE-08-0001

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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Publication Notice

Abstract

This report describes the test procedures and results of the product evaluation for the Tactical Communications Bridge-2 (TCB-2). The TCB-2 is an audio gateway device manufactured by Ink Communications, 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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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 laboratory tests to evaluate the functionality of the Tactical Communication Bridge-2 (TCB-2). The TCB-2 is manufactured by Link Communications, Inc. (http://www.link-comm.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 TCB-2 enables interoperability between wireless and wireline communication systems by multiplexing audio input signals to the audio input ports of several radios. The TCB-2 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 TCB-2 is designed to enable one user to simultaneously broadcast to 10 radios, each of which can be programmed for one of five available talk groups. There is a minimum of two radios per talk group.

To exercise the functionality of the TCB-2, ITS developed a series of focused test procedures to evaluate:

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

In general, the TCB-2 performed as specified, as the test results in this report demonstrate. This report notes two areas of concern. The first issue was observed sensitivity to static discharge. This caused the voice coder to go into a mode that did not allow audio signals to pass through the TCB-2. The manufacturer has addressed this issue through a firmware update (via revision V26.6.2.2.16.37.1), but it may be desirable to provide grounding prior to contact with the device. The second issue was observed during a practitioner field exercise. RF emissions from the TCB-2 caused radios tuned to a particular channel to break squelch even when the device was not in transmission mode. The TCB-2 was subsequently evaluated in the laboratory where an

[1] VOX means voice operated transmit.

informal RF emission scan was conducted. The scan confirmed a peak in RF noise emissions from the TCB-2 in the very high frequency (VHF) public safety band. This issue has been reported to the manufacturer for its consideration.

Document Scope and Intended Audience

This report presents the procedures employed in the technical evaluation testing for the TCB-2, and also summarizes the results. The TCB-2 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, 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 an 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 baseband (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) 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 Link Communications, Inc. TCB-2

The Link Communications, Inc. TCB-2 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 TCB-2 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 TCB-2. It can connect to a total of 10 land mobile radios (LMRs), which potentially can be programmed into any of five available talk groups. Note there is a minimum of two radios per talk group.

Figure 1 shows the second-generation TCB-2, which supports:

- Five software-selectable talk groups capable of supporting cross-band communications between 10 LMRs
- An Ethernet port
- A local microphone
- Two analog telephone ports (many optional interface cables are available)

Figure 1: Tactical Communication Bridge-2 (TCB-2)

The grab-handled TCB-2 is metal with a metal face plates. Configuration of the device is primarily conducted through an LCD touch screen on the front of the chassis, or through a computer connected via an Ethernet or RS-232 serial line. The touch screen and remote control user interfaces can be readily used to program the device with only modest training. The touch screen may be difficult to read in bright light conditions, and may need to be protected from harm in rugged environments. The TCB-2 provides single-password security for administration and control of the device.

For all tests, setup and operation of the unit were conducted according to manufacturer documentation. This report refers to Version 2.2 of the *Tactical Communications Bridge 2 User Manual* as “the TCB-2 user’s manual.” The unit was conformance tested in accordance with vendor-supplied product specifications detailed on the Link Communications, Inc. Web site (http://www.link-comm.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 TCB-2.

3.1 Specifications Testing

Specifications testing determines how well the unit performs relative to the manufacturer’s specifications. This report evaluates the following TCB-2 specification parameters:

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

3.2 Performance Testing

Performance testing quantifies the performance of the TCB-2 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 are considered important for purposes of this evaluation and were assessed:

- VOX input threshold
- VOX attack time and throughput delay
- Audio distortion – THD+N (Total Harmonic Distortion + Noise)
- Crosstalk

3.3 Observations

Section 4.3 describes significant observations concerning:

- Sensitivity to static discharge
- RF emissions

4 TCB-2 Evaluation

This section refers to the TCB-2’s 10 LMR ports as Dual Radio Interface Module (DRIM) port 1 to 10. Figures in this section also reflect the Telephone Interconnect Module (TIM) supporting two analog phone lines, and the microphone port. The TCB-2 accepts both audio input and ouput (I/O) signals at its interface ports.

Figure 2 shows how connections to the audio input and output signals were made using audio I/O cables. ITS engineers custom-made the cables that mate with the DRIM interface ports. Each cable provides the connections to the TCB-2 interface ports using a pigtail with XLR connectors on each end: one for audio input and one for audio output. Connector pin-out information for the RJ-45 connectors on the TCB-2 can be found in the TCB-2 user's manual. The cables that connect the test equipment with the DRIM, TIM, and microphone interfaces were either purchased from Link Communications, Inc. or custom-manufactured by the test engineers.

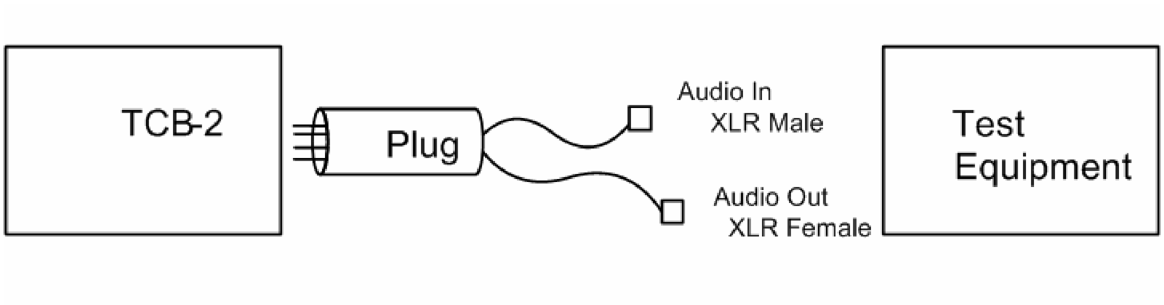

Figure 2: Audio I/O Cable

Audio signals are routed from one interface to the next according to the talk group settings on the front panel, and are available at the audio bus. These signals are present at various test points on the main circuit board.

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)
- Agilent 33220A Arbitrary Waveform Generator
- Agilent E4443A PSA Series Spectrum Analyzer

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

The power supply provided by the manufacturer exhibited 60 cycle noise, as well as significant noise across a wide bandwidth sufficient to interfere with the measurements. As a consequence, the measurements described here were conducted using a laboratory grade power supply. [3]

4.1 Conformance to Manufacturer's Specifications

The following tests measure the TCB-2's conformance to published specifications, and summarize the results obtained. Each test comprises the following components:

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

- 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

- Balanced > 50 ohms

Test Procedures

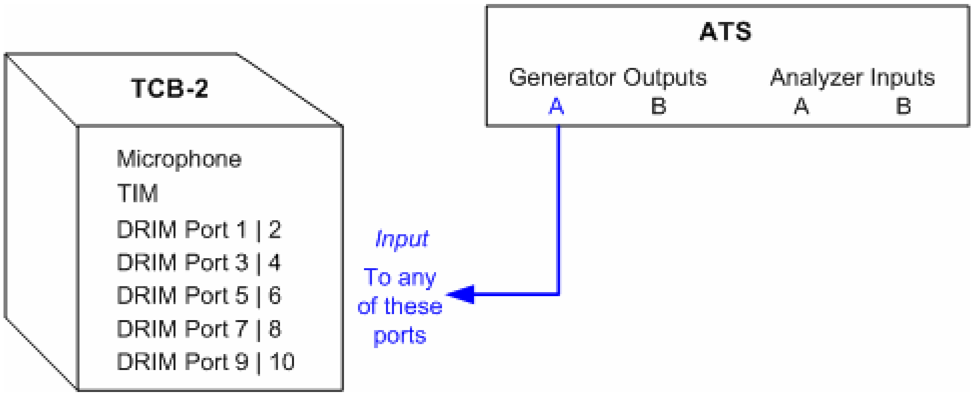

Figure 3: Input Audio Impedance

1. For each interface, connect the TCB-2 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 TCB-2 from the Generator Output A port of the ATS.
3. From the front panel of the ATS, select the Gen Load softkey. This will automatically measure the input impedance of the interface under test.
4. Record the input impedance measurement from the front panel display of the ATS.

Test Case Results and Summary

Table 1: Balanced Input Impedance

Interface	Measured Impedance (ohms)
DRIM port 1	2630
DRIM port 2	2580
DRIM port 3	2450
DRIM port 4	2540
DRIM port 5	2720
DRIM port 6	2790
DRIM port 7	2480

Interface	Measured Impedance (ohms)
DRIM port 8	2560
DRIM port 9	2880
DRIM port 10	2760

All ports meet the >50 ohm impedance specification. They should function properly under normal operating conditions.

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

- Balanced 600 ohms

Test Procedures

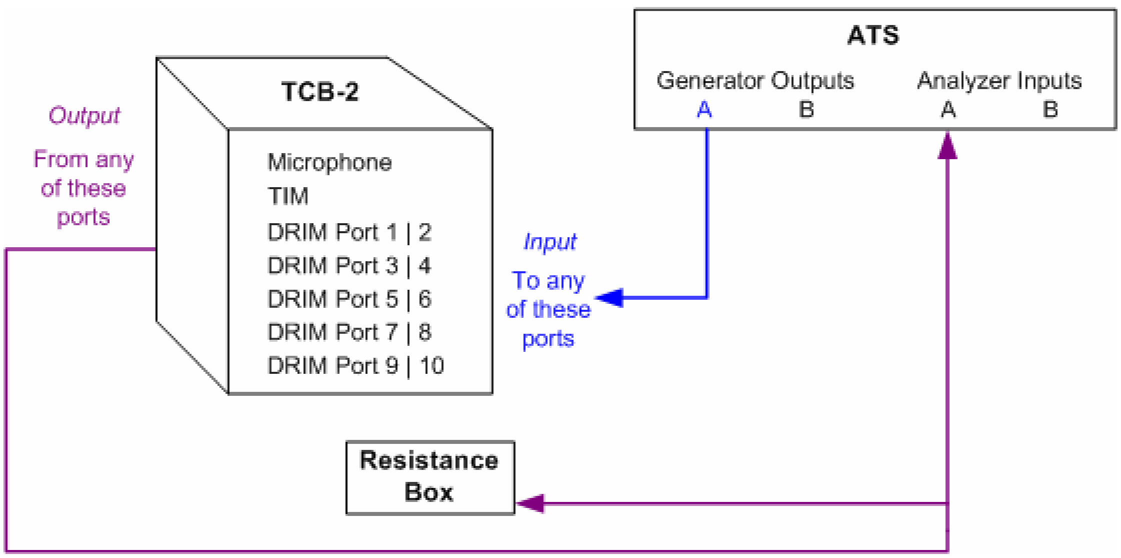

Figure 4: Output Audio Impedance

1. For each interface, assign the interface being tested to talk group 1.
2. Assign one of the other interfaces to talk group 1. This will be the input interface. Ensure that no other interfaces are assigned to talk group 1.
3. Connect ATS I/O cables to the interface being tested and to the input interface.
4. At the input interface, connect the audio cable's input pigtail to the Generator Output A port of the ATS.
5. At the interface under test, 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 270 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 interface. 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 interface that yields a 50 percent reduction in the output voltage, should equal the output impedance of the interface.
9. Record the output impedance value.

Test Case Results and Summary

Table 2: Summary of Measurement Results

Interface	Output Impedance (ohms)
DRIM port 1	480
DRIM port 2	390
DRIM port 3	440
DRIM port 4	470
DRIM port 5	460
DRIM port 6	450
DRIM port 7	450
DRIM port 8	440
DRIM port 9	430
DRIM port 10	420

Operationally, the difference between the specified 600 ohm impedance and the measured values is insignificant for typical usage.

4.1.3 Input Audio Level

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

- Input signal range: 150 mVpp (millivolt peak-to-peak waveform) to 8 Vpp (volt peak-to-peak waveform)

Test Procedures

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

In both experiments, the automatic gain control (AGC) was turned off via the RS-232 control port. The command ***13 pp s** was used. Where ***13** is the command that controls a receiver's

AGC setting, **pp** is the port number and **s** is either “1” or “0”, to turn the AGC on and off, respectively. See the TCB-2 user’s manual for TCB-2 remote control details.

For the minimum level tests, an additional audio filter was required to reduce the noise floor.

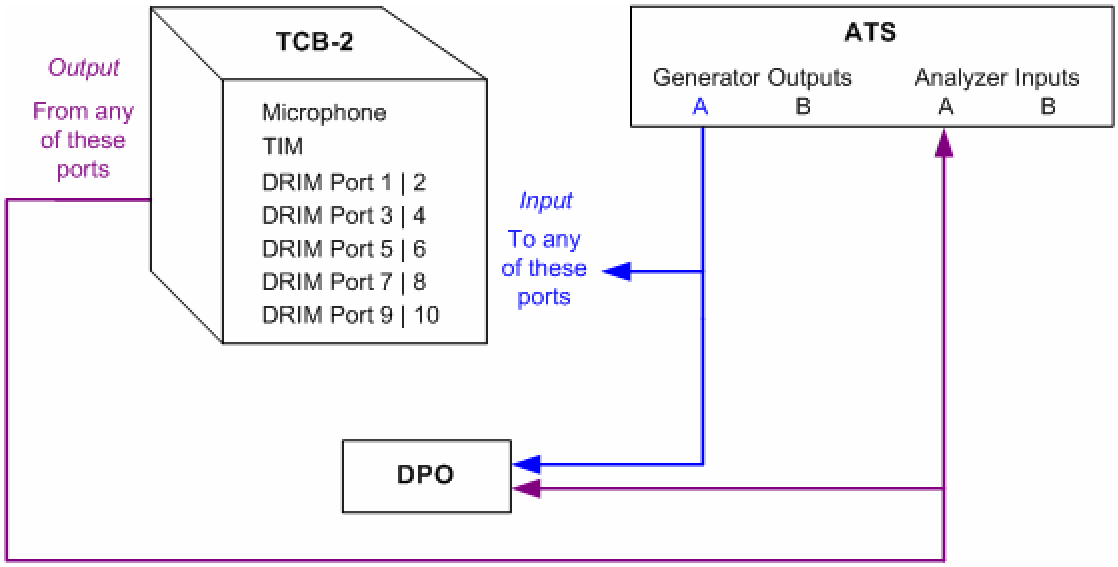

Figure 5: Input Audio Level

1. Assign the interface to be tested to talk group 1. This will be the input interface.
2. Assign the output interface to talk group 1. Ensure that no other interfaces are assigned to talk group 1.
3. For the minimum level tests, connect the ATS I/O cables to the filter input. Connect the filter output to the DPO and the input port of the TCB-2.
4. For the maximum level tests, connect the ATS I/O cables to the interface under test and the input interface.
5. At the input interface or the filter input, connect the audio cable’s input pigtail to the Generator Output A port of the ATS.
6. At the output interface, connect the audio adaptor’s output pigtail to the Analyzer Input A port of the ATS and in parallel with the DPO.
7. Set the output level of the ATS to the desired input level measured at the DPO.
8. Record the ATS THD+N and the measured levels on the DPO.

Test Case Results and Summary

For the results in Table 3, the input to the TCB-2 was applied to DRIM port 4 (Rx[4] sensitivity was set to 50 percent microphone level). The output was measured from DRIM port 7 (Tx[5] level set to 50 percent). The harmonic distortion was also measured.

[4] Rx means receiver.

[5] Tx means transmitter.

Table 3: Non-AGC Input Output Response

ATS Output Level (mVp)	TCB-2 DRIM Input Port Level (mVpp)	TCB-2 DRIM Output Port Level (mVpp)	THD+N (Total Harmonic Distortion + Noise) (%)
50	124	390	1.78
75	172	530	1.26
100	208	690	1.02
125	256	820	0.81
150	296	970	0.65
175	336	1110	0.55
200	410	1320	0.48
225	450	1460	0.43
250	490	1600	0.38
275	530	1880	0.35
300	640	2040	0.33
350	720	2320	0.29
400	800	2560	0.25
450	900	2840	0.24
500	1000	3160	0.22
550	1160	3700	0.21
600	1280	4100	0.2
650	1320	4500	0.2
700	1470	4800	0.19
750	1520	5000	0.19
800	1600	5300	0.19
850	1720	5500	0.19
900	1800	6200	0.22
950	1880	6800	0.95
1000	1960	7000	1.91

For the results in Table 4, the input to the TCB-2 was applied to DRIM port 4. The output level was measured from DRIM port 7. The harmonic distortion was also measured as an indicator of the quality of the output audio.

Table 4: Non-AGC Maximum Input Response

ATS Output Level (Vp)[6]	TCB-2 DRIM Input Port Level (Vpp)	TCB-2 DRIM Output Port Level (mVpp)	DRIM Input Port 4 Rx Sensitivity (%)	DRIM Output Port 7 Tx Level (%)	THD+N (%)
9.3	8.04	184	0	0	1.6
9.3	8.04	2600	0	100	1.63

Table 3 confirms that the TCB-2 can accept the specified minimum input signal of 150 mVpp.

Table 4 indicates that the TCB-2 can accept a maximum input signal of 8 Vpp with an output level ranging from 184 mVpp to 2.6 Vpp.

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 can provide an appropriate signal to a variety of devices. Most balanced audio devices accept a signal of 1.67 Vpp, so the available output range should encompass this value.

Datasheet Specification

- Output signal range: 0 Vpp to 4.3 Vpp

Test Procedures

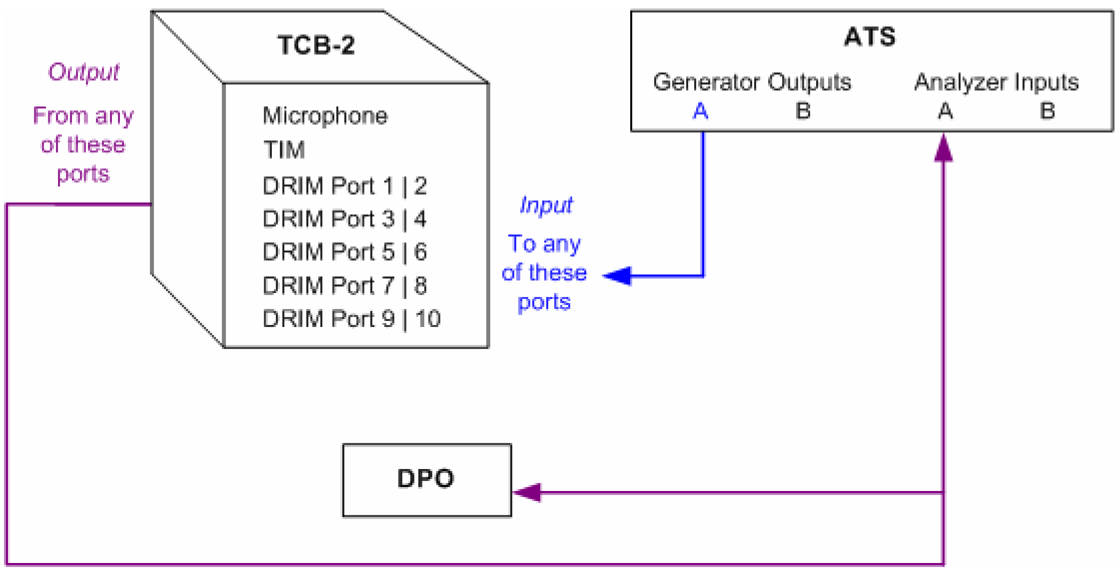

Figure 6: Output Audio Level

This test was done with the TCB-2 ports set to "Hand Held" radio personality mode.

1. Verify that the switch setting on the cards for the ports being tested are set to *Balanced Input* or *Balanced Output*. (See section 2.2.2 in the TCB-2 user's manual.)
2. Connect the Analyzer Input A port of the ATS to the desired TCB-2 input port.

[6] Vp is the peak signal level in volts.

3. Connect the TCB-2 output port under test to the Analyzer Input A port of the ATS.
4. Select the *Setup* tab from the TCB-2 touch screen.
5. Choose the output port of interest from the graphical *Setup* menu.
6. Choose *Manually Adjust Settings*.
7. Select the *Line* or *Mic* buttons, depending on the test desired.
8. Adjust the Tx Level to the desired level.
9. Select *Apply* to activate these settings.
10. Press *Return*.
11. Enable or disable the AGC.
    - For the first set of tests, taken at various Tx Level settings, the AGC was enabled.
    - For the second set of tests, the AGC was turned off. This can be done by DTMF programming, or via remote terminal connected to the TCB-2 serial port. (See section 3, Programming and Setup, in the TCB-2 user's manual, for details on enabling and disabling the AGC).
12. Run the test.
13. Repeat the preceding steps for all remaining interfaces.

Test Case Results and Summary

Table 5: TCB-2 Output Level Test with AGC Enabled and 354.3 mVp Input

Interface	Chassis Slot	Line Level			Mic Level		
Software Selected TX Level		**3% (Vp)**	**50% (Vp)**	**97% (Vp)**	**3% (mVp)**	**50% (mVp)**	**97% (mVp)**
DRIM port 1							
DRIM port 2	4	0.0724	1.157	2.233	11.01	20.3	26.95
DRIM port 3	5	0.0733	1.198	2.318	1.15	12.24	23.5
DRIM port 4	2	0.0660	1.07	2.075	0.836	10.92	21
DRIM port 5	3	0.0751	1.232	2.385	1.13	12.89	24.51
DRIM port 6	2	0.0680	1.11	2.146	0.948	11.52	22
DRIM port 7	3	0.0735	1.205	2.332	1.109	12.49	23.78
DRIM port 8	2	0.0672	1.094	2.113	0.961	11.28	21.5
DRIM port 9	3	0.0722	1.197	2.295	1.109	12.31	23.62
DRIM port 10	2	0.0673	1.095	2.114	0.977	11.35	21.7

For several output level adjustments, Table 5 indicates the range of output the device is capable of producing for a typical input.

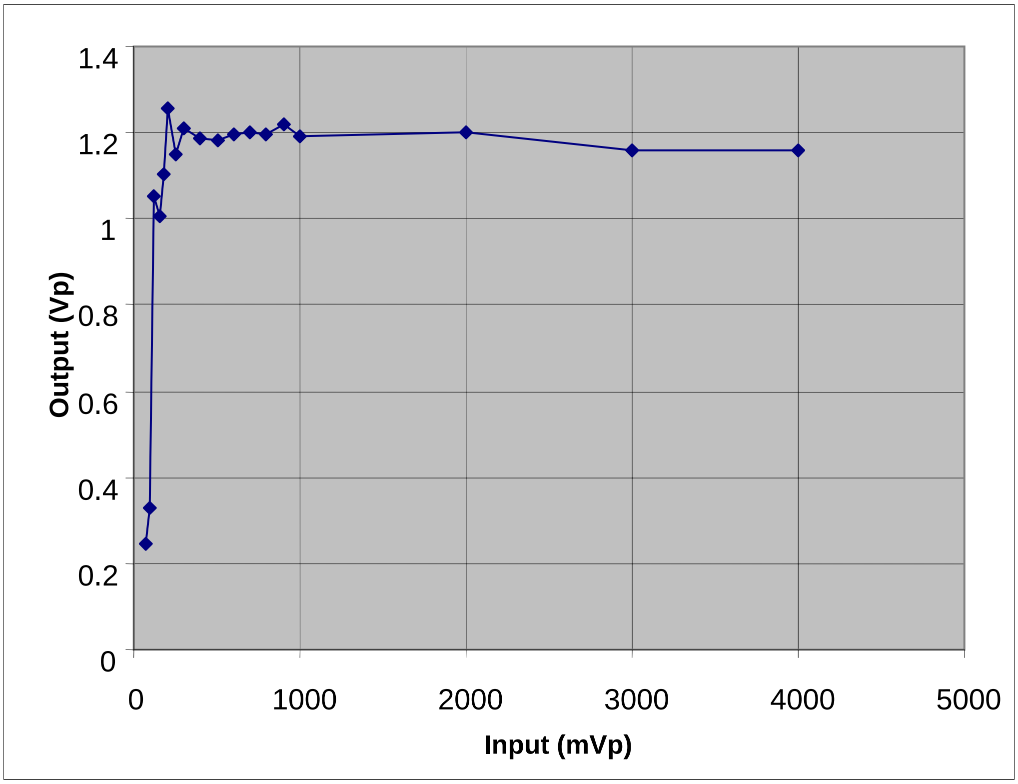

Figure 7: Audio Output Level Versus Input Level with AGC on at 50 Percent TX Level

Figure 7 indicates that the AGC for the device under test keeps a relatively constant output level for input signals that are between 0.175 Vp and 4 Vp.

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

The TCB-2 user's manual provides the following passband[7] specification:

- Input – 2 Hz to 3.5 kHz (-3 decibel (dB) point)
- Output – 15 Hz to 3.5 kHz (-3 dB point)

[7] Passband is the range of frequencies passed by an audio device. Passband is normally measured at the "-3 dB point." This is the frequency point where the amplitude response is attenuated by 3 dB relative to the main passband.

Test Procedures

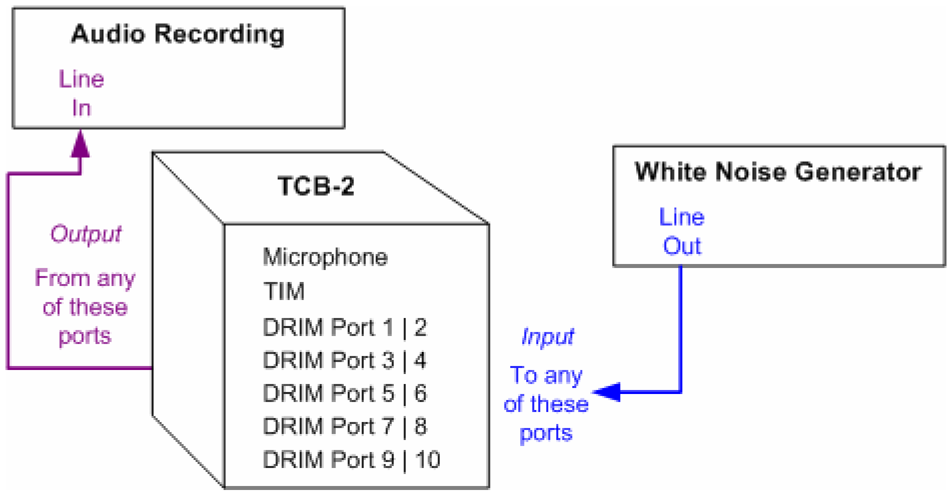

Figure 8: Frequency Response

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

1. For each output interface to be tested, assign a single input by making the appropriate talk group 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

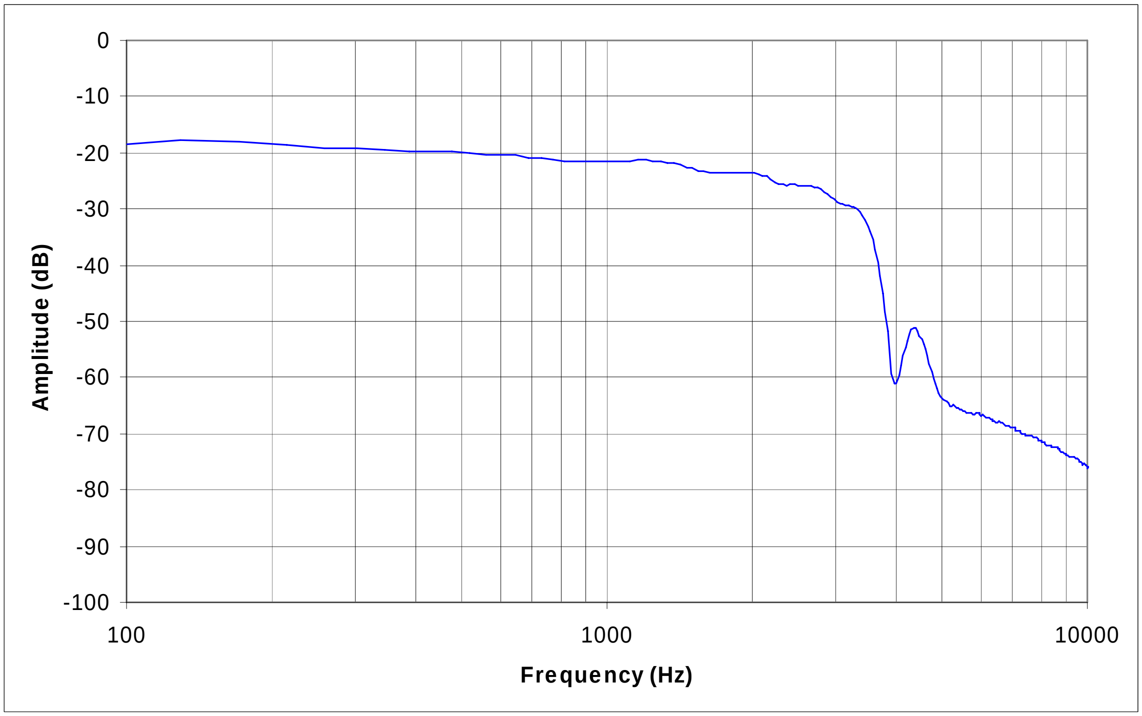

Figure 9: Frequency Response Input Port 3 to Output Port 7

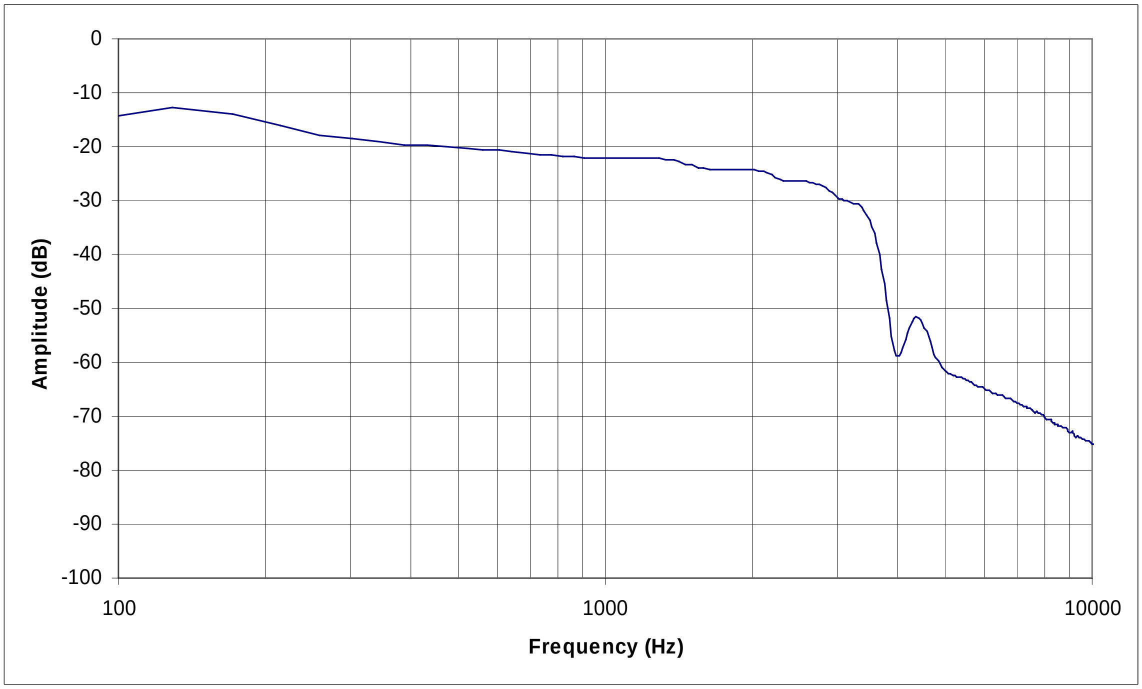

Figure 10: Frequency Response Input (Microphone), Output (Port 7).

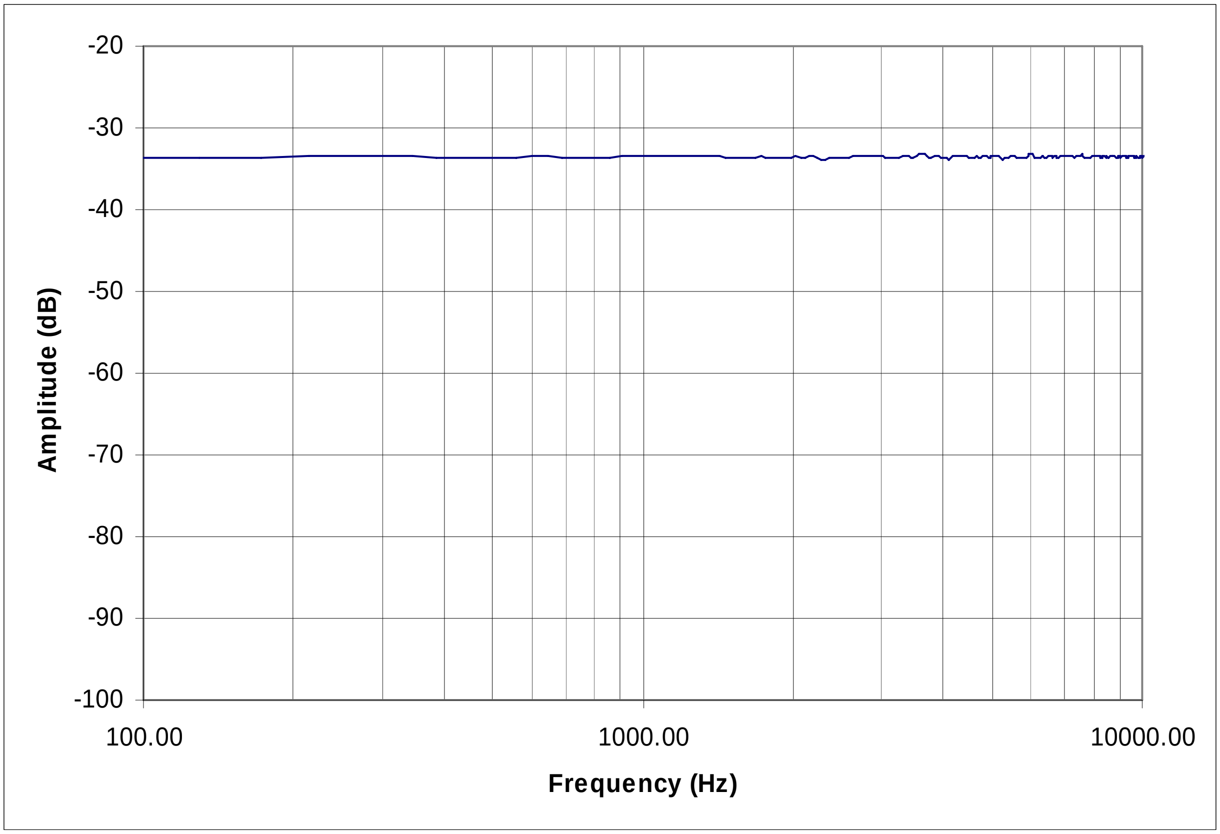

Figure 11: FFT of Input Noise Used to Determine Frequency Response

The frequency response of the TCB-2 achieved the -3 dB point at approximately 2000 Hz, as opposed to the specified 3500 Hz. At 3500 Hz, the frequency response was at approximately -10 dB. This could cause some voices, particularly those with higher frequency components, to sound slightly muffled.

In addition to falling off more than specified at the high end, the microphone input had a relative gain of more than 3 dB at frequencies below 250 Hz.

4.2 Other Characteristics Not Specified by the Manufacturer

The next sections list measurements for performance parameters not specified by the manufacturer, including: VOX input threshold, VOX attack time and throughput delay, audio distortion, and 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 to happen. 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

- Adjustable

Test Procedures

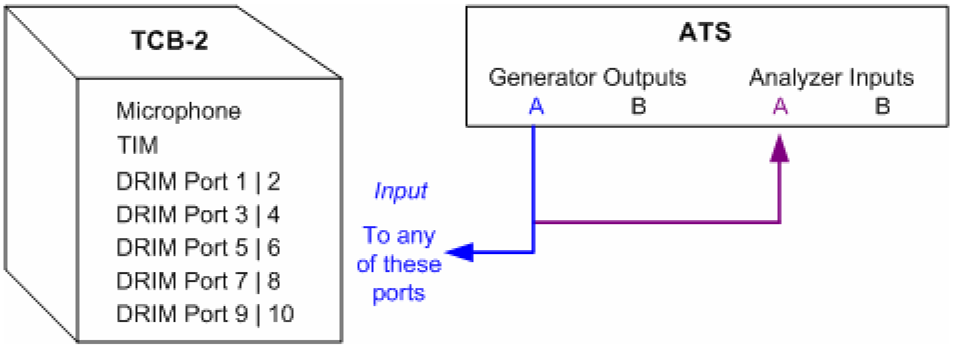

Figure 12: VOX Input Threshold

1. For each interface, connect the TCB-2 audio input to the Generator Output A port of the ATS.
2. Configure a 1 kHz sine wave as the input signal to the TCB-2 from the Generator Output A port of the ATS. Use either the maximum or minimum specified input level, 150 mVpp or 8 Vpp, respectively.
3. On the TCB-2, select the VOX response and adjust until the VOX triggers.
4. Record the output amplitude from the ATS and the VOX trigger threshold on the TCB-2.

Test Case Results and Summary

Table 6: Summary of Measurement Results

TCB-2 Input Interface	Input Level (mVpp)	Input Level Threshold (%)	Input Maximum (Vpp)	Input Maximum Threshold (%)
DRIM port 2	150	8	8	50
DRIM port 3	150	8	8	52
DRIM port 4	150	8	8	50
DRIM port 5	150	8	8	52
DRIM port 6	150	8	8	50
DRIM port 7	150	8	8	51
DRIM port 8	150	8	8	50
DRIM port 9	150	8	8	50

Table 6 shows the necessary VOX threshold setting, for the specified minimum input level 150 mVpp, and for the maximum input level 8 Vpp. The VOX input threshold should be adjusted in the range of 8 percent to approximately 50 percent.

4.2.2 VOX Attack Time and Throughput Delay

Throughput delay is the amount of time it takes a speech signal to pass from the device's input port to its output. It is separate from, but often related to, VOX attack time.

VOX attack time is the time interval between the receipt of a valid audio signal by the device, 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.

Datasheet Specification

- N/A

Test Procedures

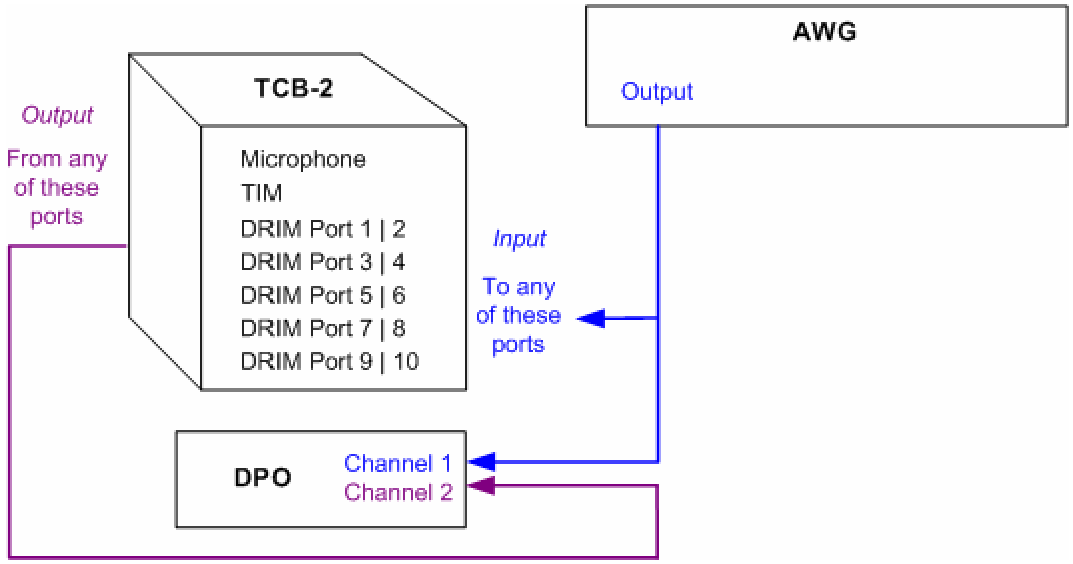

Figure 13: VOX Attack Time and Throughput Delay

1. Connect the output of an Agilent 33220A Arbitrary Waveform Generator (AWG) to the TCB-2 input interface under test and to the DPO. (An ATS can be used as an alternative to an AWG.)
2. Configure the AWG to give a 100 millisecond (ms) 1 kHz burst with a 5-second duty cycle.
3. Set the DPO to single-sweep mode, externally triggered from the AWG.
4. Connect the audio bus to the second channel of 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 TCB-2 interface. Record the time difference from the input signal to the output signal.

Test Case Results and Summary

Table 7: Input Port 4, Output Port 8 VOX Timing

Interface	VOX Setting	Min Attack Time (ms)	Max Attack Time (ms)	Throughput Delay (ms)
DRIM port 8	Medium	60.4	108	35

No difference was evident between slow, medium, and fast attack time settings on the TCB-2. Table 7 shows typical values for VOX timing. Attack times in this range could cause noticeable clipping of portions of words at the beginning of a segment of speech.

The throughput delay was very consistent at 35 ms over a large number of samples. The delay introduced would generally not be cumbersome in relation to other delays in a radio system.

4.2.3 Audio Distortion – SINAD and THD+N

SINAD, or the ratio of Signal + Noise + Distortion to Noise + Distortion, is a commonly used rough 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 approaching these values (that is, it has a significantly higher value), this 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 would generally be considered discernibly audible distortion. Exceeding that threshold may cause difficulty in speaker recognition or in the identification of the emotional state of a speaker.

Test Procedures

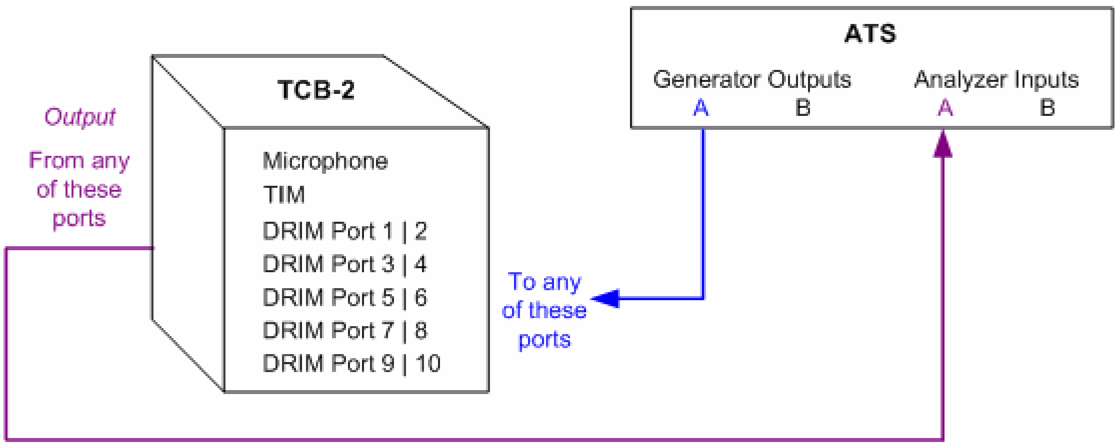

Figure 14: Audio Distortion - THD+N

1. Configure the ATS to measure THD+N, using the front panel softkeys.
2. Connect the input interface to the ATS, and apply a 1 kHz sine wave at an amplitude of 1.186 Vp.
3. Using the ATS, measure the THD+N and SINAD level across a bandwidth of 22 Hz to 22 kHz.
4. Repeat the above steps for all output interfaces.

Test Case Results and Summary

Table 8: Summary of Measurement Results

Interface	SINAD (dB)	THD+N (dBV)	THD+N (%)
DRIM port 2	47.7	0.9	0.413
DRIM port 3	54.4	1.17	0.197
DRIM port 4	50.1	1.19	0.303
DRIM port 5	50.2	1.72	0.313
DRIM port 6	51.1	1.29	0.284

Interface	SINAD (dB)	THD+N (dBV)	THD+N (%)
DRIM port 7	49.1	1.1	0.352
DRIM port 8	48.2	1.1	0.395
DRIM port 9	49.7	1.01	0.324
DRIM port 10	49.9	1.13	0.319

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

4.2.4 Crosstalk

Crosstalk occurs when the content of a signal on one path through a system bleeds over into other parts of the system. Being significantly out of the bounds of the specification could cause conversations of different talk groups to become confused or unintelligible. For example, a conversation from one talk group might be heard on a talk group for which it was unintended.

Test Procedures

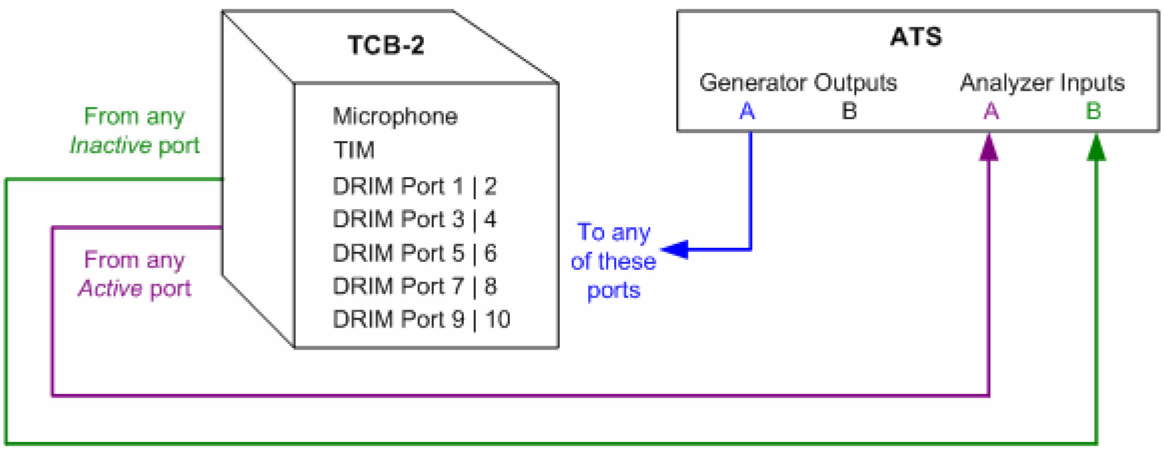

Figure 15: Crosstalk Measurement

1. Configure the ATS to measure crosstalk, using the front panel softkeys.
2. Connect the input interface to the ATS, and apply a 1 kHz sine wave at an amplitude of 250 mVp.
3. Using the ATS measurement, determine the crosstalk in dBV.[8]
4. Repeat the above steps for all output interfaces.

Test Case Results and Summary

Table 9: Summary of Crosstalk Measurement Results

Interface	Driven Interface	Crosstalk (dBV)
DRIM port 3	DRIM port 4	-70
DRIM port 4	DRIM port 3	-66.9

[8] dBV is decibels relative to 1 volt peak-to-peak.

Interface	Driven Interface	Crosstalk (dBV)
DRIM port 4	DRIM port 6	-70.3
DRIM port 5	DRIM port 6	-68.3
DRIM port 6	DRIM port 5	-69.6
DRIM port 6	DRIM port 4	-69.5
DRIM port 7	DRIM port 8	-65.5
DRIM port 8	DRIM port 7	-69.5
DRIM port 8	DRIM port 10	-65.5
DRIM port 9	DRIM port 10	-70.5
DRIM port 10	DRIM port 9	-65.4
DRIM port 10	DRIM port 8	-65.5

The crosstalk between ports on a single dual port card and between cards appears to be similar. Measurements between cards in Table 9 are shaded. Those not shaded are within the same card.

Crosstalk values indicate that this device should not pose a significant concern regarding crosstalk.

4.3 Observations

During the evaluation of the TCB-2, certain observations caused some concern about application of the device to public safety communications. These are:

- Sensitivity to static discharge
- RF emissions

4.3.1 Sensitivity to Static Discharge

The first significant observation in testing the device was that it seemed to be sensitive to static discharge. Events such as touching the exterior of the device without grounding oneself, or plugging a connector in, could cause the device to stop passing voice signals. Communication with the manufacturer revealed that this issue had to do with the vocoder in the device getting into a locked mode. The manufacturer provided a firmware revision that appears to address this issue. Note that, because of this issue, **users of this device are encouraged to ensure that their firmware is Rev. V26.6.2.2.16.37.1 or later**.

4.3.2 RF Emissions

During a public safety training exercise conducted in Boulder County, Colorado, the TCB-2 was deployed to assist the participants, consisting of local and county law enforcement, fire response, and emergency medical services practitioners, and to enable recording of much of the audio traffic during the exercise. Shortly into the exercise, some users complained about certain channels containing high levels of static. Further investigation revealed that some RF energy, enough to break squelch on nearby radios that were tuned to 154.0 MHz, was coming from the TCB-2. To more accurately quantify this issue, the TCB-2 was brought into a screen room, and an informal RF emissions scan was conducted in the laboratory, as detailed below.

Test Procedures

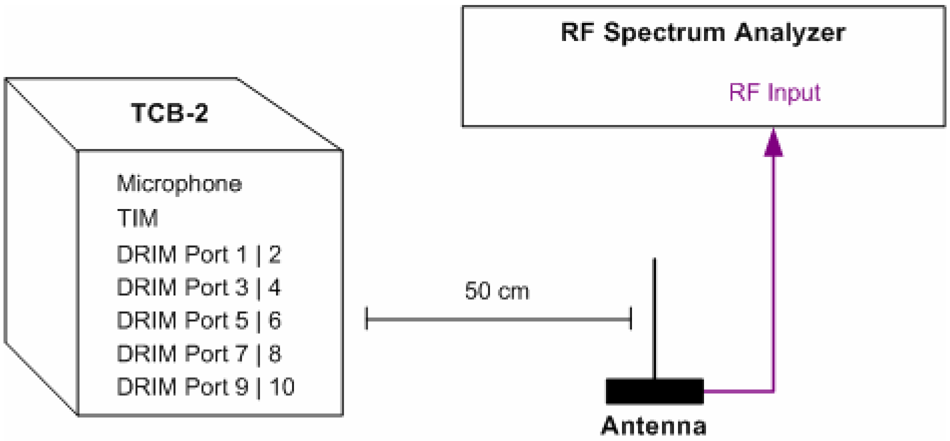

Figure 16: RF Emission Measurement

1. Configure the RF Spectrum Analyzer to measure RF energy from 20 MHz to 400 MHz, which encompasses the VHF band where interference was observed.
2. Position the antenna probe at 0.5 meters 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 the above step with the device under test powered on.

Summary of Measurement Results

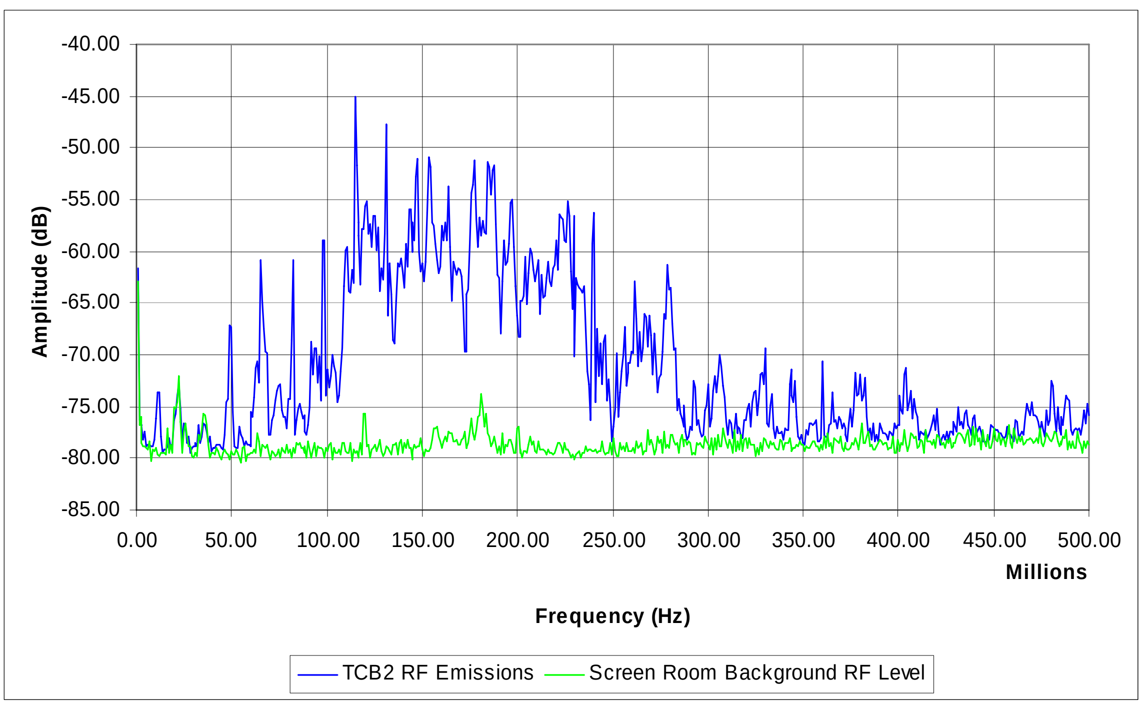

Figure 17: RF Emissions from 20 MHz to 400 MHz

The four highest RF energy peaks which were evident when the device was on were 114.55 MHz (-45.0 dBm), 131.20 MHz (-47.7 dBm), 149.85 MHz (-51.1 dBm), and 153.68 MHz (-51.0 dBm).

The RF energy at 154.0 MHz, the frequency at which interference was observed, was -51.3 dBm.

There was a broad frequency band where energy levels increased by 15 or more dB (approximately 110-240 MHz).

The device does appear to introduce significant RF energy into the environment. The spikes which occur in and around the VHF public safety band have the highest potential to interfere with public safety communications.

These findings have been reported to the manufacturer for its consideration.

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. In this case, 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

DHS – The U.S. Department of Homeland Security

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

DRIM (Dual Radio Interface Module) – An input/output module on the TCB-2

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

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

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

TCB-2 (Tactical Communications Bridge 2) – A device manufactured by Link Communications, Inc. that connects radios having different frequencies.

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 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